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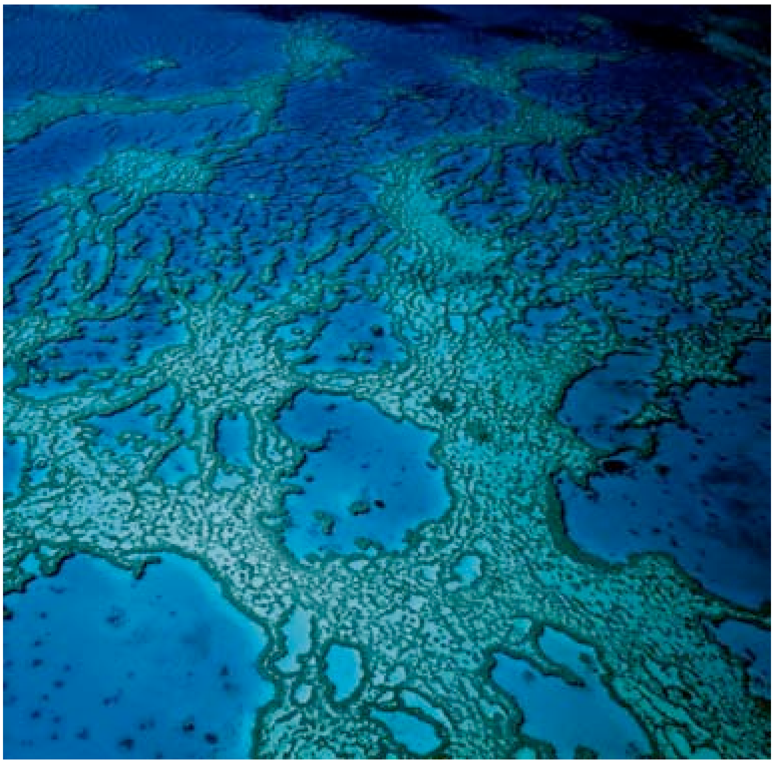
GREAT BARRIER REEF 2050

Implications of Climate Change for the Australia's Great Barrier Reef

WWF-Australia February 2004



PART 1 - THE SCIENTIFIC EVIDENCE

Overview

The earth is undergoing accelerating climate change that is being driven by rapidly increasing greenhouse gas concentrations. This is changing the conditions under which the earth's fauna and flora have flourished over the past several million years. There is now extensive evidence of changes to the distribution, abundance and health of earth's terrestrial and aquatic ecosystems. Species are migrating towards the poles, ecosystems like coral reefs are experiencing increasing stressful conditions and populations of organisms are in decline as a result of a combination of climate change and other anthropogenic impacts.

The first part of this report reviews the scientific evidence of climate change and details how recent changes in the environment have lead to massive changes in the health of the world's ecosystems. It then focuses on the special issue of coral reefs, describing first the major changes that have occurred across the world's reefs and then focusing on the world's largest coral reef, the Great Barrier Reef. This reef system is the jewel in the crown as far as coral reefs are concerned. It is also the most pristine and best managed coral reef ecosystem in the world. However, there are few reasons for complacency as to the increases in stresses over the next 20-40 years. The major influence will come from seas that will be warmer by as much as $2^{o}C$. Calculated thermal stress (based on Degree Heating Months, DHM) will be 3-6 times higher in 2050 than even the worst recent period of thermal stress seen on coral reefs so far. This is likely to result in thermal stress annually that will greatly exceed the stress seen during the worst bleaching events so far (1998 and 2002).

It is important to realise that climate change is not the only factor that has or will change the way reefs look. While we do not have much control over the rise in sea temperature over the short-term, reducing the factors that are likely to be eroding reef resilience (poor coastal land use and over-fishing) will improve the ability of coral reefs like the Great Barrier Reef to survive the added impacts associated with climate change.

Change to the health of our ecosystems as a result of climate change is inevitable. Even under the best case scenario, losses of at least 50% of the Reef's living coral cover are likely to occur by 2050. How humans will be affected by these changes is still uncharted yet is enormously important. Careful description and definition of the links between physical and chemical changes, biology and the human dimensions of economic and social impacts is central to understanding the economic and social ramifications of climate change. In the last section of Part 1, four sets of futures are developed in order to set the scene for the development of the social and economic perspectives on the expected decline in the natural values of the Great Barrier Reef.

1. *Climate Change*

Climate change is one of the greatest challenges facing human populations over the next 100 years. In addition to increases in the overall temperature of the earth, changes are expected in a large range of climate variables including patterns of rainfall and drought, ice volume, ocean temperature, chemistry and sea level. Evidence of rapid changes in these variables is now overwhelming. The role of humans in these changes is equally undeniable scientifically. According to the Intergovernmental Panel on Climate Change (IPCC 2001a) "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." These changes are bringing and will bring major changes to elements of the biosphere like coral reefs. This section reviews the scientific evidence of climate change and establishes the basis for the four climate change scenarios explored within this report. Within these futures, the possible trajectory of coral reef regions like the Great Barrier Reef will be examined. As was discussed in the introduction to this report, the impact of changes in climate is very dependent on the human context in which is occurs. Information developed in this section is one layer of many and it will be clear that it is the response and actions of people on and around the Great Barrier Reef will be critical in determining the resilience and hence future of this vast ecological resource under increasing levels of climate change.

Recent climate change

Global average temperature

Quite substantial changes have already occurred in the heat trapping behaviour and hence average temperature of the earth. Since the beginning of instrumental records around 1880, global temperature has increased by $0.6 \pm 0.2\ ^{o}C$, with the 1990s being the warmest decade (Jones et al. 1999). Within this decade, January-May 1998 was also the warmest period (IPCC 2001, National Climatic Data Center, Asheville, NC) for more than a century.

Longer term perspectives on the earth's temperature come from climate proxies. These are records of temperature derived from chemical or physical changes to materials such as coral skeletons, tree rings and ice cores. A range of careful isotopic measurements can yield very accurate records of global temperature. When many sources are compiled, proxy data indicate that global temperature has been relatively stable during the past millennium and that changes over the past 50 years exceed those seen in the past 1000 years. The trajectory in global temperature is 10-50 times steeper over the past 50 years than it has been over any other century in the past 400,000 years (Figure 2, 3, Table 1).

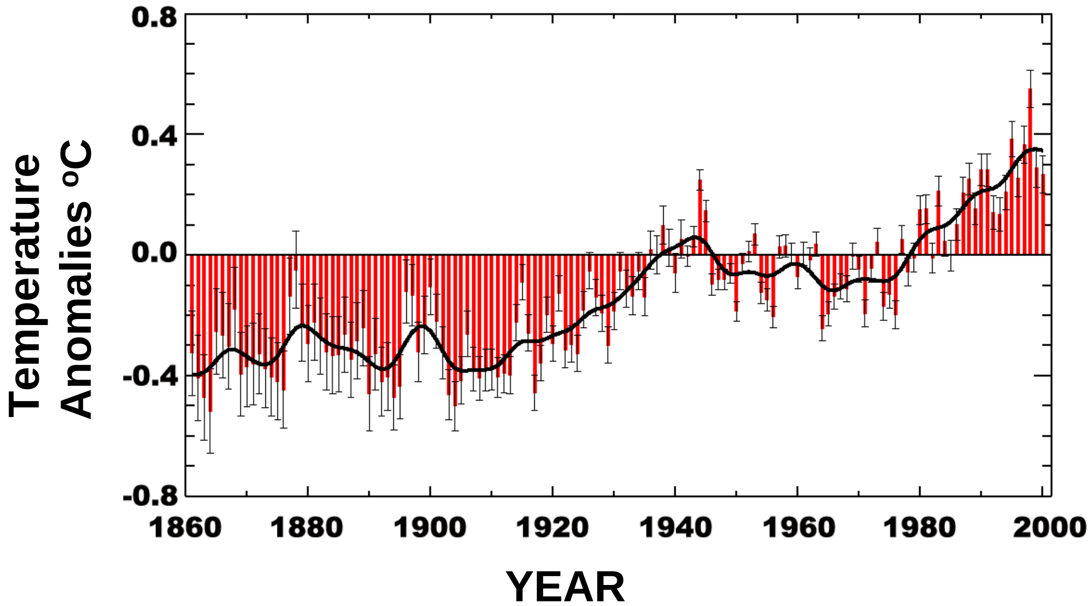


Figure 1. Instrumental records (from thermometers) of global temperature anomalies for the past 140 years (Source IPCC 2001a).

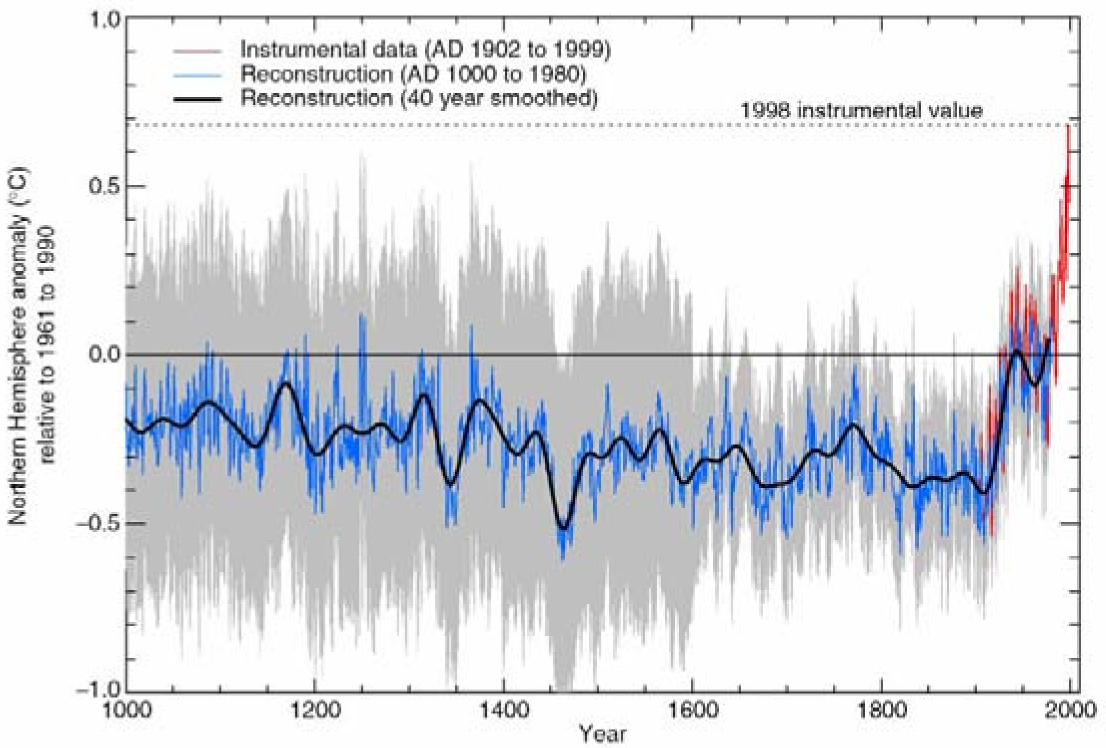


Figure 2: Temperature reconstruction for the Northern Hemisphere over the past 1000 years from tree rings, corals, ice cores, and historical records (blue line) and instrumental data (red) from AD 1000 to 1999. Time smoothed data (black), and two standard error limits (gray shaded) are also shown. (Source: IPCC 2001a)

Greenhouse gases

The majority of the recent climate change is associated with changes to the greenhouse gas concentrations in the atmosphere (IPCC 2001a). Greenhouse gases are both natural and human derived elements of the atmosphere that absorb and emit radiation at specific infrared wavelengths (heat) emitted by the Earth's surface. These compounds modify the heat exchange between the earth and its surroundings such that the global temperature is maintained above that of surrounding space (-18°C). This property of the earth's atmosphere is termed the greenhouse effect. Greenhouse gases include carbon dioxide (CO_2), water vapour (H_2O), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3). There are also a number of synthetic fluorine, chlorine and bromine containing compounds that impart a greenhouse effect. Significantly, compounds such as the chlorofluorocarbons (also known for their ability to degrade the earth's ozone shield) are the strongest greenhouse gases on a per molecule basis.

Over the past century, the concentrations of greenhouse gases have been changing. This has led to the increased greenhouse effect. Most of this change has been due to human activities such as the burning of fossil fuels, the clearing of forests and the increase in agricultural activities. These have lead to changes in the balance of the greenhouse gas constituents in the atmosphere. These trends are currently accelerating (Figure 3, 4). Changes to the function of gas exchange across land, sea and ice interfaces as a result of this warming are also now contributing added influences on the rise of global temperatures.

Long-term perspectives on greenhouse gases and global temperature indicate that the two are tightly coupled. Ice cores provide unique data from the entrapped air inclusions that enable direct records of past changes in atmospheric trace-gas composition. A collaborative project between Russia, the United States, and France at the Russian Vostok station in East Antarctica in January 1998 has yielded continuous ice cores of 3,623 m (Petit et al. 1997, 1999). Within the Vostok ice cores, there is a close correlation between Antarctic temperature and atmospheric concentrations of CO_2 (Barnola et al. 1987). Examination of the carbon dioxide concentrations within the core show glacial-interglacial transitions in which atmospheric CO_2 concentrations rose from 180 to 280-300 ppm (Petit et al. 1999).

Perhaps the most dramatic conclusion from the Vostok CO_2 record is that present-day CO_2 concentrations (now over 370 ppmv) are unprecedented during the past 420,000 years at least (Figure 3). Concentrations seen in the pre-industrial Holocene (approximately 280 ppmv) can be observed during all interglacials within the past 400,000 years, with the highest values (~300 ppmv) being found approximately 323,000 years ago. Similar statements can be made about temperatures derived from the ice core record. Other ice core data for the past 30,000 - 40,000 years (Delmas et al. 1980; Neftel et al. 1982) show good agreement with the Vostok ice core data.

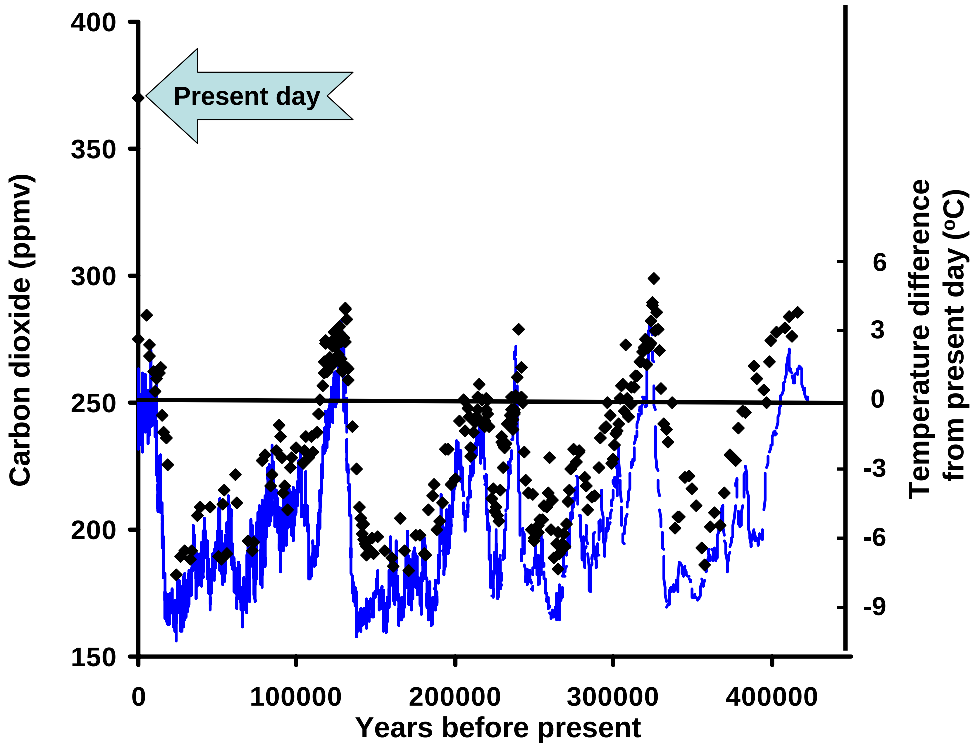


Figure 3. Variation in carbon dioxide (black symbols) and temperature variation relative to today (blue line) in Antarctica from ice core data drilled at the Vostok station. Carbon dioxide data are replotted from Barnola *et al.* (1999) and temperature data from Petit *et al.* (1999). Present day carbon dioxide levels are indicated by the arrow.

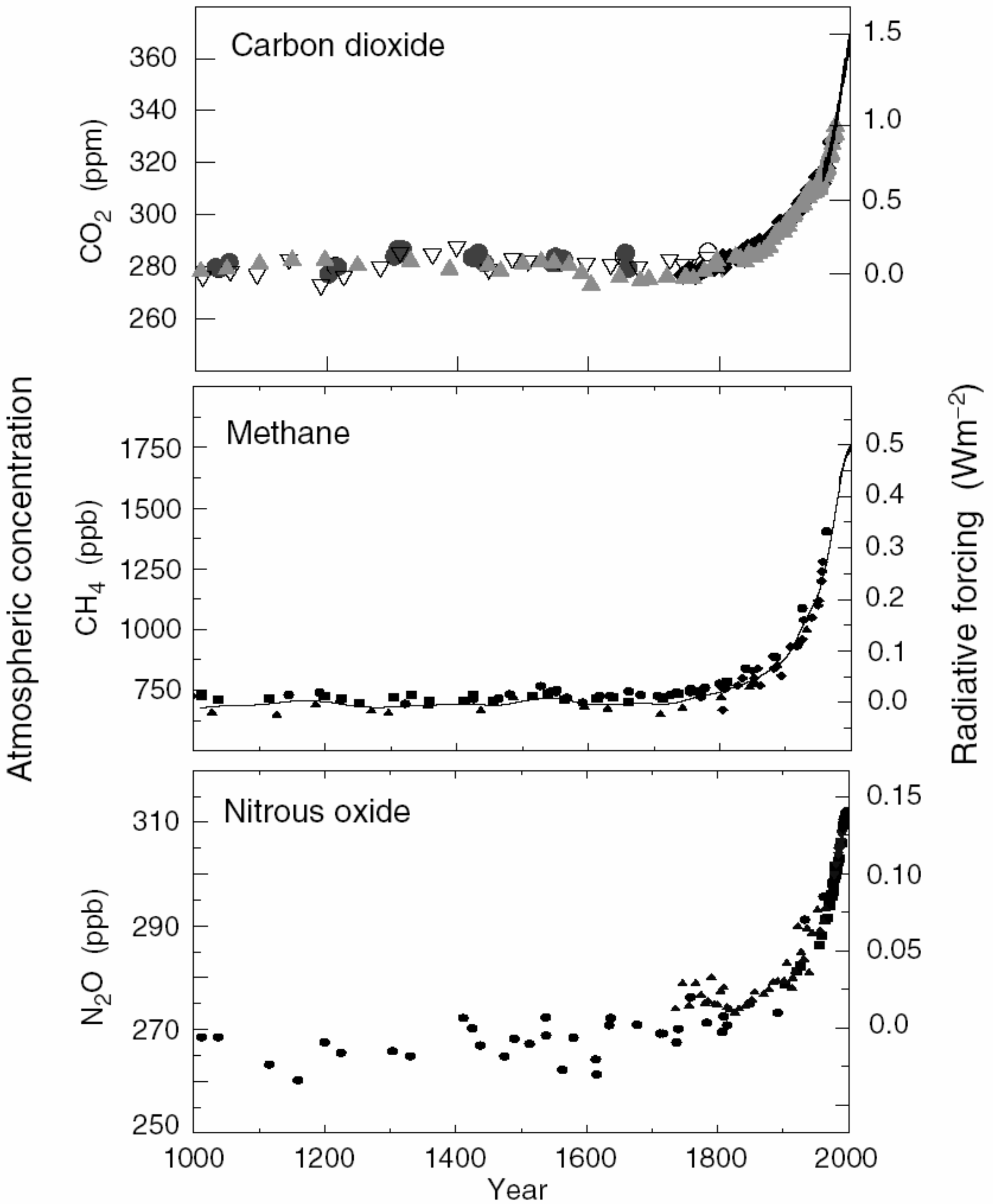


Figure 4. Changes in the atmospheric concentrations of three prominent greenhouse gases over the past 1000 years. Data shown are from gas bubble data within ice core and firn (compacted snow) from several sites in Antarctica and Greenland (shown by different symbols). These are supplemented with the data from direct atmospheric measurements from the last few decades (shown by the line for CO_2 and incorporated in the curve representing the global average of CH_4). Also shown is the calculated radiative forcing resulting form the addition of these gases to the atmosphere (right hand axis). Source: IPCC (2001a)

While overall global temperatures are increasing, it is salient to note that different parts of the climate system are responding at different rates. For example, polar temperatures are increasing at rates that are faster than in temperate or tropical areas of the planet. Components like the ocean (due to the higher thermal inertia of large volumes of water) are responding at a slower rate within each latitude. In the latter case, these lag times are on the order of 75% that of air temperature responses. This means that a $1^{o}C$ change in air temperature will be accompanied by a $0.75^{o}C$ change in the surface layers (0-100 m) of the ocean.

How the climate has changed in the past thousands or millions of years is still an evolving story. There are examples in the past of relatively rapid periods of change (e.g. during shifts between ice age and interglacial periods). While there is evidence for short periods of even higher rates of change in climate, those present in records like the Vostok data tell an interesting story. The most rapid rates of increase in atmospheric carbon dioxide within the Vostok ice core data range from 0.30 to 0.96 ppm per century (Table 1, Figure 3). The most recent changes (those over the past century) dwarf these (100-200 fold higher) while future rates may be as much as 500 fold higher. Similar conclusions may be drawn from regression data calculated from the temperature data in the Vostok ice core. In this case, the most rapid transitions (seen as the earth came out of glacial periods or ice ages) only range up to 0.2 ^{o}C per century. Again recent changes of 0.6 ^{o}C over the past century and those projected under even the mildest IPCC scenarios (2.8 ^{o}C per century under the A1B scenario or 3.8 ^{o}C per century with the A1F1 scenario) are much higher. The observation that changes of a similar absolute magnitude (e.g. 100 ppm) occurred over hundreds of years and not decades, further reinforces this conclusion. Given that these previous periods of change were associated with major changes in regional flora and fauna across the globe, it is highly likely that the earth's biota will respond strongly to current climate change. As will be developed later, the evidence that the earth has already responded to a 0.6 ^{o}C over the past century is undeniable (Walther et al. 2002; Parmesan and Yohe 2003).

Other aspects of climate have changed as a result of changes in global temperature. This has already had profound effects on organisms that are often restricted by their adaptive capability to survive freezing stress. For example, the freeze-free periods have increased in most mid- and high-latitude regions. This has led to expansion of freeze susceptible plants and animals up the slopes of alpine areas and into more northern latitudes (Walther et al. 2002). In these areas, there has been a 10% decrease in snow cover and ice extent since the late 1960s. Inspection of precipitation regimes across the planet indicates that changes over the past 100 years have been neither spatially nor temporally uniform (Walther et al. 2002). Cooling, for example, has occurred in some regions. A 301-year snow accumulation record from Mount Logan, in northwestern North America, indicates that this area has been receiving an increasing amount of snow over the past 60 years (Moore et al. 2002). This is due to the sustained surface warming over western North America throughout the period 1870-2000, resulting in shifts (increases) in cold air and precipitation over locations like Mount Logan.

Table 1. Regression values (rates of change) calculated for periods of most rapid change within the Vostok ice core. Also shown in table (for comparison) are rates of change over the last 100 years and that projected to occur from climate change over the next century for different 3 different IPCC scenarios.

A. Maximum rates of change in carbon dioxide (using data from Barnola *et al.* 1999).

Period	**ppmv per 100 yr**
24,315 to 9.523 yr Before Present (BP)	0.52 $\pm$ 0.080
130,653 to 143,732 yr BP	0.72 $\pm$ 0.034
240,006 to 248,364 yr BP	0.96 $\pm$ 0.097
325,400 - 355,795 yr BP	0.30 $\pm$ 0.043
Recent (last 100 yrs)	100
Projected (B1) - 2002-2100	150
Projected (A1T) - 2002-2100	330
Projected (A1B) - 2002-2100	530

B. Maximum rates of change in temperature (using data from Petit et al. (1999).

Period	**^{o}C per 100 y**
11,191 - 16,808 BP	0.092 $\pm$ 0.005
130,467 - 145,006 yr BP	0.135 $\pm$ 0.003
237,866 - 241, 792 yr BP	0.227 $\pm$ 0.005
322,638 - 332,164 yr BP	0.117 $\pm$ 0.003
Recent (last 100 yrs)	0.600
Projected (B1) - 2002-2100	2.500
Projected (A1T) - 2002-2100	2.400
Projected (A1B) - 2002-2100	2.800

Climate change and the ocean

Strong physical links exist between ocean temperature and global climates. In a similar way to the atmosphere, the process by which climate change will affect the ocean is highly complex, affecting oceanic circulation and chemistry. Even minor changes to sea temperature, for example, are likely to result in changes to the currents that flow across the earth's surface. Once changed, currents can affect the flow of heat between regions of the world. In addition to feeding back on terrestrial climate change, changes to current flow and direction can have dramatic influences on local marine conditions with impacts being felt on ecosystems such as coral reefs and temperate kelp forests. There are also a plethora of more subtle influences such as reduced or increased genetic connectivity of marine populations as currents change.

The physical structure of the earth's oceans.

Two major transport layers dominate the ocean. Surface waters (100 to 400 m, depending on season and latitude) are made up of low density seawater that is generally warmer, and better mixed, illuminated and oxygenated. These surface waters of the ocean move under the combined influence of wind movements, the Coriolis Effect and the location of landmasses such as continents and islands (Figure 5A). Huge gyres in each hemisphere circulate water within each oceanic basin. As a result of the Coriolis effect (inertial forces due to the rotation of the earth), Northern Hemisphere gyres rotate clockwise while those of the Southern hemisphere rotate counter clockwise. At very high latitudes gyres tend to flow in the opposite direction. Smaller currents and eddies form spin off from these main gyres.

The surface waters bring heat to higher latitudes. This heat warms higher latitude areas on both land and sea with huge consequences for life at higher latitudes. Without the Gulf Stream, for example, which brings warm water from the south to north Atlantic, the terrestrial and aquatic climates of northern Europe would be significantly colder. This has been proposed as one of the changes that may occur in Europe under climate change (IPCC 2001a).

Below the surface layer of the ocean are colder, denser waters that move as function of the thermohaline circulation (Figure 5B). The boundary between the two layers of the oceans is defined by a large-scale change in seawater density known as the pycnocline. Thermohaline circulation involves a massive, long-lived flow of water from low to high latitude and from deep to shallow and back again. The thermohaline circulation is driven by the temperature differential between equatorial and polar locations. This force leads to a rapid cooling and eventual sinking (due to increasing density) of warm saline water originating from lower latitudes. As a result of water sinking at the poles, a "conveyor belt" like system operates in which deep waters move toward the equator while the surface components of the thermohaline circulation move polewards. The residence time of deep water can be as long as 200-500 years for the Atlantic Ocean and 1,000-2,000 years for the Pacific Ocean.

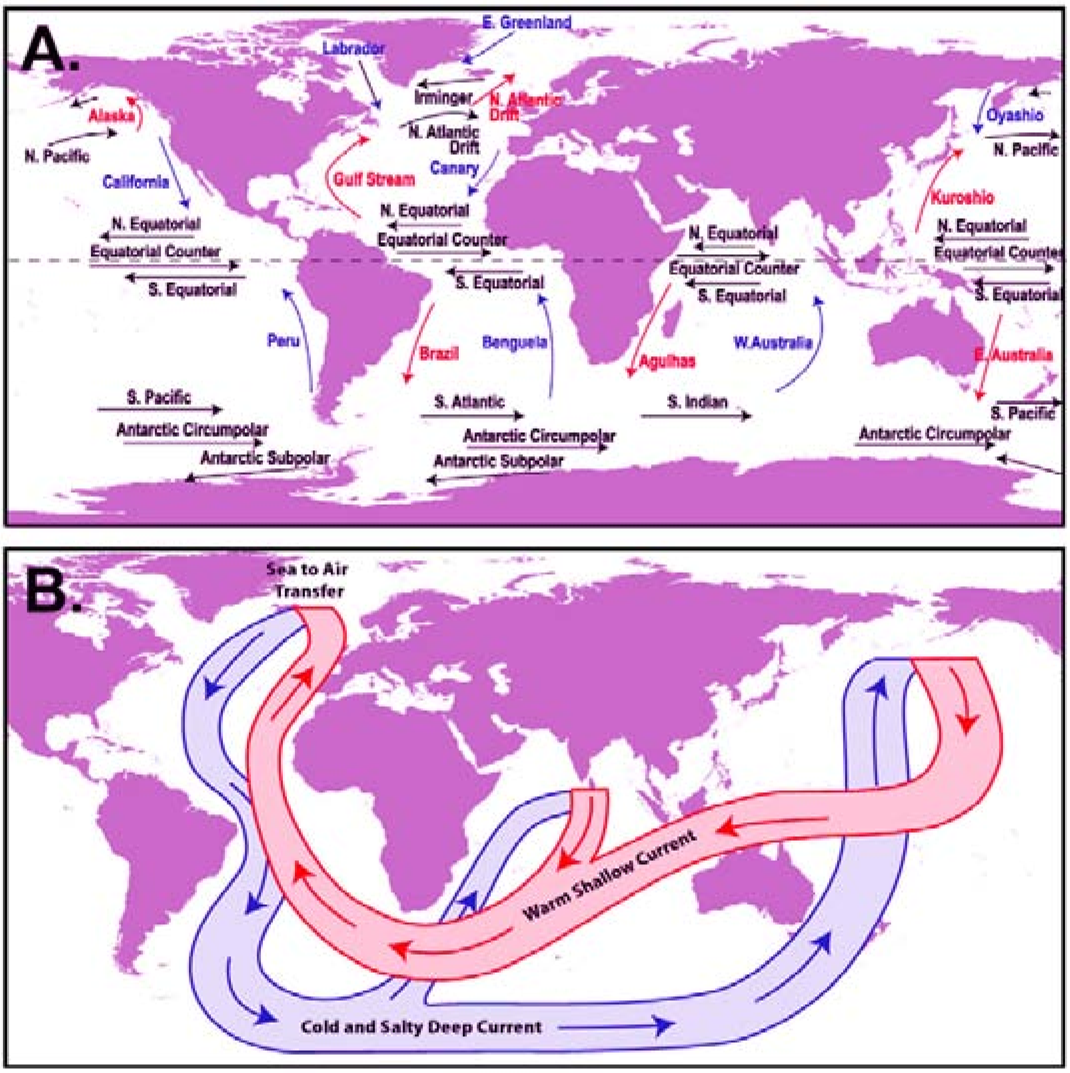


Figure 5. A. Main currents in today's oceans. Circulation of water across the planet is a complex relationship between climate and planetary motion. B. Interaction between surface and deep-water currents as a function of location (global conveyor belt). Colder more saline water has a greater density than warmer less saline water. As water moves from the warmer lower latitudes to the poles it cools and sinks, motivating movement of oceanic waters across the earth.

The structure of the world's oceans is a major determinant of oceanic productivity. Deep waters tend to be rich in inorganic nutrients such as phosphates, nitrates, and carbonates due to the sinking of organic material out of the photic zone (0-100 m) over time. High rates of primary productivity results when this deep, nutrient rich water is brought to the surface (e.g. through Ekman Transport or upwelling). These zones of high productivity are critical to fisheries and the marine food web generally.

Recent changes

Climate change is having a major impact on three fundamental variables associated with oceanic environments. These are the temperature, calcium carbonate saturation state and the sea level. While each variable is likely to have different overall impacts on life in the ocean, the combination of all three changes is expected to have a major impact on the distribution and abundance of marine organisms.

a. Calcium carbonate saturation state (Ω)

When carbon dioxide is present above a solution, carbonic acid forms as carbon dioxide interacts with the water molecule. As a result, the concentration of critical ions such as carbonate (which is important for calcification) decreases in concentration. The net effect of this is that the carbonate alkalinity of seawater (a measure of the availability of carbonate ions) will decrease as carbon dioxide within the earth's atmosphere increases (Gattuso et al. 1998, Kleypas et al. 1999). This is best represented by the calcium carbonate saturation state (Ω):

$$\Omega = \frac{[Ca^{2+}][CO_3^{2-}]}{K'_{sp}}$$

where K'_{sp} is the stoichiometric solubility product for a particular mineral phase of $CaCO_3$ (calcite, aragonite, or high-magnesian calcite). According to Kleypas et al (1999), the calcium carbonate saturation state has already decreased on average 0.5-1.0 since 1880 (from equatorial values around 4-4.5). The consequences of these changes are still being mapped although it is expected, based on the results of Langdon et al. 2000 and others, that a decrease in Ω should result in a decrease in calcification rate.

b. Sea level

Sea level was 120 m below where it is today during the last ice age. Over the past 100,000 years, sea level has fluctuated significantly as temperature has modified the volume of the ocean and affected the storage of ice in glaciers and at the poles. During the transition out of this period of glaciation, sea level changed at an average rate of 10 mm/yr (rates were as high as 40 mm/yr at some times). During the interglacial, rates of sea level rise have been much slower (0.1 to 0.2 mm/yr over the last 3,000 years; Church et al, 2001). Not surprisingly, changes in sea level have had major impacts on the abundance and particularly the distribution of both marine organisms and ecosystems.

There is a growing consensus that the mean global rate of sea level rise during the 20th century has been nearly 2 mm/yr, which is 10-fold higher than the average of the past several millennia. These data have been generated from tide gauge data taken since the late 19th century, historical land records, and geological evidence from the late Holocene period (Douglas et al. 2002).

c. Sea temperature increase

Ocean temperature is responding rapidly to heating of the earth's atmosphere. The heat content of the global ocean has increased 2.3 x 10^{23} joules between the mid-1950s and mid-1990s, which represents a volume mean warming of 0.06 °C. This increase in heat content of the ocean has not been distributed evenly. Substantial increases have occurred in the upper layers of the ocean, with the mean temperature increase for the upper 300 m of the global ocean over the same three decades being 0.31 °C (Levitus *et al.* 2000). Deep oceanic warming is also occurring and rates also vary strongly with latitudes (Barnett et al. 2001, Gille 2002).

Changes in global temperatures can directly affect the rates and directions of ocean water movement. Most global circulation models indicate that the thermohaline circulation of the planet, for example, is likely to weaken as greenhouse warming continues. Dickson et al (2002) produce convincing evidence of a rapid and sustained freshening (decreased salinity) of the deep Atlantic Ocean. Though these changes may appear small (0.03 ppm salinity change over the past 40 years), they indicate that major changes may be in store for the heat budget and functioning of the earth's oceans. As the "conveyor belt" (Figure 5B) is critical for both terrestrial and marine environments, changes to this critical oceanic system are being monitored with increasing interest by those interested in future climate trajectories.

The El Niño Southern Oscillation (ENSO) is a major determinant of both terrestrial and marine climates in the southern hemisphere. Important aspects such as coral bleaching are triggered by ENSO events. Some changes in ENSO over the past 100 years appear to have occurred with events becoming stronger and more frequent. Complete consensus is missing at this point however. Recent ENSO events (over the 20th century) appear also to have been strong compared with ENSOs of previous cool (glacial) and warm (interglacial) periods (Tudhope et al. 2001).

Future climate change

Anthropogenic activities such as clearing forests and burning fossil fuels are changing the composition of the atmosphere and climate (IPCC 2001a). The big question is how the magnitude and rate of climate change will vary over this century. Future changes in climate are to some extent already determined due to the long residence times of gases in the atmosphere. Effects of past emissions may last for hundreds of years. In the case of CO_2, effective residence times (time for removal of 63% of the anthropogenic excess of a greenhouse constituent in the atmosphere if anthropogenic production falls to zero) are of the order of approximately 230 years or more (Fuglestvedt et al. 2001). This essentially means that activities from 100-200 years ago are still major determinants of today's atmosphere. Many other greenhouse constituents have shorter residence times. Methane (CH_4) has an estimated mean residence time of 10 years (Prather, 1996, 1998); Nitrous oxide (N_2O) 100 years, (Prather, 1996, 1998), and the chlorinated fluorocarbons, CFC-11 and CFC-12, 50 and 102 years respectively (Prather et al., 1995). How residence times vary between atmospheric components depends on the complex relationships between concentrations and the many sources and sinks that exist for each component.

Projections of future conditions on the planet are based on complex mathematical models (general circulation models or GCMs) that simulate future additions and removals of greenhouse gasses and the resulting heat trapping behaviour of the atmosphere. They also increasingly take into account behaviour and interaction of components of the climate system. Greenhouse gas concentrations and climate change projected by these models are subject to large uncertainties in the effects of both natural processes and human activities. This has lead to scenario building exercises that take into account different sets of conditions and assumptions. The Intergovernmental Panel on Climate Change has extensively reviewed the outputs of the major GCMs for 40 quantitative scenario variations as part of its Special Report on Emission Scenarios (IPCC 2000). Appendix E shows the quantitative projections for four 'marker' scenarios and two additional variations on these. They are based on four SRES scenario storylines that differ in how "global regions interrelate, how new technologies diffuse, how regional economic activities evolve, how protection of local and regional environments is implemented, and how demographic structure changes" (IPCC 2001b). See Table 2 for a brief summary of the four storylines and Chapter 12 (Part 3) for detail on their use in developing specific stories and projections for the Great Barrier Reef.

The results of considering both natural and anthropogenic forces plus different social and political futures give a full range of scenarios or possibilities that have been published in the recent IPCC Third Assessment report (IPCC 2001a). These give a range of future global responses that include ranges of 2-3 fold increases in GHG concentrations, a 1.4 to 5.8°C and 0.3 to 0.5 m increases in temperature and sea level by 2100 respectively (Figure 6, all 40 SRES quantitative scenario variations, IPCC 2001a).

Projected terrestrial changes

As stated in the IPCC Third Assessment Report, the globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100 (IPCC 2001a, full range of 40 SRES scenarios and based on a number of climate models). These changes are in addition to significantly increasing the number of climate variables that are critically important for terrestrial ecosystems. According to the IPCC (2001a), it is likely to very likely that the following changes will be seen in the latter half of the 21st century:

- Higher maximum temperatures and more hot days over nearly all land areas
- Higher minimum temperatures, fewer cold days and frost days over nearly all land areas
- Reduced diurnal temperature range over most land areas
- Increase of heat index over land areas
- More intense precipitation events in some areas
- Increased summer continental drying and associated risk of drought
- Increase in tropical cyclone peak wind intensities
- Increase in tropical cyclone mean and peak precipitation intensities

As changes of a much smaller magnitude have resulted in major changes already in the distribution of terrestrial organisms (review, see Walther et al. 2002; Parmesan and Yohe

2003), there is little doubt that future climate change will bring about major changes in the health and distribution of terrestrial organisms and ecosystems.

Projected changes in the ocean

As with terrestrial climates, changes to atmospheric composition and global temperature will also change conditions in the ocean. The principal changes are associated with the following three variables.

a. Calcium carbonate saturation state (Ω)

Gattuso et al. (1998) and Kleypas et al (1999) demonstrate that doubling carbon dioxide concentrations in the atmosphere will decrease the aragonite saturation state in the tropics by 30 percent by 2050 (under a doubling of carbon dioxide). A decrease in calcification rate of similar magnitude (25%, range 11-40%, Langdon 2000) as a result of reduced carbonate saturation state (under CO_2 doubling) has now been shown in a variety of corals and other marine animals and plants. Greenhouse emission scenarios that produce even greater changes to atmospheric carbon dioxide will lead to even greater decreases in the ease with which calcifying organisms and processes can precipitate calcium carbonate.

b. Sea level

Global sea level will increase as planetary temperatures rise mainly due to the thermal expansion of ocean water (responsible for about 70% of the increase), the melting of glaciers and changes to the volume of Arctic and Antarctic ice sheets. The expected increase in sea level is approximately 9-29 cm over the next 40 years, and 28-98 cm by 2090 (Church et al 2001, IPCC 2001a). These changes have major ramifications for human infrastructure in coastal areas. A 25 cm rise, for example, would displace most people from the delta regions of major rivers such as the Nile, Ganges and Yangtze as well drowning Pacific and Indian Ocean nations such as the Maldives, Kiribati and Tuvalu (Church et al. 2001).

In concert with the direct effects of coastal inundation are the impacts of storm surge (Nichols et al. 1999). Impacts on marine ecosystems will vary according to the proximity to coastlines, in some cases only minor changes are likely while in others major impacts are likely. According to Nichols et al. (1999), sea-level rise could cause the loss of up to 22% of the world's coastal wetlands by 2080. Combined with other human impacts, this number is likely to climb to a loss of 70% of the world's coastal wetlands by the end of this century.

c. Sea temperature

The increase in temperature of the surface layers of the ocean has been observed to lag by 75% when compared to increases in global temperature. The expected change in sea temperature by 2100 is, therefore, considered likely to be in the realm of 1.5-4.5^{o}C with the increase continuing for several centuries there after at a slow rate (IPCC 2001a; Figure 7). Whether or not sea temperatures in the tropics will reach a ceiling of 32^{o}C is still a matter of debate. Also important to local marine temperatures are changes to the strength and direction of oceanic currents. By the far the greatest natural disturbance has been associated with the El Niño Southern Oscillation (ENSO). The functioning of this weather system affects many of the currents throughout the world (see Figure 1A). Changes in the functioning of climate systems like ENSO have also been projected to occur under climate change by many greenhouse gas driven global circulation models. GCM runs done with the Max Planck model, ECHAM4, simulate ENSO with a high degree of realism (Timmermann et al. 1999) and show more frequent El Nino conditions and stronger cold events occur in the tropical Pacific Ocean as greenhouse-gas concentrations are increased.

Table 2. Summary of four scenario storylines described in the Special Report on Emission Scenarios (IPCC 2000). See Chapter 12 (Part 3) for full detail, development and adaptation to the future analysis of the Great Barrier Reef.

- The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, 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. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system.

- The A2 storyline and scenario family describes 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 high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

- The B1 storyline and scenario family describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward 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.

- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Source: IPCC (2001a)

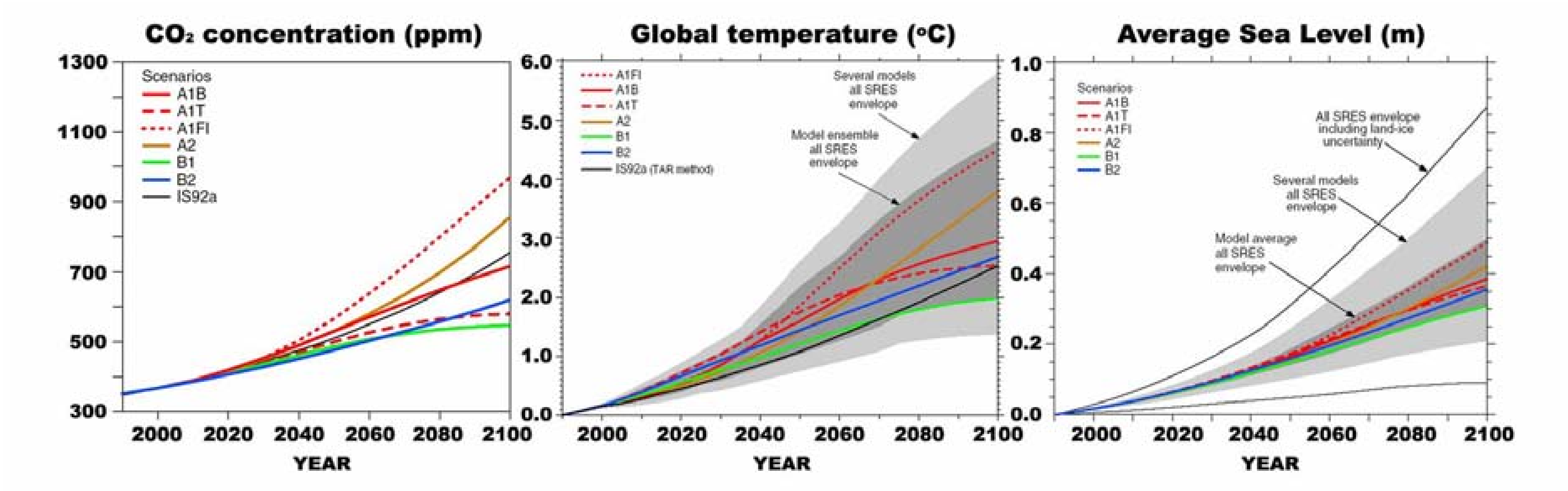


Figure 6. Carbon dioxide, global temperature and sea level for 6 of the SRES scenarios (IPCC 2001 b; see text for explanation of specific scenarios.) Emissions of other gases and other aerosols were included in the model but are not shown in the figure. Reference to the "several models all SRES envelope" are for a basic model tuned to a number of complex models with a range of climate sensitivities. "All SRES" envelopes refer to the full range of 35 IPCC SRES scenarios. The "model average all SRES envelope" shows the average from these models for the range of scenarios. It is important to that warming and sea level rise from these emissions would continue well beyond 2100 due to the long resident times of greenhouse gases in the atmosphere. Modified from IPCC (2001a).

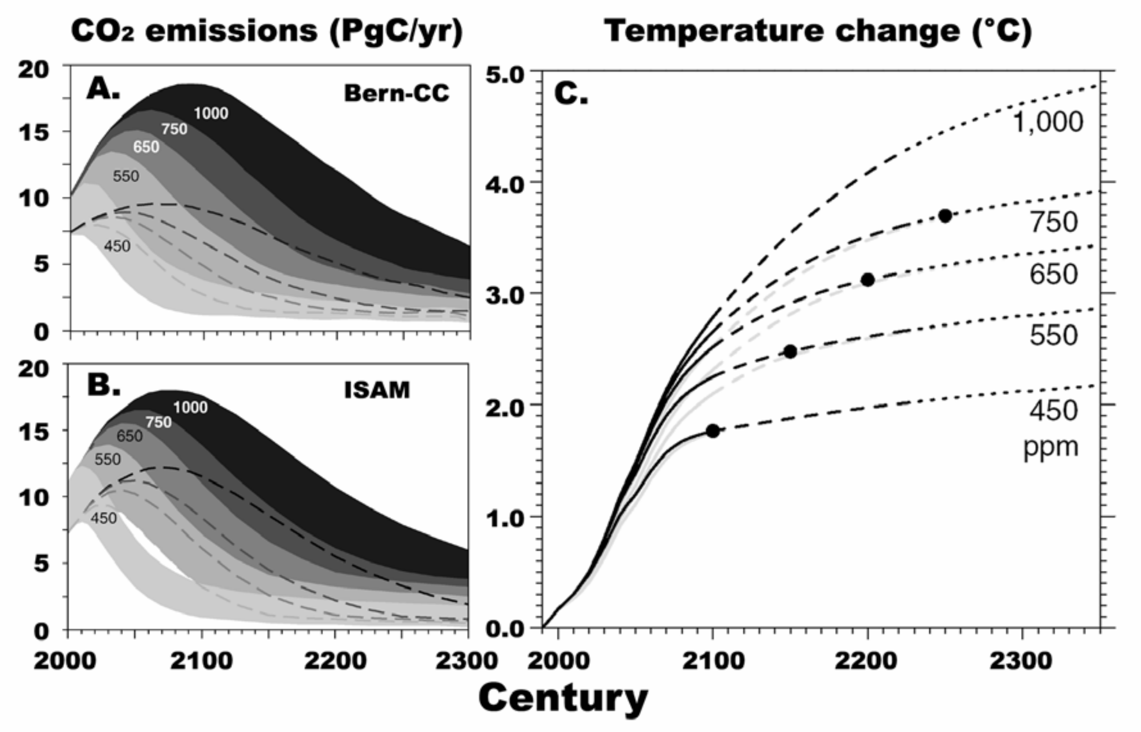


Figure 7 Projected change to CO_2 concentration and global temperature beyond 2100 assuming stabilization scenarios at 450, 550, 650, 750 and 1000 ppm. Note, two models are compared, A. Bern CC and B. ISAM to show differences in models of how emissions must change if stabilization is to occur by 2100. C. Expected temperature change in global temperature if stabilization is achieved (mean model). The results are the average produced by a simple climate model tuned to seven as Atmosphere-Ocean General Circulation Models (AOGCMs). The baseline scenario is scenario A1B which is specified only up to 2100. After 2100, the emissions of gases other than CO_2 are assumed to stabilize at their A1B 2100 values. Note that the maximum temperature continues to change in the lower scenarios due to the slow adjustment of global elements like the ocean. Adapted from the IPCC 2001a.

Conclusions

The greenhouse gas composition of the earth's atmosphere has changed more rapidly than any change recorded within the last half a million years. We are currently experiencing concentrations of carbon dioxide that have not been seen in this same period. Past changes in greenhouse gas concentrations have been matched by corresponding changes in global temperature. Global temperatures have increased by 0.6^{o}C since 1880, and are continuing to rise rapidly. Based on a large number of general circulation models, the Intergovernmental Panel on Climate Change (IPCC) projects increases in atmospheric carbon dioxide and temperature that range between 100 to 650 ppm and 1.5 to 6^{o}C respectively. These changes in the terrestrial setting are expected to increase the number of climate extremes relative to 1990, change patterns of rainfall and affect evaporation rates.

Similar large-scale changes are likely in aquatic environments. Sea temperature and level, current velocity and direction, as well as calcium carbonate alkalinity are all expected to change markedly. It is important to realize that the degree of change under different scenarios will be indistinguishable over the short-term (20-40 years) but will differentiate into low and high rates depending on actions that are taken over the next few decades. If, for example, greenhouse gas emission rates are reduced dramatically as fossil fuels are phased out and energy efficiency increased, final concentrations of carbon dioxide may be as low as 450 ppm and sea warmer by only 2^{o}C. If, on the other hand, business as usual dominates, carbon dioxide concentrations may stabilize at 1000 ppm and our seas warm (eventually) by as much as 6^{o}C. While change is inevitable given the long residence times of carbon dioxide and other greenhouse gases in the atmosphere, the course of action over the next decade will be critical in determining the amount of change that will occur in the earth's ecosystems.

2. Impact on ecosystems

The organisms that make up the rich life forms of the earth are finely tuned to the physical and chemical makeup of their environment. This is primarily due to the relative stability of environmental conditions over thousands of years. Not surprisingly, changes to the mean or range of these conditions can have substantial effects on populations, communities and ecosystems. These responses may be mild, as organisms adjust their physiological processes to the new conditions (acclimation) or acute, as organisms sicken or experience higher mortality rates as their thresholds for particular conditions are exceeded. The latter may result in a shift in the genetic structure (adaptation) and/or geographic range of a population (range shift). In all of these observations, there is an important interplay between the rate of change of the environment and the rate at which the genetic structure and tolerance of organisms can vary.

Substantial changes have already occurred in both terrestrial and marine ecosystems with only a 0.6^{o}C change in global temperature (review: Walther et al. 2002). These past changes give us some insight into what might happen as the earth continues to warm. Given the size of the change expected under even the most minimal greenhouse scenario (an increase in 2^{o}C by 2100 under B1), however, it must be kept in mind that future changes can only be partially understood in the context of changes that have occurred over the past century.

Most of the impact due to climate change detected so far can be grouped according to changes in the timing of biological events (phenology), changes to the distribution and abundance (including range shifts) and changing community complexity and dynamics.

Terrestrial ecosystems

There is ample evidence of changes to the distribution and abundance of terrestrial organisms (Hughes 2000, Walther et al. 2002, Parmesan and Yohe 2003). According to Walther et al (2002), "There is now ample evidence that these recent climatic changes have affected a broad range of organisms with diverse geographical distributions."

Phenological shifts

Phenology is the study of the timing of seasonal activities of plants and animals. It has a long history of study due to the popularity of such amateur activities as gardening, bird watching and butterfly collecting, all activities in which the timing of behavioural events such as flower opening and seasonal arrival-departure have been monitored for centuries. Careful inspection of long-term records indicates strongly significant statistical trends in phenological characters of plants, birds and butterflies. These trends also track changes in climate indices such as the NAO (North Atlantic Oscillation; Walther et al. 2002). Table 3 lists examples of phenological characters which have changed over the past 30-60 years. In all cases, phenological characters have changed in the direction expected as warming occurs. That is, in cases where frost may have previously prevented a biological event from happening (e.g. flower and leaf unfolding), the event has advanced forward in time as warming has eliminated the number of frost days.

Table 3. Timing of biological events that normally occur in the northern hemisphere spring. Expanded from Walther et al. (2001)

Organisms changing	**Change observed in phenological character**	**Reference**
Australian alpine birds	Earlier arrival of migratory alpine bird species in the 1980s and/or 1990s, compared to 1970s	Green & Pickering (in press), cited in Hughes (2002)
European plant species	Flowering and leaf unfolding is now occurring 1.4 to 3.1 days per decade earlier than 30-48 years ago.	Menzel and Estrella (2001)
US plant species	Flowering and leaf unfolding occurring 1.2 to 2.0 (3.8) days per decade earlier than 35 to 63 years ago.	Menzel and Estrella (2001)
British butterfly (18 species)	Earlier appearance by 2.8 to 3.2 days per decade than 23 years ago	Roy & Sparks (2000)
British amphibians	Earlier breeding than 25 years ago	Beebee (1995)
Numerous European and North American bird species	Earlier spring migration by 1.3 to 4.4 days per decade and breeding by 1.9 to 4.8 days per decade than 30 to 60 years ago	Bairlein & Winkel (2001)

Range shifts

The range or distribution of organisms is tightly linked into the local conditions at any one point on the continuum of conditions that vary with latitude and the local influences of weather and other variables. Any change that alters these conditions sets in motion further changes in the distribution of a particular species or range shift.

There is now ample evidence of the poleward migration of terrestrial species in response to climate change. Parmesan and Yohe (2003), for example demonstrate in their recent review in *Nature* that there is now no longer any doubt as in addition to changes in latitudinal distribution, species have also moved upward in altitude within alpine areas (Table 4, Hughes 2000, Walther et al. 2002). As discussed above, these changes are quite major yet the amount of warming so far is only 0.6^{o}C. As further warming occurs, quite substantial changes will continue to occur in the distribution and range of terrestrial species. This will create major challenges for how ecosystems are managed and species conserved.

One of the consequences of changes in the distribution of suitable environments for species is the greater (or lesser) risk of invasion by alien species. For example, warming of

Australian alpine areas has led to the greater success of invasive species such as rabbits at higher altitudes (Green & Pickering in press, cited by Hughes 2002). Similar, the invasion of Swiss forests alpine by evergreen exotic species has escalated over the past 50 years as the number of days on which frost has occurred has dropped to near zero in 2001 (Walther et al. 2002). The potential invasion of greater numbers of warm adapted species is likely to be major issue for people responsible for managing ecosystems.

Table 4. Examples of changes in community structure with recent changes in climate. Adapted and expanded from Walther et al. (2001) and Hughes (2002).

Organisms changing	**Direction of change**	**Reference**
Australian forests and grasslands	Expansion of rainforest at the expense of eucalypt forest and grasslands in QLD	Harrington & Sanderson 1994; Hopkins et al. 1996
Australian alpine invasions	Encroachment by *Eucalyptus pauciflora* into subalpine grasslands near Mt Hotham, VIC	Wearne and Morgan (2001).
Mangroves and saltmarshes in the estuaries of QLD, NSW, VIC and SA	Landward transgression of mangroves into saltmarsh environments over the past five decades with saltmarsh losses ranging up to 80%. Transgression rate by mangroves of 17 m per year from 1949 to 1979 in Gulf of St Vincent, SA	Saintilan & Williams (1999)
Grey-headed flying fox (*Pteropus poliocephalus*)	Flying fox have extended ranges southward from their northern boundary by about 750 km since the 1930s	Tidemann (1999).
Sea birds	8 species have formed new breeding locations (or expanded minimal presences) well south of their historical range.	Dunlop (2001)
Alpine treelines in Europe and New Zealand	Advancement towards higher altitudes.	Kullman (2001), Meshinev et al. (2000) and Wardle and Coleman (1992)
Arctic shrub vegetation (Alaska)	Expansion of shrubs in previously shrub-free	Sturm et al. (2001)
Alpine plants in the European Alps	Elevational shift of 1 to 4m per decade	Grabherr et al. (1994)
Antarctic plants and invertebrates	Changes in distribution within continent	Kennedy (1995)
North America and Europe butterfly species (39 spp)	Northward range shifts up to 200km over 27 years	Parmesan et al. (1999), Parmesan (1996)
Lowland birds in Costa Rica	Extension of distribution from lower mountain slopes to higher areas	Pounds et al. (1999)
British birds (12 spp)	18.9 km average range movement northwards over last 20 years.	Thomas & Lennon (1999)
Canadian foxes	Northward expansion of red fox (*Vulpes vulpes*) range and simultaneous retreat of Arctic fox (*Alopex lagopus*) range.	Hersteinsson & MacDonald (1992)

Community dynamics

A consequence of changing phenology and range shifts of species is that new assemblages of species that are likely to result at any location and time. This will mean different dynamics and interactions among species that may ultimately affect the resilience of ecosystems to further changes within their environment. How these new assemblages will function in space and time is unknown. However the recent nature of their origin plus the fact that conditions are continuing to change mean that the ability of scientists to project the structure and dynamics of future assemblages of organisms is minimal. There is little doubt, however, that changes in community dynamics have and are occurring.

There are numerous examples of past changes that hint at how complex these "futures" might be for terrestrial assemblages. Delay in the spring arrival of some species of birds has led to increased nest competition between species that arrive earlier. Disease and parasite success is particularly sensitive to the pathogen growth rates and the density of hosts. The former has been linked directly into the disappearance of Costa Rican amphibian species. Drier conditions in the montane forests appear to have led to disease epidemics that have led to the extinction of constituent frog fauna (Pounds et al. 1999). Other examples include the mistiming that can arise as different elements within an ecosystem change. Warmer spring weather in Europe, for example, has disrupted the hatching of the winter moth (*Operophtera brumata*) and the unfolding of oak buds. This in turn has led to the peak of insect availability being out of synchrony with the peak demand of nestling birds like the Great Tit (*Parus major*).

Marine ecosystems

The biological components of marine ecosystems appear to be as vulnerable to climate change as those that make up terrestrial ecosystems. These effects are adding to ecosystems that are over-exploited (Jackson et al. 2001; Meyers and Worm 2003) and impacted by a large range of other factors. Differences between the vulnerabilities of species in the two environments may arise due to differences in life cycle characteristics and physical nature of the medium in which the two exist. Increasing risks of desiccation with increasing temperature only face those marine organisms that are intertidal. However, increases in the number of extreme heat events are a problem for organisms living in both environments. Equally, marine organisms tend to have water borne larvae with wide dispersal ranges while many terrestrial organisms tend to have localised dispersal and much smaller ranges. Some examples of these differences will be discussed here. The central focus in the following chapters on coral reefs will serve to fill out the introductory comments here.

The marine ecosystems bordering the earth's islands and continents and are generally dominated by food webs that depend on attached plants (algae or angiosperms) or waterborne phytoplankton. These organisms are the basis for more than 60% of the productivity of the ocean and are critically important to the flow of resources within the ocean. Changes to environmental conditions such as light, temperature, salinity and wave stress have direct impacts on their health and functioning. Marine organisms like those in terrestrial ecosystems, may experience large diurnal and seasonal variation in the environment conditions surrounding them. Even so, these organisms are still sensitive to shifts in environmental conditions that exceed those to which they are adapted. As a result, it is not surprising there are now many marine examples in which recent climate change has already produced pronounced changes in the abundance and distribution of organisms within these habitats.

Phenological shifts

The study of changes in phenology as a result of climate change is less well developed for marine organisms. Fisheries provide the only data in this respect (catch data, seasonal arrival of target species) and even here, records are less well developed than those emanating from the databases developed by amateur butterfly, bird and gardening communities. No comparable studies of marine organisms have been developed as yet. Marine communities are likely to have been changing in the same way that the phenology of terrestrial communities has been changing. Some examples of these changes are contained in the examples of shifts in range and community dynamics discussed below.

Range shifts

There has been a poleward range shift of intertidal marine species (Barry et al. 1995, Southward et al. 1995), which is similar in overall pattern to that seen for the distribution of bird and butterflies (Parmesan et al. 2000). Comparison of surveys of composition rocky intertidal communities at Monterey on the mid Californian coastline for the period 1931 to 1933 and 1993 to 1994 clearly indicate that species ranges have shifted northward (Barry et al. 1995). The geographic distribution of 45 invertebrate species was compared in this study over a 60 year period and the abundances of 8 out of 9 southern (warm adapted) species were found to have increased and while 5 out of 8 northern (cold adapted) species had decreased. Similar observations have been made for intertidal communities in southwest Britain and the western English Channel, which show extensive changes in species composition and abundance over the past 70 years (Southward et al. 1995). Warm-water species have replaced the colder water ones, as in the California example.

Changes in the temperate intertidal communities have also been matched by changes in the composition of benthic fish communities. Holbrook et al (1997) recorded the northerly intrusion of warm-water fish in concert with long-term changes in sea temperature along the Californian coastline. Again, southern warm water species increased in abundance while more northerly species retracted northward. Similar changes have been seen in polar seas as well. Beaugrand et al (2002) demonstrate a reorganization of the North Atlantic copepod community structure as a result of warming. Again, warm water species show poleward range shifts, while cold water species show poleward contraction. These changes may also have complex outcomes in terms of the organisms that live there.

Community dynamics

The complex dynamics associated with the changing abundances of key organism are only just beginning to be understood. Probably the most graphic examples are to be illustrated in the next chapter on coral reefs. In this case, the major structuring organism (reef-building corals) is severely impacted by elevated water temperatures. These changes will be discussed in detail as the focus for this study falls more on coral reef and the Great Barrier Reef specifically. It is important to consider a few examples from other ecosystems that illustrate the importance of climate change to marine ecosystems in general.

As outlined in the first chapter, the most rapid climate change is occurring at the poles. Major changes in ice volume have already occurred as a result of increasing global temperature (de la Mare 1997, Kerr 1999) and temperatures in both polar regions have been the highest they have been for thousands of years (Ovenpeck et al 2001, Barbraud and Welmerskirch 2001). These climatic and associated changes are having major impacts on the organisms living in the earth's polar regions. As a result, community dynamics in this region are changing rapidly.

Densities of krill (euphausid crustaceans that graze the rich seas of Antarctica during the late spring and summer) are a critically important component of the Antarctica food chain. Krill abundance has decreased in populations sampled at the tip of the Antarctic Peninsula by an order of magnitude from 1984–85 to 1995–96 (Loeb et al 2001). This decrease has been matched by the opposite trend by salps (pelagic tunicate *Salpa thompsoni*). Salps are filter feeders that benefit from open waters that remain ice free. Krill (late larvae, juveniles and adults) on the other hand feed on the microalgae that proliferate on the bottom of sea ice during the late winter. The impact of lower krill numbers is already being felt. Adele Penguin (a key predator of krill) populations have decreased by 70% since 1987. Reduced fledgling survival is associated with this decline, potentially a result of the preferred prey item, krill, being less abundant. A similar relationship holds for Emperor Penguins. Since the 1970s, Emperor Penguin numbers have declined by 50%, largely due to a major change in adult survivorship associated with warmer seas and lower sea ice cover (Barbraud and Weimerskirch 2001). While an exhaustive cataloguing of the biological changes occurring in polar regions as a result of climate change is beyond this review, it is now beyond a shadow of a doubt that major changes are occurring there as well.

The polar oceans also illustrate further how small changes in climate can have major impacts on community dynamics with quite often serious impacts on constituent organisms. Reduced sea ice, for example, has impacted the reproductive biology of seals in the Arctic (Kelly 2001). Ringed seals are vulnerable to earlier snowmelts due to the premature destruction of their subnivean lairs, exposing pups to extreme weather and increased predation. Pacific walruses, on the other hand, need ice to support pups while they feed on benthic invertebrates during suckling. The edge of sea ice is only suitable when above waters of less than 100m in depth that are optimal for feeding. Recent sea ice retreat in the Beaufort and Chukchi seas has led to a decreased water depth and a reduction in available foraging areas for the ringed seal that are close enough to suckling areas (Kelly 2001).

Conclusions

Walther et al. (2001) adequately sum up our current understanding of whether the earth's ecosystems have responded to climate change over the past 100 years. The multi-authored team from expert areas from polar to tropical ecosystems and from land to sea concluded that there "*is now ample evidence of the ecological impacts of recent climate change, from polar terrestrial to tropical marine environments. The responses of both flora and fauna* *span an array of ecosystems and organizational hierarchies, from the species to the community levels. Despite continued uncertainty as to community and ecosystem trajectories under global change, our review exposes a coherent pattern of ecological change across systems. Although we are only at an early stage in the projected trends of global warming, ecological responses to recent climate change are already clearly visible.*" Similarly, Parmesan and Yohe (2003) review the direction and magnitude of change in their recent *Nature* paper. These authors exhaustively tested whether or not data sets from a huge array of studies showed change in that expected from climate change. Their conclusions are summed up by their statement within the *Nature* article *"We define a diagnostic fingerprint of temporal and spatial 'sign-switching' among appropriate long-term/large-scale/multi-species data sets, this diagnostic fingerprint was found for 279 species. This suite of analyses generates 'very high confidence' (as laid down by the IPCC) that climate change is already affecting living systems."*

There is little doubt that the earth's biota is changing in response to the changing climate. This has major implications for Australia, which is renowned for the beauty and intact state of its terrestrial and aquatic ecosystems. It is perhaps ironic that the nation that has the highest per-capita emission rate (emissions of 27.9 tonnes of CO_2 per person in 1999, following closely by Canada and then the USA; Turton and Hamilton 2002) may have the most to lose in terms of intact and highly biodiverse marine and terrestrial ecosystems. In the next chapter, the focus shifts to the special case of coral reefs and then to one of Australia's greatest environmental and economic assets, the Great Barrier Reef.

3. Coral Reefs

Coral reefs are the most diverse marine ecosystems on the planet and have a central importance to the tropical coastlines. Complex and productive, coral reefs more biodiverse than any other marine ecosystem. In addition to this, coral reefs provide critical support for at least 100 million people across the planet (Bryant et al. 1998). Unfortunately, recent evidence suggests that coral reefs are also very sensitive to environmental changes like climate change (Hoegh-Guldberg 1999). In the words of Klaus Toepfer, the United Nations Environment Programme Executive Director, "Coral reefs may be the ecosystem equivalent of the canary in the coal mine, giving early warning that the world's ecosystems can no longer cope with growing human impacts." (UNEP 2000). The canary analogy is apt, although to lose a canary of such importance begs the question as to whether coral reefs really are the canary or, to keep within the analogy, "half the mining team".

This chapter outlines the importance and threats that face coral reefs across the planet. Reviewing this information is central to placing the health and importance of the Great Barrier Reef within the global context. The Great Barrier Reef is currently among the healthiest and best managed coral reef ecosystems in the world. Despite this, it is threatened by a number of direct and indirect human activities. As we shall see, coral reefs are in very poor shape worldwide. According to the authors of the Global Coral Reef Monitoring Network, an estimated 40% of the world's coral reefs will be lost by 2010, and another 20% in the 20 years following unless urgent management action is implemented (Wilkinson 2000). The combination of climate change amid an intense setting of other impacts and stresses has reduced the resilience of reef systems to a point where most are threatened by elimination. The Townsville Declaration on Coral Reef Research and Management (Hughes et al. 2002, 2003; Pockley 2003) highlights the near unanimous opinion of the world's leading scientists that the coral reefs are globally and critically endangered.

The current state of coral reefs

Coral reefs supply food and resources (e.g. limestone building materials) to communities that often live immediately adjacent to coral reefs. They play critically important roles as sources of income and resources through fishing, tourism, building materials, coastal protection and biodiscovery (Carte 1996). Approximately 15% of the world's population (approximately 0.5 billion people) live within 100 km of coral reef ecosystems (Pomerance 1999). The majority of human communities living along coral coastlines are economically poor and directly depend on coral reefs for their survival through subsistence foraging (Bryant el al. 1998). The value of this type of support is hard to estimate economically but runs into the tens of billion of dollars each year (Bryant et al. 1999).

In addition to direct support to subsistence fishers, commercial fishing in the rich waters of coral reefs generates at least 6 million metric tons of fish catches globally on an annual basis (Munro, 1996). This income is important to both developing and developed countries. Coral reefs also provide a rich source of income from tourism, with people travelling thousands of miles in many cases to dive, fish and swim in the scenic locations offered by coral reefs. Reef associated tourism, for example, added an estimated $89 billion to the gross domestic product (GDP) of the Caribbean region (Jameson et al., 1995 cited by Pomerance 1999). In Australia, as will be developed in Part 2, estimates of the wealth generated by the Great Barrier Reef currently in excess of $2 billion per year (Part 2). The average contribution of tourism in 1999 (tourism and travel GDP) to fourteen Caribbean economies was 43% of the total GDP for these countries (Dixon et al. 2001:37). The last paper, however, tends to downgrade the importance of reefs in favour of a general theme of 'sun, sand and sea', as implied by the following passage late in the publication: 'In some locations, coral reefs are an important part of the resources used by the tourist sector, both through direct use (such as diving) and because of the protection reefs can provide from storms. Overuse and inappropriate use can severely damage reefs and impair these benefits' (p 46) In other words; reefs in the present-day Caribbean region are an important asset to be nurtured and protected, but not the quintessential tourist attraction.

The extraordinarily high biodiversity of coral reefs is inherently difficult to value formally. The sheer scale of the coral reef biodiversity, with its hundreds of thousands of unexplored gene pools, perhaps negates the need to calculate this formally. About 100,000 species have been described from the world's 375,000 km^2 of coral reef. This is a tiny fraction of an estimated 0.5 to 2.0 million species that live on coral reefs (Spalding et al. 2002). Other estimates range as high as 9 million species being associated with coral reefs (Bryant et al. 1998). This biodiversity has an increasing value as a storehouse of potential novel compounds. Recent advances in the molecular sciences (e.g. robotic sequencing and screening, microarrays and molecular databases) are making gene and pharmaceutical discovery many hundreds of times faster than it was even a decade ago. Excellent prospects exist for the discovery of new medicines, chemicals and materials from these vast ecosystems. Economic wealth is being built upon these discoveries (e.g. conotoxins from *Conus* sp., Dutton et al. 2002; pocilloporin from reef cnidarians, Dove et al. 2001; anti-cancer drugs from sponges Wallace 1997). While this exploration in its infancy, it is significant to note half of the potential pharmaceuticals being explored at present are from the oceans, and many of these are from coral reef ecosystems.

Coral reefs may be even more valuable in ways that are often unappreciated. By breaking the force of oceanic waves, corals reefs provide protection along tropical coastlines all over the planet (including the Caribbean as quoted above from Dixon et al. 2001). This protection is critical for coastal cities and towns, and for other ecosystems such as sea grass and mangrove communities that require calm waters in which to grow and proliferate. While these ecosystems have inherent tourist and biodiversity value, their value as critical nursery grounds within the network of coastal habitats is enormous. Many commercially important species spend their early life history stages in these rich habitats.

Reef-building corals: the framework builders of coral reefs

Coral reefs flourish in warm shallow seas. Their abundance varies as a function of latitude with the greatest abundance of corals being located closest to the equator. Light, temperature and the carbonate alkalinity of seawater decrease in a poleward direction, making the formation of carbonate reefs more difficult at higher latitudes (Kleypas et al. 1999a). In many ways, the productivity and biodiversity of coral reefs is at odds with the nutrient depleted waters of the earth's tropical oceans. Starting with Charles Darwin, visitors to coral reefs have marvelled at how these productive ecosystems exist in waters that otherwise support only the lowest phytoplankton populations (Darwin 1842, Odum and Odum 1955). Coral reefs can support (or did in the past, see Jackson et al. 2001) massive populations of fish, birds, turtles and marine mammals (eg, Maragos, 1994; Kepler et al, 1994). Akin to the cactus gardens of tropical nutrient deserts, coral reefs tightly recycle nutrients between often closely associated mutualistic partners. This has been identified as the feature for why coral reefs are so diverse in this otherwise desolate setting of tropical oceans (Muscatine and Porter 1977, Hatcher 1988).

Reef building corals build the framework of coral reefs through their calcareous exoskeletons that may remain long after the animal-plant tissue has been removed. These skeletons are in turn cemented together via the combined activity of calcareous algae and simple sedimentary infilling and consolidation. The resulting structure becomes the habitat for thousands of species of animals, plants, fungi and protists. While approximately 93,000 species have been described from the world's coral reefs, estimates of potentially undescribed species range from 948,000 to up to 9 million (Reaka-Kudla 1996).

Reef-building corals live in a mutualistic symbiosis with single celled dinoflagellate algae known as zooxanthellae (Trench 1979). These tiny plants live inside the cells of the coral host and continue to photosynthesize in the light as they would if they were free-living. Instead of retaining the sugars and amino acids that result from this activity for their own growth and reproduction, zooxanthellae export more than 95% of their photosynthetic production to the coral host (Muscatine 1967; Muscatine 1990). In return, zooxanthellae have direct access to the waste products of animal metabolism (fertilizer), which are lacking in the surrounding waters. The close association of animal (heterotroph) and plant (phototroph) avoids the problem of inorganic nutrients and food substrates becoming diluted within the vast nutrient poor waters of the tropics. The success of coral reefs in the otherwise nutrient deserts of tropical oceans is seen as a direct consequence of the mutualism exemplified by corals and their zooxanthellae (Muscatine and Porter 1977).

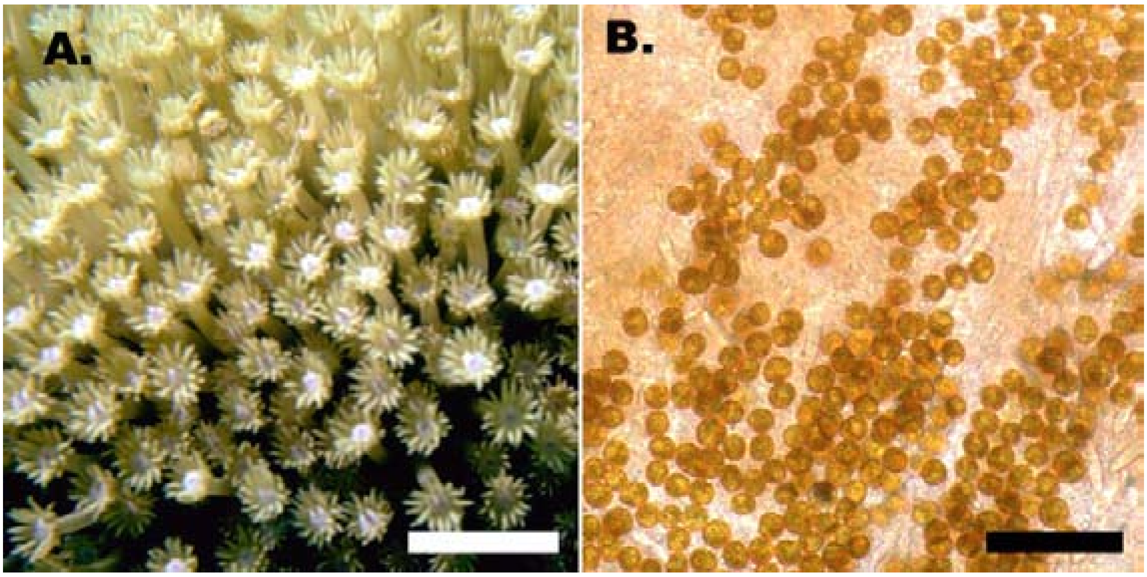


Figure 8. A. Polyps of the reef-building coral *Goniopora tenuidens* (scale bar = 2 cm) B. Zooxanthellae from tentacle squash of *G. tenuidens* (scale bar = 50 µm). Photographs: Ove Hoegh-Guldberg.

Some studies suggest that genetic diversity within coral symbionts may be a strong foundation for adaptation of corals to rising temperatures, although the weight of evidence suggests the opposite. Until 1980, all reef-building corals were thought to contain a single species of symbiotic dinoflagellate called *Symbiodinium microadriaticum* (Freudenthal 1962; Taylor 1983). Starting with Robert Trench and associates at the University of California at Santa Barbara (Trench 1979; Schoenberg and Trench 1980a, 1980b), however, results accumulated to reveal that zooxanthellae in reef-building corals are a collection of many taxa (Rowan et al. 1997; Loh et al. 1997). A recent survey of the molecular identity of symbionts from 86 host species from the Great Barrier Reef representing 2 genera from Class Hydrozoa, 6 genera from Subclass Alcyonacea, and 32 genera from Subclass Zoantharia (28 scleractinian, 1 actiniarian, 2 zoanthidean, and 1 corralimorpharian) found 23 distinct types of zooxanthellae (LaJeunesse et al 2003). Many hosts have 2 or more genetic varieties of zooxanthellae in their tissues. The meaning of the large molecular diversity of symbionts in corals is an area of active research. While some molecular differences appear to be associated with distinct physiological behaviours (Rowan et al. 1997; Rowan 1998), it is not a foregone conclusion that molecular differences always correlate with physiological differences (Hoegh-Guldberg et al. 2002). This will be discussed further in the section on adaptation and physiological tolerances.

Human impacts on coral reefs

Coral reefs have persisted for almost 200 million years even after brief absences following global calamities such as the asteroid strike at the Cretaceous Boundary. They show enormous resilience in geological time (i.e. over millions to tens of millions of years). Paradoxically then, coral reefs appear to be highly sensitive to the increased direct and indirect pressures from human activity. This sensitivity was recently highlighted in the Townsville Declaration on Coral Reef Research and Management (Pockley 2003; Hughes et al. 2002; Hughes et al. 2003) which concluded “Overfishing and pollution have driven massive and accelerating decreases in abundance of coral reef species and have caused global changes in reef ecosystems over the last two centuries. If these trends continue, coral reefs will decline further, resulting in the loss of biodiversity and economic value.” According to some estimates, almost a million species are likely to face extinction before 2040 (Reaka-Kudla 1996).

The effect of human population growth in tropical oceans can only be described as an onslaught of destructive activity. Jackson et al. (2001) demonstrate from paleological, archaeological, and historic data that a range of disturbances including overfishing and coastal development, have consistently led to major changes in ecosystem structure and health. In many ways, the processes involved are subtle. Hughes (1994) illustrated major changes that are wrought when herbivores are consistently removed by fishing to the point where reef resilience was lost and a permanent phase shift to algal dominated communities occurred. Coral communities around the island of Jamaica used to have (prior to 1977) coral cover in excess of 70%. It is currently below 5% in most places. Several natural factors interacted with anthropogenic stresses to produce this outcome. Firstly, Hurricane Allen reduced coral cover to 22-38% (from 47% to 70%, Hughes 1994). Secondly, the sudden loss of the black sea urchin, *Diadema antillarum*, due to a virus between 1982 and

1984 led to a loss of critical herbivore control of algal growth. As a result, coral settlement and growth was inhibited and coral cover dramatically declined. The problem was that fish grazers had been eliminated in the 100 year period prior to 1980 – leaving *D. antillarum* as the principal grazer. With no other grazer to take the place of *Diadema*, macroalgae (seaweeds) out-competed corals for space on the reefs along the coast of Jamaica and eventually dominating the substrate. In short, the removal of large herbivorous fish from the ecosystem led to a decline in the resilience (i.e. ability to recover from a disturbance) of the reef system (McClanahan et al. 2003; Pockley 2003). This type of circumstances has been repeated in many parts of the world as key elements like grazing fishes have been removed from coral reefs and has resulted in ecosystems that, by being thrown out of balance, do not have the complex characteristics required for resilience (Folke 2003).

In addition to over-exploitation of reef species, coral reefs have been impacted by a range of other human activities. Global climate change is compounding the effect of these other pressures, which are listed with a brief description in Table 5. They will be discussed in further detail in relation to the risks that they represent in terms of compounding the effects of climate change. Several important policy issues arise from this issue with respect to coping with climate change (see also Chapter 7). Dealing with these issues will be critical to the longevity of coral reefs like the Great Barrier Reef, especially given its current well managed and good condition.

Table 5. Principal sources of stress for coral reefs world wide. References are meant as samples of key literature and are not intended to be exhaustive. Further details on these threats can be gained from Bryant et al. (1998), Spalding et al. (2002) or from Wilkinson (2002b)

Activity	**Description**	**Reference**
Coastal development	Natural landscapes produce defined amounts of nutrient, toxins and sediment which enter into adjacent coastal areas. Coral reefs have evolved over thousands of years in these settings. When coastal development (urban centres, ports, tourist development) results in the removal of vegetation and a change in flow patterns off the land, the amount of sediments and nutrients entering the water column tends to increase. This has been implicated in stimulating algal overgrowth on inshore coral reefs and in setting off outbreaks of potential coral predators.	Bryant et al (1998), McClanahan (1999), Harborne et al (2001);
Overexploitation	Both local subsistence fishers and fishing industries are putting large pressures on fish stocks associated with coral reefs. As a result, most fish stocks in tropical as well as temperate oceans are in major decline and are at 10% of the previous unfished abundance. The removal of fish leads to a loss of functional groups (herbivores, key predators) that are important to controlling other organisms within the ecosystem. Widespread ecological changes may result.	Jackson et al. (2001); Hughes (1994); Boersma and Parrish (1999); Meyers and Worm (2003)
Destructive fishing	The methods employed to catch fish have also had major impacts on coral reefs. Cyanide fishing involves the use of cyanide to stun fish. This has quite serious impacts on surrounding reef communities. The second method that is being used widely is fishing using dynamite. In this case, the percussion effects of exploding dynamite underwater are used to stun fish (which are then collected). These cause localised destruction of reef and reef organisms.	Jones and Hoegh-Guldberg (1999); Jones et al. (1999); McClannahan et al (2002); Edinger et al. (1998); Wilkinson (1998, 2002b)
Agricultural run-off	The growth of agriculture along tropical shorelines has led to major increases in the amount of sediments, nutrients, pesticides and herbicides entering adjacent coastal water columns. These have a range of effects, including algal overgrowth and potential coral kills from the associated toxins.	Koop et al. (2001); Cortes (1994); McClanahan et al (2002)
Marine-based pollution	Chemicals dumped by shipping or coastal developments leads to a build up of compounds that poison corals and associated organisms. Associated with is physical pollution or trash. This can have major impacts on coral reef fauna when dumped from shipping or coastal communities. Plastic bags can choke turtles and fish, or cover coral reefs, blocking off the sunlight needed to keep the reefs alive. Another form of trash of significance are discarded fishing nets ("ghost nets") which can continue to cause the death thousands of fish long after decommissioning.	Bastidas et al. (1999); Abelson et al. (1999); Edinger et al (1998); Wilkinson (1998, 2002b)
Climate change	Rising sea temperatures and decreasing calcium carbonate saturation states are changing the conditions under which coral reefs have prospered for at least 400,000 years. In 1998 along, a single world wide episode of warmer than normal water temperatures, an estimated 16% of the world's corals died. This is seen by many as the number one threat to coral reefs now as oceans undergo sustained warming over the next century.	Glynn (1991); Brown (1997); Hoegh-Guldberg (1999); Done et al. (2003)

Coral bleaching and climate change

The algal symbionts of reef-building corals exist at high densities within the host tissues. The population densities of symbionts range from between 0.5 to 5 x 10^6 cells cm^{-2} of host surface under normal conditions (Drew 1972) with low rates of migration or expulsion to the water column (Hoegh-Guldberg et al. 1987). Over time, symbiotic dinoflagellate populations vary slowly in response to seasonal changes in environmental conditions (Jones 1995; Fagoonee et al. 1999; Fitt et al. 2000). These changes probably represent slow adjustments of symbioses that optimize the physiological performance of the coral-algal symbiosis as the environment changes.

Under a variety of stresses, abrupt changes to the density of zooxanthellae in symbiotic corals and other invertebrate hosts can occur (Brown and Howard 1985; Hoegh-Guldberg and Smith 1989; Hoegh-Guldberg 1999). These stresses include changes to salinity (Goreau 1964; Egana and DiSalvo 1982), light (Vaughan 1914; Yonge and Nichols 1931; Hoegh-Guldberg and Smith 1989; Gleason and Wellington 1993; Lesser et al. 1990), toxin concentrations (e.g. cyanide, Jones and Hoegh-Guldberg 1999; copper ions Jones 1997), microbial infection (e.g. *Vibrio*, Kushmaro et al. 1996) or temperature (Jokiel and Coles 1977, 1990; Coles and Jokiel 1978; Hoegh-Guldberg and Smith 1989; Glynn and D'Croz 1990). This phenomenon has been referred to as 'bleaching' due to the fact that corals rapidly lose brown colour (due to the zooxanthellae) and turn a brilliant white (Figure 9).

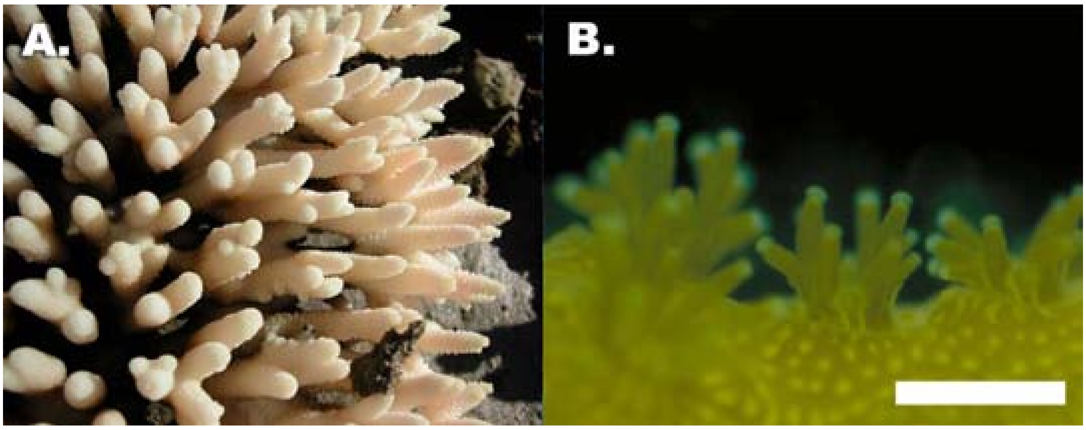


Figure 9. A. Bleached corals (*Acropora sp.*) on the inshore Great Barrier Reef during the 2002 bleaching event. Elevated water temperatures led to coral bleaching, where by the normal brown colour of the corals disappeared as the symbionts left. B. Shows the normal colour of the surface of a typical coral (*Seriatopora hystrix*). Scale bar is approximately 2 mm long. Photos by Ove Hoegh-Guldberg

Bleaching at small local scales (10-1000 m^2) has been reported for almost a century (Yonge and Nichols 1931). Bleaching at larger geographical scales, however, is a relative new phenomenon. Prior to 1979, there are no formal reports of mass coral bleaching in the scientific literature. Since that date, however, the number of reports has risen dramatically (Figure 10). Mass bleaching events have a number of possible outcomes. In mild cases, reefs will recover their colour within months. At the other end of the spectrum, mass bleaching events led to large proportions of coral communities dying. In 1998, for example, coral reefs off the Australian coastline recovered from widespread bleaching with minimal loss of reef-building coral (Berkelmans and Oliver 1999). However, in the Indian Ocean, Palau, Okinawa and North West Australia, coral communities lost up to 95% of their coral cover in the same year (Table 3).

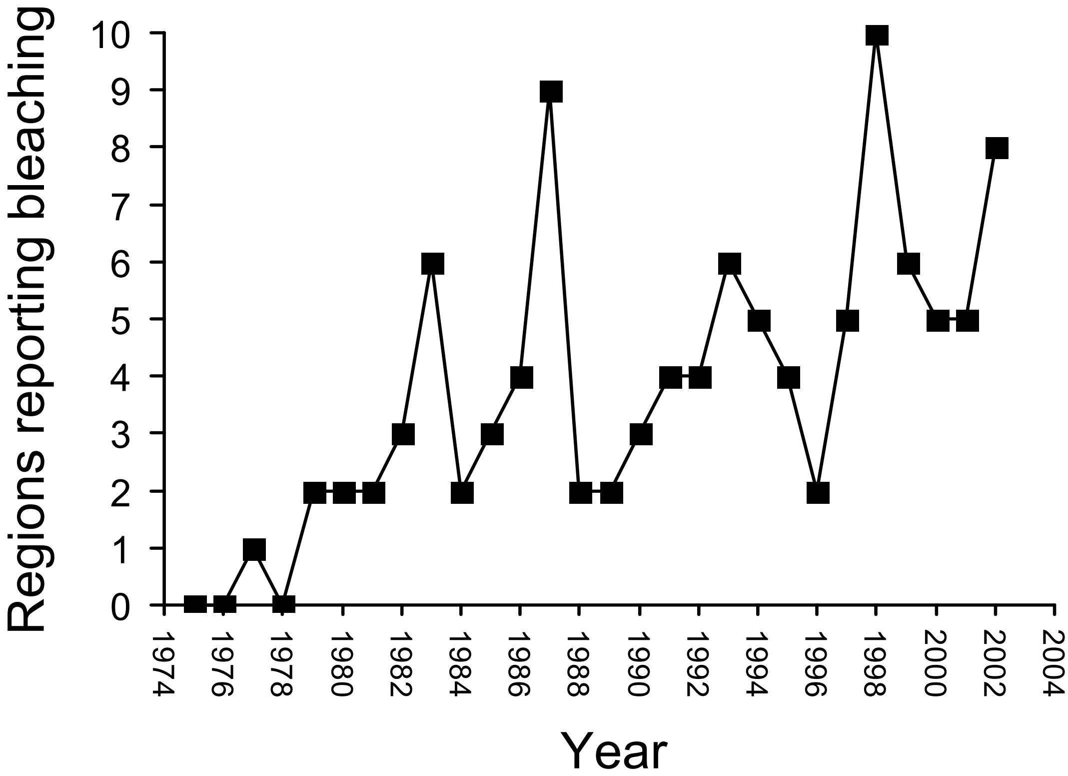


Figure 10. The number of coral reef regions bleaching since 1975. Regions were: Caribbean, Atlantic coast of South America, Western Pacific, Central Pacific, Eastern Pacific, North Pacific, South East Asia, North East Asia, Western Indian Ocean and Eastern Indian Ocean. Data collected from over 3800 bleaching records from nearly 100 countries in the ReefBase bleaching report database (http://www.reefbase.org, Dec 23, 2002).

While localized bleaching can arise as a result of any number of stresses, mass coral bleaching is tightly correlated with short excursions of sea temperature above summer maxima. Over the past 20 years, there have been six major global cycles of coral bleaching ("mass coral bleaching events"). A combination of elevated sea temperature and exposure time predicts mass coral bleaching with great certainty (Strong et al. 1996, Hoegh-Guldberg 1999, Strong et al. 2000, Hoegh-Guldberg 2001). This highlights the existence of a thermal threshold values (Figure 11). These vary with latitude, species, clone, other physical factors (e.g. light) and history (Edmunds 1994, Jones et al. 1998, Hoegh-Guldberg 1999, Berkelmans and Willis 1999, Brown et al. 2002). Despite this secondary source of variability, satellite measurements of sea surface temperature anomalies can be used to predict bleaching events several weeks in advance with more than 90% accuracy (review: Hoegh-Guldberg 1999). Sea surface temperature measurements also appear to deliver information on the intensity and outcome of bleaching events. Table 6 outlines information from the global event in 1998 in which anomaly size and exposure were multiplied together to give a degree heating month (akin to degree heating weeks of Strong et al 2000; see also Hotspot program, coordinated by the United States National Oceanic and Atmospheric Administration, NOAA: http://orbit-net.nesdis.noaa.gov/orad/coral_bleaching_index.html). The four sites that experienced major post-bleaching mortalities had three-fold higher degree heating month indices. While some fine tuning needs to be done with regard to the influence of other factors (e.g. Brown et al. 1999, Mumby et al. 2001, Berkelmans and Willis 1999), the relationship between SST anomalies, exposure time and coral bleaching and mortality gives strong indications of what the progression will be from bleaching to mortality as heat stress increases over the next century. A doubling of CO_2 (IS92a scenario) will lead to degree heating months (DHM) for most tropical regions that will be greater than three-fold higher than those which caused large scale mortality events in Palau, Okinawa, Seychelles and Scott Reef (Hoegh-Guldberg 2001).

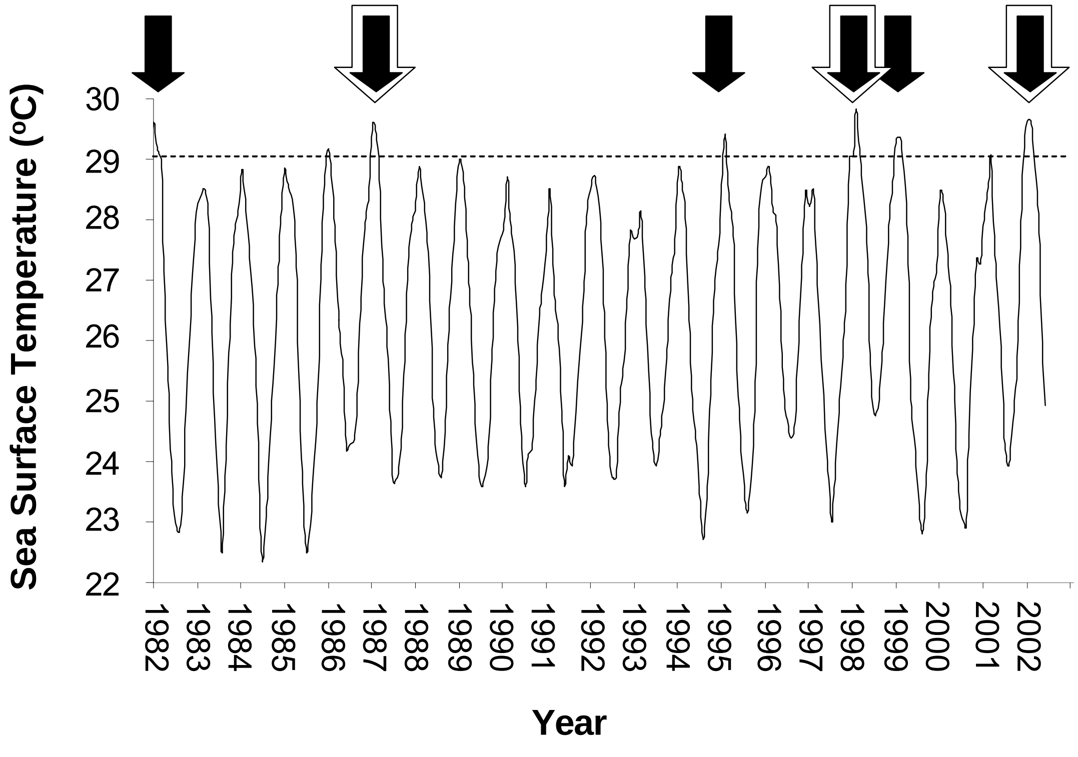


Figure 11. Sea surface temperatures and triggers for coral bleaching for offshore reefs near Townsville, central Great Barrier Reef (latitude 18.3S, longitude 146.3E). Dataset from the Comprehensive Ocean Atmosphere Data Set (COADS) and satellite observations (1990 – present), compiled from operational data produced by the National Environmental Satellite, Data and Information Service (NESDIS). Horizontal dashed line indicates the thermal threshold for 3-4 week exposure times (Hoegh-Guldberg 1999). Arrows indicate when bleaching was reported on the Great Barrier Reef (emphasized arrows indicate years in which intense bleaching occurred).

Table 6. Comparison of recent Degree Heating Months and mass bleaching mortality estimates from incidents of bleaching within the 1998 mass bleaching event (adapted from Hoegh-Guldberg 2002).

Severe events (mortality > 80%)			
Location	**Degree heating months**	**Mortality**	**Source**
Palau	3.9	70-90%	J. Bruno, unpublished data
Seychelles	3.1	Up to 75%	Spencer et al. (2000)
Okinawa	3	90-95%	Loya et al. (2001)
Scott Reef	2.6	75-90%	L. Smith and A. Heyward, unpublished data
Mean ± 95% CI	3.2 ± 0.47		

Mild events (mortality < 10%)			
Location	**Degree heating months**	**Mortality**	**Source**
Southern GBR (reef crest)	1.7	10-30%	Jones et al. (2000)
Central GBR (inner reefs)	1.4	1-16%	Marshall and Baird (2000)
Moorea (outer reef crest)	0.9	0% mortality	Personal observation (10% bleached)
Cook Is (Southern; reef crest)	0.4	0% mortality	Personal observation (5% bleached)
Mean ± 95% CI	1.1 ± 0.49		

Heat stress and mechanisms of coral bleaching

There is a considerable set of information now on why corals and their zooxanthellae bleach. Coles and Jokiel (1977) were among the first researchers to investigate heat stress in reef-building corals during a project looking at the effect of heat effluent flowing from a power plant in Kaneohe Bay in Hawaii. Coles and Jokiel (1977) noted that corals that were warmer than normal were bleached. Those that were warmest were dead. In their investigation of the physiology of heat stressed corals, they noted the rapid reduction in photosynthetic activity early in the syndrome. Some of this decrease was due to reduced zooxanthellae numbers as the corals bleached. However, subsequent work has revealed that photosynthetic decreases occur prior to the onset of the loss of zooxanthellae (Hoegh-Guldberg and Smith 1989; Iglesias-Prieto et al. 1992; Fitt and Warner 1995; Iglesias-Prieto 1995; Warner et al. 1996; Jones et al. 1998). Heat stressed corals develop an increased susceptibility to the phenomenon of photoinhibition, which is very similar to the mechanisms that are faced by all plants when they become temperature stressed. This mechanism, in which light becomes a liability, also explains the important role that lights plays as a secondary factor (Jones et al. 1998, Hoegh-Guldberg 1999).

A key observation regarding heat stress in reef-building corals is that not all corals are equally sensitive to temperature. Corals with thicker tissues and more massive growth forms (e.g. *Porites* spp., *Goniopora* spp., *Montipora* spp.) tend to be more tolerant than corals that have thinner tissues (e.g. *Acropora* spp., *Stylophora* spp., *Pocillopora* spp.). Some species of zooxanthellae may also be more thermally tolerant although the evidence is equivocal at this point (Hoegh-Guldberg 1999). The thermal threshold above which corals and their symbionts will experience heat stress and bleaching also varies geographically, indicating that corals and zooxanthellae have evolved over evolutionary time to local temperature regimes (Coles et al. 1976, Table 6, Hoegh-Guldberg 1999). Corals closer to the equator have thermal thresholds for bleaching that may be as high as 31^{o}C while those at higher latitudes may bleach at temperatures as low as 26^{o}C. Thresholds may also vary seasonally. Berkelmans and Willis (1999) revealed that the winter maximum upper thermal limit for the ubiquitous coral *Pocillopora damicornis* was 1^{o}C lower than the threshold for the same species of coral in summer. These shifts are evidence of thermal acclimation, a physiological adjustment that can occur in most organisms up to some upper or lower thermal limit.

Why corals sit so close to their thermal threshold for bleaching is of great interest, especially in the context of rising sea temperatures. The explanation is also important to perspectives as to why mass bleaching events appear to be becoming more frequent and intense. Several factors are involved in the latter. The first factor involved is the increase in tropical/subtropical sea temperatures over the past 100 years. Tropical and subtropical oceans are about 0.4 – 1.0^{o}C warmer than they were 100 years ago (Hoegh-Guldberg 1999, Lough 2000). The second factor is associated with the timing and intensity of El Niño Southern Oscillation (ENSO) events (Glynn 1988, 1991, 1993, Hoegh-Guldberg 1999). The effect of these events is that they combine to produce short periods during the summer months in which sea temperatures rise above the thermal tolerance of reef-building corals and their zooxanthellae (Figure 2). The last factor is the apparent stability of the thermal threshold of corals. It appears that rates of adaptation to changing conditions over the past 30 years are much slower than the rate of increase at which thermal stress has increased on coral reefs. This will be discussed further below as it is critical to later efforts to build scenarios of how coral reefs like the Great Barrier Reef will look later this century.

Mortality estimates of reef-building corals following bleaching

As discussed above, mortality following mass bleaching ranges from zero in cases of mild bleaching (e.g. Harriott 1985; Table 6) to close to 100% as seen at many sites in recent global events (Table 6; Wilkinson 1999). The Global Coral Reef Monitoring Network (supported by more than 30 countries, IOC-UNESCO, UNEP, IUCN and the World Bank) has produced a series of annual reports on the state of coral reefs since the mid 1990s (the latest being Wilkinson 2002). These reports, though of varying qualities, are an attempt to get a yearly snapshot of coral reef health across the planet. The numbers from 1997 to 1998 (Table 7) indicate the scale of mortality that can occur in a global cycle of mass coral bleaching. Prior to 1998, the GCRMN surveys reported a loss of 9.5% of living corals from 6 regions. During 1998, one of the warmest years on record, regions lost an average of 17.7% of their living reef-building corals. The range of mortality estimates is perhaps the most interesting detail hidden within the average. While some regions (e.g. Australia and Papua New Guinea) lost an estimated 3%, regions like Arabian Gulf and Wider Indian Ocean lost 33% and 46% respectively during the single event in 1998.

Table 7. Summary of net estimates of the disappearance of reef-building corals during surveys carried out by the Global Coral Reef Monitoring Network (adapted from GCRMN 2000).

Location	**% destroyed pre 1998**	**% destroyed in 1998**
Arabian Region	2	33
Wider Indian Ocean	13	46
Australia, Papua New Guinea	1	3
Southeast & East Asia	16	18
Wider Pacific Ocean	4	5
Caribbean Atlantic	21	1
Average (region)	**9.5**	**17.7**

The novelty of recent changes on coral reefs is an important part of understanding global events. Several studies have looked into the past behaviour of reefs and have come up with some compelling data that indicate that recent mass mortalities of the 1990s have not been seen for at least the last 3,000 years. *Acropora cervicornis* for example, was a dominant species across the central shelf lagoon of Belize up until 20 years ago. In the 1980s, however, disease (white band disease) resulted in the complete mortality of *A. cervicornis*. Stands of the foliose (scroll-like) coral *Agaricia tenuifolia* quickly replaced *A. cervicornis* in the early 1990s but were wiped out by the high water temperatures of 1998. The mortality of *A. cervicornis* in the 1990s left an unambiguous layer of coral branches in the sediments of reefs throughout the Caribbean. Investigation of reef deposits reveals that the scale of these mortality events appears to have been unique in the past 3000 (Aronson et al. 2002). Aronson and his colleagues analysed 38 cores from across the 375 km^2 central lagoon basin and could not demonstrate any similar layer in sediments stretching back at least as far as 3000 years ago.

Sublethal impacts of thermal stress

Often forgotten from the discussion of impacts of climate change on coral reefs are the sub-lethal or chronic effects of thermal stress that may or may not be associated with bleaching and/or death. These may be as important as changes in mortality schedule and have the potential to bring about large changes in growth, calcification and age structure. These in turn can fundamentally affect reef function, resilience and survival.

Reef-building corals that experience thermal stress have reduced growth, calcification and repair capabilities (Goreau and Macfarlane 1990; Glynn 1993; Meesters and Bak

1993). Not surprisingly, as thermal stress reduces the amount of photosynthetic activity and as zooxanthellae are lost from reef-building corals, the amount of energy available for these fundamental processes is reduced. In addition to this, the amount of energy available for reproduction is also potentially compromised under thermal stress. Coral species utilise a variety of reproductive modes including brooding of larvae and broadcast spawning of gametes for external fertilisation. Coral reproduction is generally sensitive to stress (Harrison and Wallace 1990) and measures of reproductive output or fecundity can be used as indicators of reactions to various stressors such as mechanical damage (Ward 1995), nutrients (Tomascik and Sander 1987, Ward and Harrison 1997, Ward and Harrison 2000) and oil (Guzman and Holst 1993).

Mass coral bleaching has been reported to affect coral reproduction. Szmant and Gassman (1990) examined a limited number of corals (due to marine park restrictions) following a bleaching event in Florida in 1987 and found that bleached colonies did not complete gametogenesis in the season following the bleaching event. They also found that bleached colonies had 30% less tissue carbon and 44% less tissue nitrogen biomass per skeletal surface area than unbleached colonies. Ward et al. (2001) demonstrated a failure of gametogenesis in a large number of corals that were affected in the southern Great Barrier Reef by the 1998 mass bleaching event. This is similar to observations made for soft corals by Michalek-Wagner and Willis (2000). Ward et al. (2001) also demonstrated that fertilization, settlement and juvenile growth were all compromised lat the end of 1998, even though the bleaching event occurred in March of that year. The implications for reef dynamics are considerable as recovery of affected reefs can be heavily dependent on larval recruitment. There is growing evidence that low levels of larval recruitment follow periods of thermal stress on coral populations. For example, severe bleaching also occurred on the West Australian coast in 1998 and was followed by a year of failed recruitment at Scott Reef (L. Smith, Australian Institute of Marine Science, pers. comm.).

Climate change and future coral bleaching and mortality

The conditions under which coral reefs have prospered are changing rapidly. Global temperatures and carbon dioxide concentrations are now higher than they have been for at least the last 400,000 years. There is now very strong evidence that coral reefs have already experienced major impacts from climate change. Tropical oceans are 0.5-1.0^{o}C warmer than they were 100 years ago (Lough 1999). Current projections of changes to the earth's climate suggest that sea temperatures may be 2-5^{o}C higher by 2100 than they are currently. Some studies suggest that reefs will not be coral dominated by the middle of the current century (Hoegh-Guldberg 1999, 2001). The implications of these types of scenarios for tropical near shore communities and the humans that interact with them are enormous and must be considered in any serious exercise to plan the future.

Even under mild climate change scenarios, coral reefs will undergo major increases in coral bleaching and mortality. Drawing together the responses of reef-building corals to ENSO related excursions in sea temperature over the past 20 years, Hoegh-Guldberg (1999) derived a series of simple thermal thresholds for a series of sites and compared these threshold values to future sea temperatures. As discussed previously, some variation surrounds thermal thresholds due to the influence of other secondary factors (e.g. light, history, exposure time) and the species of coral involved. However, despite the influence of these secondary factors, thermal thresholds can be used to predict bleaching events from satellite measurements of sea surface temperature. There is a threshold above which all corals will bleaching and/or die (as happened in many sites in the 1998 global event). Consequently, sea temperature is a fairly good indicator of whether a reef will bleach or not for exposure times of 3-4 weeks (Hoegh-Guldberg 1999). Estimates of past and future sea temperatures were generated by a range of General Circulation Models areas of tropical ocean and compared to these threshold values. Excursions beyond the line (Figure 12A) were scored as bleaching events (Figure 12 B) while those below were not. This analysis was repeated for several models with and without the influence of such factors as aerosol cooling.

The results of this analysis were quite dramatic. In every model run attempted, sea temperatures rose over the early part of the 21^{st} century such that they exceeded the threshold for bleaching more and more. Perhaps of great concern was that summer temperatures (without the influence of ENSO events) eventually exceeded the threshold levels. In two cases, Phuket and Jamaica, winter temperatures eventually exceeded the bleaching threshold on an annual basis.

It is important to understand that the appearance of a single line on these analyses does not imply that all corals bleach at a single precise temperature. This line represents an average of a range of behaviors or sensitivities. The variation around this line is probably not large and extends to no more than 0.5^{o}C above or below the threshold. The very fact that satellite measurements of sea temperature are relative consistent in their ability to predict bleaching of corals on coral reefs supports the idea that an average threshold is useful. The sources of variability around this threshold index involves both genetic and environmental factors and are discussed by Hoegh-Guldberg (1999) and Hughes et al. (2003).

One of the caveats that needs to be attached to the study of Hoegh-Guldberg (1999) is that it was done prior to the release of the IPCC Third Assessment Report. It used the now relatively optimistic IS92a scenario (a doubling of carbon dioxide by 2100). IS92a now tracks between B1 and B2 which are the lower edge of the IPPC scenarios (see Figure 6). As stated before, IS92a scenarios yield degree heating months values that are triple those that caused the major mortality events of Palau, Okinawa, Seychelles and Scott Reef (Table 6). Given that future scenarios will quite possibly sit in the middle to high IPCC range, projections based on IS92a (Hoegh-Guldberg 1999) may be conservative relative to the recent IPCC scenarios.

Biological consequences of future climate change

If corals cannot change their tolerance to thermal stress over and above what they have exhibited in the last two decades, then the rise in sea temperatures is almost certainly likely to increase the mortality rates of corals at any one location. The approach of Hoegh-Guldberg (2001) was applied to estimating the number of catastrophic events that would occur as sea temperatures increase. As seen in the analysis done in the Pacific (Hoegh-Guldberg et al. 2000, Hoegh-Guldberg 2001), thermal stress (measured by degree heating months) increases steadily until thermal stress on reefs is 5-10 times greater than the thermal stress was in the worst affected areas of 1998 (Figure 13). Operating objectively on the past behaviour of coral reefs, two categories of response were studied:

a. Reefs that bleach but recover: Reefs that experience 0.5 Degree Heating Months (DHM) during the summer months will experience mass bleaching. They will recover if stress levels return to previous levels.

b. Reefs that experience almost total coral mortality: Reefs that are exposed to 3.2 DHM per year or more will experience almost complete mortality of their coral populations. This is conservative as reefs probably experience major mortality events at lower Degree Heating Month values (e.g. Scott Reef, 2.6 DHM in 1998; Table 6).

To understand how reefs will respond to increasing thermal stress, we need two further assumptions. The first is that reefs that bleach every second year will experience a decrease in reef quality. This is logical given that bleaching has strong sub-lethal effects on both growth and reproduction (see section entitled "Sub-lethal impacts of thermal stress"). Equally, total mortality events that occur three times per decade will no longer have coral dominated reefs. This is clearly supported by the observation that reefs like those of Palau, NW Australia and Okinawa have not recovered fully from the 1997-98 mass bleaching event. Wilkinson (2002) sums this issue up in the Executive summary to the latest Global Coral Reef Monitoring Network assessment of coral reefs world-wide in relationship to the reefs showing the fastest signs of recovery since the last global mass bleaching event "There has been considerable recovery in the unstressed reefs of Southeast and East Asia and Palau, and also along the Great Barrier Reef of Australia, but it will take several decades before reefs return to pre-1998 status. There is broad concern that another Climate Change/El Niño event could arrest the recovery." The overwhelming conclusion however is that mass mortality events like those of Palau, Scott Reef and Okinawa cannot occur every 3-4 years without eventually bringing coral cover to close to zero. This assumption is probably highly conservative given that the anomaly size continues to grow (>> 3.2 DHM) in addition to the frequency.

These issues are recognised by Done et al. (2003, Table 1) in a useful table that defines the types of ecological impacts on coral reefs with an estimate of recovery times. "High level" and "catastrophic" ecological impacts have return times of 20 and 50 years, respectively. Clearly, even 3 "high level" events per decade would clear reefs of coral cover (let alone 3 "catastrophic" impacts which is probably closer to that posed by a 3.2 DHM event). Recent community modelling work has reinforced this conclusion. Using a cellular automaton model developed for coral communities, Johnson et al. (2003) have demonstrated that merely having events with DHM values of 1.2 every 10 years into the next century is enough to reduce coral cover by 50%. Adding stress levels like those seen when events (similar to that of 3.2 DHM) occur every 3-4 years produces outcomes in which coral cover is extremely remnant (Johnson et al. (2003).

The results of this analysis are striking. If reef-building corals and their symbionts do not change their tolerance (see below), then rapidly increasing sea temperatures will cause annual bleaching events by 2020 in Jamaica and Phuket, and by 2050 in Tahiti. More importantly, mass mortality events (years with DHM values of 3.2 or more) will increase steadily toward the middle and last half of the century. Using the criteria established above, reefs will shift to non-coral dominated states by 2020 in Jamaica, 2030 in Phuket and 2050 in Tahiti.

Escape clauses: Can adaptation match the rate of increase in sea temperature?

Faced with rising sea temperatures and the prospect of coral tolerances being exceeded, "adaptation" to these rising stress levels has been suggested as one view of the future (Done 1999, Done et al 2003). Simplistically, adding the same rate to the thermal threshold of stressed corals as the seawater temperature is increasing over time would eliminate any increase in coral bleaching and mortality (Hoegh-Guldberg 2001). There is little evidence, however, of a strong adaptive (genetic) response by reef-building corals to the increase in thermal stress. It is important to realise that adaptation here is taken in the strict academic context of genetic change in the tolerance of populations or corals and not in the broader sense of Done (1999) which includes community compositional changes. These have already been discussed above. The former lies at the core of increasing the threshold of coral populations while the latter represents changes that are likely to be negative as species are lost and reef resilience is decreased (see further discussion below).

The problem is, as outlined in Chapter 1, rates of change are much higher than most of the environmental transitions seen in the recent geological record. The current growth of greenhouse gas concentrations is two orders of magnitude greater than seen during glacial transitions. Future growth of gas concentrations is even higher. There is also very little if any evidence that suggests that corals and their zooxanthellae have been adapting to the changes in sea temperature over the past 20 years. As mortality appears to be increasing not decreasing (see Hoegh-Guldberg 1999 and Wellington et al. 2001 for recent reviews), and thermal thresholds of coral populations appear to be in similar places as where they were 20 years ago (e.g. Hoegh-Guldberg et al 1997; Brown 1997), evidence at first glance appears to favour the suggestion that rates of change are exceeding the rates at which reef-building coral populations can adapt. To some, this may not be surprising given the slow growing, largely asexual organisms (corals) and their complex intracellular symbiosis (with a unicellular dinoflagellate protist).

Consideration needs to be given to processes that introduce change. Increasingly more tolerant genotypes are unlikely to arise due to mutation given the rarity of these events over the short periods involved. This leaves three possibilities. The first is that the population contains individuals that are more tolerant and that these are selected as stress increases. The second is that tolerant stock recruit from areas (e.g. lower latitudes) that are historically warmer. The last is by swapping their algal symbionts for other more tolerant varieties (Buddemeier and Fautin 1993).

a. Inherent variability as a source of tolerant genotypes.

Genetic diversity occurs with any given population of a coral species. Increases in thermal stress will lead to the selection of more tolerant varieties over those that are less so. The result of these processes is that populations are likely to evolve to become more heat tolerant even if genetic variability has decreased as more vulnerable genotypes are eliminated. Two elements of this process need to be established if this type of change is to occur on coral reefs. The first is inherent variability in thermal tolerance within coral populations. The second is that selection acts to eliminate some but not all genotypes within a population.

There is little doubt that different individuals within a coral species have different tolerances. Edmunds (1994) noted differences in bleaching sensitivity among individuals of *Montastraea annularis* during mass bleaching events in the Caribbean. Similar differences across populations of corals within a single location have been noted by Glynn, Brown and others (Glynn 1993; Brown 1997). Some of these differences are due to the variation in secondary factors like light quality which varies across and between colonies and can strongly affect the susceptibility to bleaching (Jones et al. 1998; Brown et al. 2002). Other studies have shown differences may be due to different genotypes of zooxanthellae (Rowan et al. 1997). At present, these studies are in their infancy but are being pursued by a number of research groups.

The demonstration of a strong role of selection across coral populations during mass bleaching events is speculative at this point. While there is no firm data the possibility of mass bleaching events selecting for more tolerant corals, two studies hint at the fact that this may have already occurred within populations in the Eastern Pacific and Okinawa. Peter Glynn and co-workers have noted that the impact of the 1997-98 event was smaller than the impact of the 1982-83 event, even though the size of the thermal anomaly was different (Glynn et al. 2001). The authors suggest that the reason lies in the 1998 population having become tougher due to selection of more tolerant individuals in the earlier event. While this is provocative, the data to say that the stress levels were identical is lacking. The important influence of light on the outcome of a given level of thermal stress was highlighted by Mumby et al. (2001). In their study, much less bleaching occurred around Tahiti and Moorea in 1998 than expected from the calculated exposure to thermal stress. Comparison with previous bleaching events in the same area revealed that 1998 was unusually cloudy and that this probably led to lower levels of stress. As Jones et al. (1998) have demonstrated in laboratory trials, shading corals can dramatically reduce their tendency to bleach at a given temperature.

b. Immigration of warm adapted genotypes.

If the variability required for adaptive change is not present within a reef, then the second possibility is that it comes from other reefs or reef systems. On the Great Barrier Reef, this might mean that larvae from more northerly, warm-adapted reefs are transported southward to reef systems where corals are being eliminated by thermal stress. In this way, there might be a southward movement of genotypes to replace those that were finding southern locations too warm. There are two components that are critical to whether or not this mechanism is likely to occur or not. The first is a healthy source of larvae. The second is reef connectivity such that larvae can travel in substantial numbers between reefs.

Changes in climate are being felt on all coral reefs, irrespective of latitude (Hoegh-Guldberg 1999). This is due to the fact that corals and their symbionts are adapted to local conditions and sea temperatures are increasing across the planet. While some consideration may be given to safe havens or refuges for corals over the short-term, there is very little evidence of these existing when global temperatures have increased between 2 and 6^{o}C. Given the impact of stress on reproduction (see discussion above), the possibility of large numbers of gametes flowing from warm-adapted reefs to reefs where corals are being eliminated by thermal stress is unlikely.

Differences in the connectivity of reef systems and the life histories of corals have been shown to be crucial for determining patterns of recovery or decline in Caribbean reef systems (Hughes et al. 2000). Recent evidence suggests that coral populations show relatively high levels of genetic connectivity (Ayre and Hughes 2000; Hughes et al. 1999) within regions like the Great Barrier Reef. It is important to acknowledge however that genetic connectivity is not a good proxy for connectivity in ecological time. While reefs may remain connected genetically, the actual number of migrants that need to travel between reefs to maintain this connectivity may only need to be a few individuals per generation. Given that recovery of reefs would require large numbers of migrants arriving to rebuild coral populations, the demonstration of genetic connectivity does not imply connectivity on the level needed to rapidly repopulate a reef.

The long-term monitoring of coral populations on the Great Barrier Reef by the Australian Institute of Marine Science (http://www.aims.gov.au/monmap/monmap.htm) provides critical information on the repopulation of coral reefs after disturbances. Several examples from these excellent accounts of the long-term dynamics of coral communities with the Great Barrier Reef indicate that reefs that are denuded of coral cover can recover quite rapidly. Surveys within the Capricorn-Bunker group (including One Tree and Lady Musgrave Islands), on the southern end of the Great Barrier Reef, for example, show that coral cover dropped dramatically between 1988 and 1990, largely due to strong weather in the region. In 1993, hard corals such as *Acropora* species were practically non-existent at survey sites. Rapid recovery did occur however over a period of 7-8 years with coral cover at most survey sites being greater than 50% by 2000. Similar examples can be drawn from other sites on the Great Barrier Reef in which the removal of coral by the Crown-of-Thorns Starfish (*Acanthaster planci*) or cyclones was followed by a rapid recovery of coral populations.

The rapid recovery of the highly connected reef systems on the Great Barrier Reef is contrasted with other sites where reefs show low levels of apparent connectivity, and in which recovery rates have been much slower. Glynn and Colgan (1994) highlight the importance of reef connectivity with respect to the re-population of coral reefs affected by extensive coral bleaching in the eastern Pacific. In this case, very low recruitment rates due to the isolation of these reef systems means that recovery may take hundreds of years. Similarly, isolated coral reef systems off the North-West Australia appear to show very slow rates of recovery that is associated with very low recruitment rates since 1998, when coral cover was largely removed from reefs like Scott Reef. According to Wilkinson (2002) quoting Luke Smith from the Australian Institute of Marine Science, a researcher who works on the coral reefs of North West Australia: "Recovery has been slow since 1998 and coral cover has changed little from 16% in late 1998 to 18% in 2001. The extensive branching *Acropora* beds have failed to return. There are few juveniles, with small pocilloporids being the majority. There has been an almost complete failure of coral recruitment at Scott Reef since 1998. Recruitment has fallen from an average of 19 recruits per settlement plate in 1996 and 1997, to less than 1 per plate between 1998 and 2002. It is likely that Scott and Seringapatam coral reefs are self seeding because of their isolation. Consequently, recovery from the 1998 bleaching event at Scott and Seringapatam Reefs could take decades or longer, provided that there are no repeats of major bleaching events."

The importance of the supply of larvae to the rate of reef recovery following bleaching events has other implications for the impacts of climate change. Hughes et al. (1999) demonstrated that the fecundity of adult corals and the establishment of larval recruits at a particular site are tightly correlated. In their study, the variation in space and time of the fecundity of three common *Acropora* species explained most of the variation (72%) in Acroporid (staghorn coral) recruitment. The dependence of recruitment on the size and health of the adult population also suggests that the direct effects of temperature (or any anthropogenic factor) on the fecundity of corals will have direct impacts on the abundance of new recruits and hence of adult reef-building corals. This is highlighted by the Scott Reef example above. If local supplies of larvae become decimated, and other reefs are distant, then rates of recruitment will dwindle and reef recovery will be slow.

Migration of warm-adapted genotypes of coral will occur as seas warm although rates may be slower than the rate at which seas are warming. For example, warm-adapted coral species and genotypes may migrate to high latitudes but coral communities may still decline due to the fact that the rate of invasion and subsequent growth of migrants fails to match the ever increasing level of thermal stress and mortality at any particular location.

c. Remaking the holobiont (The Adaptive Bleaching Hypothesis)

It is highly likely that the properties that enable a coral to survive a given environmental circumstance will involve both coral and zooxanthellae. Both partners contribute genetic potential to the overall capabilities of the combination (or holobiont). Recent work has shown that zooxanthellae are highly diverse genetically, with many species being represented on coral reefs. One potential way to improve fitness would be to swap one genetic variety of zooxanthellae for another with a view to adopting a more tolerant genetic variety. Buddemeier and Fautin (1993) have proposed that bleaching might be adaptive behaviour that allows reef-building corals and other symbiotic invertebrates to adopt new genetic characteristics as regards thermal tolerance. Although this idea continues to attract discussion (e.g. Baker 2002 versus Hoegh-Guldberg et al. 2002), it is currently not well supported by critical evidence or experiments.

As with any valid argument, the assumptions of this proposal must all be true as the argument's logic is sound. Ware et al. (1996) formally state the assumptions of the

Adaptive Bleaching Hypothesis (ABH). This has been a useful exercise as it allows detailed scrutiny of the hypothesis and it assumptions. While some of the assumptions underlying the ABH are true (e.g. zooxanthellae are genetically diverse), several critical assumptions are not supported by available evidence. For example, the hypothesis critically requires that "bleaching provides an opportunity for the host to be repopulated with a different type of partner". To date, the invasion of a bleached host by a new species of zooxanthellae has not been seen. While there is evidence that this has happened in geological time frames, the required observation that it can operate on the time scale as a bleaching event has not been observed. Attempts to infect aposymbiotic coral larvae (Weis et al. 2001) with the zooxanthellae of other coral hosts always resulted in ineffective establishment of a new symbiosis compared to that of the native symbiont. Similar results have been observed for other symbiotic hosts (Trench 1979).

It is important to realise that multicladal symbioses (those that contain more than one type of zooxanthellae) which can shift the ratio of different clades or types of algae are not evidence of the Adaptive Bleaching Hypothesis. As argued by Hoegh-Guldberg (1999), the observation of a change in the proportion of pre-existing genotypes also does not qualify as "the host to be repopulated with a different type of partner". Remixing may extend the range of corals but it will not result in the rapid shifts in the genetic potential of coral populations that are required if coral populations are to keep up with climate change under even the mildest scenarios.

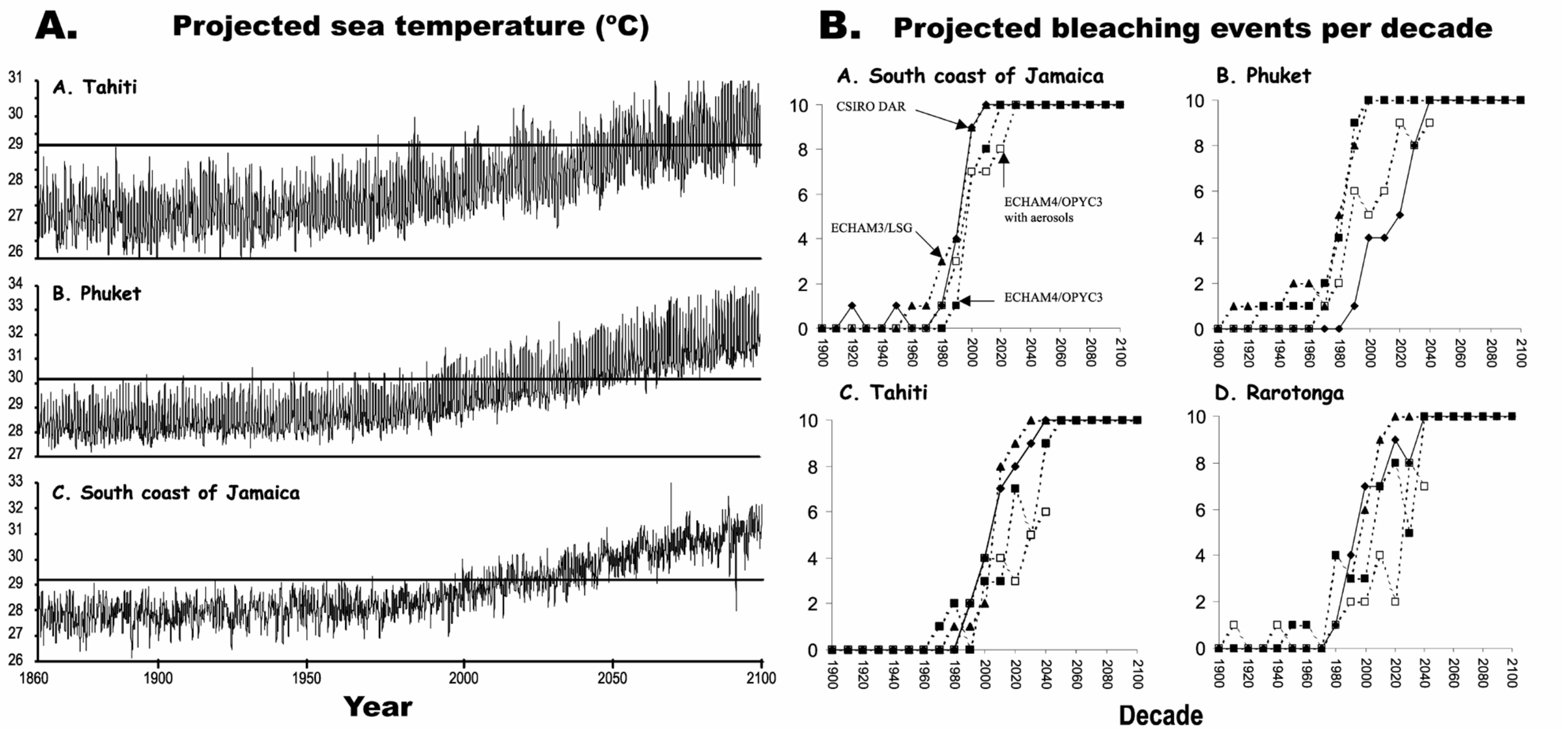


Figure 12. A. Sea surface temperature data generated by the global coupled atmosphere-ocean-ice model (ECHAM4/OPYC3, Roeckner et al. 1996) and provided by Dr Axel Timmermann of KNMI, Netherlands. Temperatures were generated for each month from 1860 to 2100, and were forced by greenhouse gas concentrations that conform to the IPCC scenario IS92a (IPCC 1992). Effects of El Niño–Southern Oscillation (ENSO) events are included. Horizontal lines indicate the thermal thresholds of corals at each site. Date were generated for four regions: Tahiti (17.5°S,149.5°W), Phuket (7.5°N,98.5°E), Jamaica (17.5°N,76.5°W), and Rarotonga (21.5°S,159.5°W, data not shown). B. **Fig. 9.** Number of times per decade that predicted temperatures (see part A) exceed coral threshold levels (bleaching events) for (A) Jamaica, (B) Phuket, (C) Tahiti and (D) Rarotonga. Both figures were reproduced from Marine and Freshwater Research Vol. 50 (O Hoegh-Guldberg, 1999) with permission of CSIRO PUBLISHING.

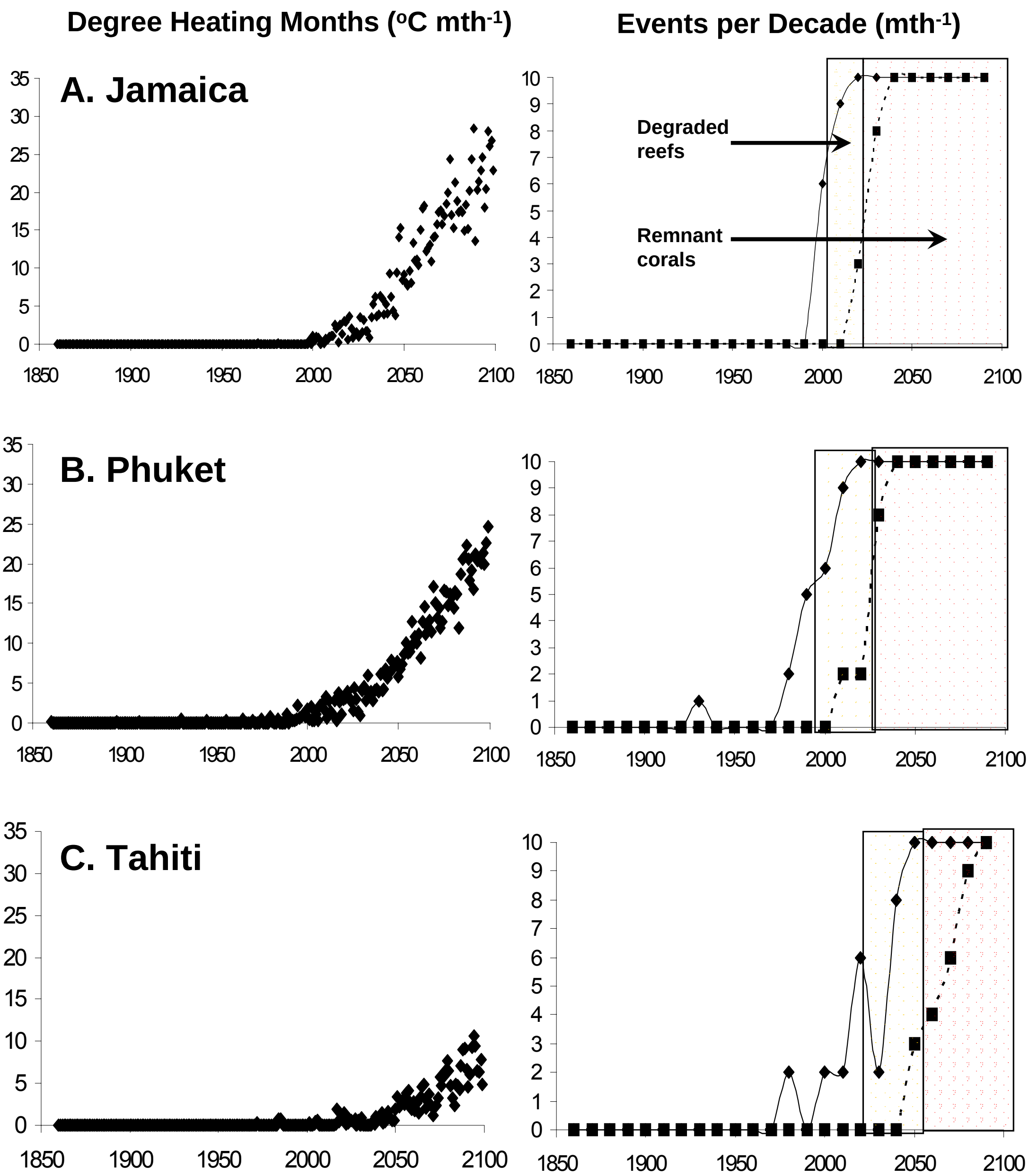


Figure 13. Projected patterns of bleaching projected for reefs along the south coast of Jamaica (17.5°N, 76.5°W), Phuket (7.5°N, 98.5°E) and Tahiti (17.5°S,149.5°W) from 1860 up to 2100. Sea temperature data from the ECHAM4/OPYC3 (Roeckner et al. 1996) model (details in Hoegh-Guldberg 1999). Left hand figure in each case shows the accumulated DHM values once they had exceeded 0.5 DHM. Right hand figure shows the frequency of bleaching events per decade over the next century (DHM > 0.5, solid line) and severe events (DHM > 3.2, dotted line). Yellow box shows period in which reefs are in decline (coral cover beginning to decrease). Red box is period in which coral is remnant (< 5%) based on the assumption that coral communities will be unable to survive three severe bleaching events per decade (severe as those seen in Okinawa, Palau, Seychelles and Scott Reef in 1998).

Where will the world's reefs be in 2050?

If there is not a strong case for adaptation playing a role in modifying the thermal tolerances of the reef-building corals that make up today's coral reefs, then the scenarios presented in Figure 12 and 13 must eventuate. According to these scenarios, reef-building corals will no longer dominate today's "coral" reefs by the middle of this century. In this intervening period, reefs will have progressively lower amounts of reef-building corals. There are several serious ramifications of coral reefs that are no longer dominated by reef-building corals. The first is that much of the productivity and nutrient dynamics of reefs and coastal waters is likely to change as corals become rare. Secondly, due to the combined effects of thermal stress and increased carbon dioxide, the calcification on coral reefs is likely to be much reduced. This may led to the net erosion of reefs among other issues. The third is that biodiversity of coral reefs will be substantially reduced. And the last is that coral reef associated fisheries are likely to change as waters warm and benthic habitats change.

a. Productivity, nutrient dynamics and benthic habitats.

Coral reefs are regions of high productivity within otherwise low productivity waters of the tropics (Darwin 1842; Odum and Odum 1955). While some reefs prosper in turbid, high nutrient waters inshore, most coral reefs are located in low nutrient waters. As stated at the outset, the highly evolved associations that typify coral reef are central to their success. Reef-building corals are the basis for the high levels of primary productivity of coral reef ecosystems. Photosynthetic energy captured by the zooxanthellae of corals is released directly to the water column as mucus or is consumed directly by filter-feeders, particle feeders and corallivores (Muscatine and Porter 1977, Hatcher 1988). Other primary producers are dependent on the habitats (e.g. substrate, back reef lagoons) that corals build. Coral reefs also have highly evolved nutrient dynamics, with most coral reefs acting as sinks for inorganic nutrients (Hatcher 1988). The net effect of these nutrient dynamics is that coral reefs often support primary production values that may be as much as several hundred fold higher than those of surrounding tropical oceans (Hatcher 1988).

While it is hard to generalise, reefs that lose reef-building coral cover undergo fundamental changes in the types of organisms that dominate the substratum. Red coralline algae, macrophytes and cyanobacteria tend to dominate reef substrates following the loss of reef-building corals. While little has been done so to understand how these new ecosystems function, primary productivity is almost certain to have varied from the original coral dominated ecosystem. Surfaces also play a key role in the nutrient dynamics of coral reefs and hence changes are likely within the nutrient dynamics of coral reefs. All of these changes are likely to have implications for organisms living on coral reefs.

A potentially important link between these types of changes and other organisms that are likely to be important to humans is that between coral bleaching and the incidence of the fish toxin, ciguatera. In French Polynesia, the benthic dinoflagellate, *Gambierdiscus* spp., is the primary causative agent when people eat poisoned fish. *Gambierdiscus* produces a toxin that builds up in the tissues of fish grazing reefs where it lives. Chinain et al. (1999) studied the seasonal abundance and toxicity of *Gambierdiscus* spp. on reefs around Tahiti and found peak densities of the dinoflagellate following a severe bleaching event in 1994. The authors speculated that coral morbidity may be another critical factor in the coral bleaching led to blooms of

Gambierdiscus spp. by providing ``new surfaces" for colonization by opportunistic species of macroalgae that are ideal hosts for *Gambierdiscus* spp. cells. The recent review of ciguatera by Lehane and Lewis (2000) also conclude that the link between global climate change, mass coral bleaching and incidences of ciguatera is strong and may explain the growing numbers of cases of poisoning in the Pacific and elsewhere. Again, the authors speculate that healthy coral populations are not good habitats for the cyanobacteria that manufacture the ciguatera toxin and hence events like coral bleaching and mortality that reduce the abundance of corals will lead to an increase in the abundance of the toxin forming cyanobacteria.

b. **Calcification**

Calcification is one of the most important processes occurring on coral reefs. Through the energy expensive process of calcification, calcium carbonate has built up on coral reefs over time. The net effect is the large areas of carbonate reef that dot the world's oceans and the large deposits of calcium carbonate (limestone) dating from previous periods of reef growth. Through this process, the physical structure of the habitats in which thousands of species live has been created, and at a larger scale, coastlines protected by the oceanic barriers represented by coral reefs.

Reef-building corals and other symbiotic organisms produce the large amounts of calcium carbonate rock that are required to counter the significant forces of erosion. A fairly well supported hypothesis is that the dinoflagellate symbionts of these organisms produce the large amounts of energy needed to precipitate calcium carbonate (Barnes and Chalker 1990). The addition of CO_2 above seawater will lead to the formation of carbonic acid and a decrease in the calcium carbonate saturation state. Gattuso et al. (1998) and Kleypas et al. (1999) calculated that doubling of atmospheric concentrations of carbon dioxide will lead to a 30% decrease in calcium carbonate saturation state (**Ω**). As calcification is directly dependent on the available pools of ions for calcification, these authors proposed that there would be a direct decrease in calcification. Since this work, several studies have shown unambiguously that calcification is essentially linearly dependent on **Ω** (Langdon et al., 2000; Leclercq et al., 2002).

As coral reefs represent a fine balance between calcification and erosion, decreases of this magnitude are potentially problematic and could result in the net erosion of existing coral reef matrices. Normal rates of calcium carbonate deposition by corals range up to 20 cm $year^{-1}$ (extension rate of colony tips). Rate of reef growth (which is essentially the balance between deposition and erosion) is about 1-2 cm $year^{-1}$ (Pittock 1999). This implies that 90% of the calcium carbonate deposited is removed by erosion. Within this simple perspective, a decrease of 30% in deposition should place reef systems into net erosion (by 20%).

Given the key roles that reefs play in providing habitat and protecting coastlines, the implications of the net erosion of coral reef structures are enormous. At this point in time, the process and potential rates of erosion (through physical and biological agents) is little understood. Clearly illuminating on these processes and their relationship to the rates at which calcium carbonate is likely to be deposited in the future should be a priority for research.

c. **Biodiversity**

Our understanding of the impact of losing coral as thermal stress increases is still in its infancy. Even the mildest climate change scenarios project substantial decreases in the amount of coral cover. Community changes like those seen by Loya et al. (2001) in Okinawa are broad sweeping, with the loss of sensitive coral species and the retention of more tolerant genera and species. While the reef may become more "tolerant", the loss of the high diversity of coral species may affect other more global aspects such as reef resilience and recovery rates (Hughes et al 2003). How the changes in coral cover and diversity will affect the thousands of other organisms on coral reefs is still being examined. Organisms that depend on corals for food or shelter and which reproduce via external fertilization might be predicted to face extinction as their primary habitat corals become extinct. The response of fish communities over the short term has yielded some surprises. In the Seychelles, for example, Spalding and Jarvis (2002) found that the overall structure of fish communities had changed very little despite massive decreases (3-20 fold) in living coral cover after the 1997-98 bleaching event. Counter to this is the observation of rapid decreases in the abundance of species that are obligate corallivores. These species are directly dependent on the presence of coral for their existence, disappearing quickly if coral is removed. The Orange-spotted filefish (*Oxymonacanthus longirostris*, Figure 14), a coral obligate, rapidly disappeared from Okinawan reefs after the 1998 bleaching event (Kokita and Nakazona 2001). Abundances of some fish also appear to increase following the loss of reef-building corals from reef communities. Lindahl et al. (2001), for example, showed an overall increase in fish abundance after the 1998 mass bleaching event on Tanzanian reef systems. This was largely linked to an increase in herbivores. Similar conclusions have been seen in studies at other sites by Chabanet (2002).

Other organisms are also likely to respond to changes in coral cover. For example, over 55 species of decapod crustacean are associated with living colonies of a single coral species, *Pocillopora damicornis* (Abele and Patton 1976, Black and Prince 1983). Nine of these are known to be obligate symbionts of living pocilloporid coral colonies. Branching corals of the genus *Acropora*, for example, have 20 species of obligates symbionts that depend solely on *Acropora* providing a habitat. It is important to point that the spacing of corals on a habitat may be critical for the reproductive success of coral associates that require sexual reproduction to proceed to the next generation. As corals become rare (i.e. spaced further and further apart), these organisms may be threatened as the chance of finding a partner or attaining successful fertilization becomes vanishing small.

Our understanding of the impacts of climate change on biodiversity is in its infancy and must be a high priority of future studies. While the pathway and time course of this change is undefined, few experts are suggesting that biodiversity will be unaffected by a rapid loss of reef-building corals from the system. The irony is that corals, by way of being asexual for at least part of their life cycle may be the least prone to extinction, being able to hang on at low density until conditions improve. On the other hand, the hundreds of thousands of dependent species, being highly dependent on sexual reproduction, may not.

Figure 14. The Orange-spotted File fish (*Oxymonacanthus longirostris*) largely disappeared from Okinawan reefs after the collapse of coral populations during the 1998 mass bleaching event (Kokita and Nakazona 2001). Some fish stocks appear relatively unaffected by the loss of coral communities; others (probably obligate corallovores like *O. longirostris*) show rapid responses to the loss of coral stocks. (Photo by O. Hoegh-Guldberg).

d. Impacts on coral associated fisheries.

In addition to the direct changes that are being seen in benthic fishes on coral reefs, there is growing evidence that fisheries are likely to change as warming continues. Fishing yields are likely to be reduced as reef viability decreases (Carte 1996; Munro 1996), leading to much-reduced yields of protein for dependent human populations. Tropical fishery yields are already on the decline world-wide in response to many other anthropogenic factors, and present problems may be exacerbated by the projected increase in tropical sea temperature.

There may also be other more subtle changes. There is now strong evidence that oceanographic and climatic variability may play a dominant role on fish stocks (Klyashtorin 1998, Babcock-Hollowed et al. 2001, Attrill and Power 2002). The evidence takes two forms. The first is that fish stocks are tightly correlated with measures of climate variability such as the El Niño Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) indices. The second is that climate shifts (e.g. 1^{o}C increase in sea temperature in the late 1970s) produce major changes in dominant fish stocks in areas like the North Atlantic.

Klyashtorin (1998) has explored how major Atlantic and Pacific commercial species have varied in relationship to the atmospheric circulation index (ACI) from 1900-1994. ACI is a measure of basic atmospheric conditions in the Atlantic-Eurasian region. Atlantic and Pacific herring, Atlantic cod, European, South African, Peruvian, Japanese and Californian sardine, South African and Peruvian Anchovy, Pacific salmon, Alaska Pollock, Chilean jack mackerel undergo decadal changes in fish abundance that are tightly correlated (correlation coefficients of 0.7-0.9) with the ACI and other indices of climate variability. Similar conclusions were identified by Babcock Hollowed et al. (2001). These authors examined data sets for the North Pacific and Bering Sea and found strong associations between ENSO and PDO variability and data for catches of over 55 different fish stocks. The authors related these changes in fish stocks to changes in recruitment success driven by warmer or colder seas, which in turn affected aspects of the food webs that ultimately supported the species being fished.

There is probably no single explanation of why climate variability drives fish stocks. In some cases, subtle changes to conditions at crucial stages in the life history of the fish species may be important (e.g. conditions in estuaries, Attrill and Power 2002). Other effects may be broader in nature and have their effect through their influence on primary and secondary production in marine ecosystems. Large increases in catches of the western stock of the horse mackerel (*Trachurus trachurus* L.) in 1987 were associated with an increase in phytoplankton and zooplankton stock over the same period (Reid et al. 2001). The latter originated from the warmer conditions that in North Sea in 1987. The links between primary production are complex. Continuous Plankton Recorders (CPR), for example, have been deployed for more than 67 years in various oceans and tell an interesting story. The abundance of *Calanus* (a copepod and key planktonic species) is highly correlated with climate indices like the NAO with abundance in many declining since 1955.

These examples highlight the probability that fisheries are likely to experience major changes in the species that are available to be fished. While some species are likely to decrease, others may increase over time, suggesting that long term investments in specific fishing infrastructure may not be wise as the pace of environmental change increases. These issues will be discussed further in relation to the specific industries of the Great Barrier Reef.

Conclusions

There is now abundant evidence that the earth's ecosystems have already change substantially after only 0.6^{o}C change in global temperature. Terrestrial ecosystems have seen dramatic changes in the distribution of alpine trees, grasslands, insects, birds and butterflies. Species from historically warmer climates are shifting in a poleward direction while species from colder climates are retracting. Similar changes have been seen in marine ecosystems. In some cases, structurally important organisms like reef-building corals appear to have experienced major impacts on their health and distribution. Coral bleaching, when corals loose their critical dinoflagellate plant symbionts, has increased from a local to global scale since the 1970s. Prior to 1979, cases of mass bleaching across regions are unknown in the scientific literature. The 1998 mass-beaching event, in which corals in all regions of the globe with coral reefs bleached, was the largest single event in recorded history. It coincided with the warmest sea temperatures on record in many reef systems. On some reefs, bleaching during 1998 eliminated reef-building corals as dominant organisms from reef structures where they have been dominant organisms for eons. These changes have led in turn to secondary changes in the distribution and abundances of organisms that use corals as primary habitat or as a food source.

Projections of changes in water temperature do not bode well for coral and the reefs that they help build. Already increases in water temperature of only 0.6^{o}C since 1880 have increased the bleaching and mortality of reef-building corals across the planet. Projected increases of between 2 and 6^{o}C by 2100 will increase stress levels on coral reefs from between 5 and 10 fold what they are on reefs today. These levels of change in sea temperature are unsustainable by corals growing where they are today, even under the milder scenarios in which seas only warm by 2^{o}C. While genetic adaptation is discussed by a few authors (e.g. Done 1999), direct evidence of adaptation by corals is currently missing. Paleological arguments that reefs have been through similar changes are marred by the fact that current rates of change are probably 2-3 orders of magnitude higher than those seen under even the most rapid periods of climate change and the fact that Paleological methods lack the precision to see the important, human-relevant changes of the order of 100-200 years. The latter is important in assessing the impact of past change at the human time scale (see discussion by Pandolfi 1996, 1999). While the fossil record might reflect the persistence of coral reefs over geological time, evidence of a decline in reef quality over 100 years is difficult or impossible to detect with current Paleological methods. Unfortunately, these are the time scales that are most important to humans.

4. Climate Change and the Great Barrier Reef

The Great Barrier Reef stretches along the coast of North East Australia and is the world's largest continuous reef system. It includes about 3,000 individual reefs, most of which are included in the largest and perhaps best managed marine park in the world. An Act of Parliament proclaimed the Park in 1975. In 1981, the Great Barrier Reef was inscribed on the World Heritage Register, a status increasingly being seen as an international obligation to maintain an area of world importance in a condition which will enable future generations to appreciate its unique features (GBRMPA 1998a). It has continued to play a leading role as one of the most pristine examples of coral reefs globally. Unfortunately, as with coral reefs elsewhere, the Great Barrier Reef is facing challenges from both local and climate driven sources.

Regional changes in climate

Australia's average temperature on land has increased by approximately 0.6^{o}C from 1910 to 1999. As with the global trends in temperature, most of this increase has occurred since 1950 (Collins and Della-Marta 1999; Lough 2000). 1998 was Australia's warmest year on record with the 1990s being the warmest decade closely followed by the 1980s (second warmest, Collins and Della-Marta 1999). Current rates of change are approximately 0.1 - 0.2^{o}C per decade over most of Australia. As with the global ocean, sea temperatures in Australia's oceans are also increasing rapidly with rates approaching 1^{o}C per century (Lough 1999; Hoegh-Guldberg 1999). Significantly, Lough (1999) who examined a wide array of data sources including *in situ* data loggers, blended satellite data and data from so-called "ships of opportunity", concluded that sea temperatures seen during the 1990s within the Great Barrier Reef were the highest on record.

Other changes in climate may have importance to corals and coral reefs. River flow can have major impacts on local inshore reef systems. Rainfall in Queensland is expected to decrease (–10% to +5% by 2030 and –35% to +10% by 2070; CSIRO 2001), which might be seen as benefiting the conditions under which corals grow due to lower run-off rates. Australia, however, is also projected to become considerably drier leading to greater rates of soil erosion which may see greater sediment loads. Again, human activity within the catchments that flow in the Great Barrier Reef can determine the magnitude of the change being effected by these changes in climate. Changes in climate (e.g. longer periods of drought) can also impact the amount of sediment and hence the health of coastal coral populations.

Bleaching on the Great Barrier Reef

The Great Barrier Reef has experienced seven mass bleaching events since 1979. These events were recorded in February-March of 1980, 1982, 1987, 1992, 1994, 1998 and 2002 (Oliver 1985, Hoegh-Guldberg and Smith 1989, Hoegh-Guldberg et al 1997, Oliver and Berkelmans 1999, Dennis 2002). There are no reports of mass bleaching events prior to 1979. Since 1979, bleaching events have become more intense and widespread, culminating in the statements that

1998 and now 2002 were the strongest bleaching events on record (Berkelmans and Oliver 1999, CRC 2002).

Causal factors

Bleaching within the Great Barrier Reef Marine Park have always been associated with doldrums conditions in which the clear skies and calm seas led to a rapid warming of the upper layers of the water column (William Skirving, NOAA/AIMS, personal communication). These conditions conform to the doldrums conditions reported for a large number of other advents of mass bleaching.

Elevated temperature accurately predicts the development of mass bleaching in the Great Barrier Reef. The worst cases of mass coral bleaching on the Great Barrier Reef in 1998 and 2002 were foreshadowed by elevated sea temperatures (Dennis 2003, Berkelmans et al. 2003). Elevated temperatures generally precede mass coral bleaching in the Park by as much as 2-3 weeks. The development of the sea temperature anomalies is compared between 1998 and 2002 (Figure 15A). In 1998, seas began to warm by late January with the development of the full anomaly occurring by early February. A similar pattern was followed by warming in 2002 except that it started earlier and was centred over the Coral Sea as opposed to being centred off south east Australia. The latter is reflected in the fact that the greatest exposures to stress (as indicated by the highest DHM values, Figure 15B) occurred off the central portion of the Great Barrier Reef.

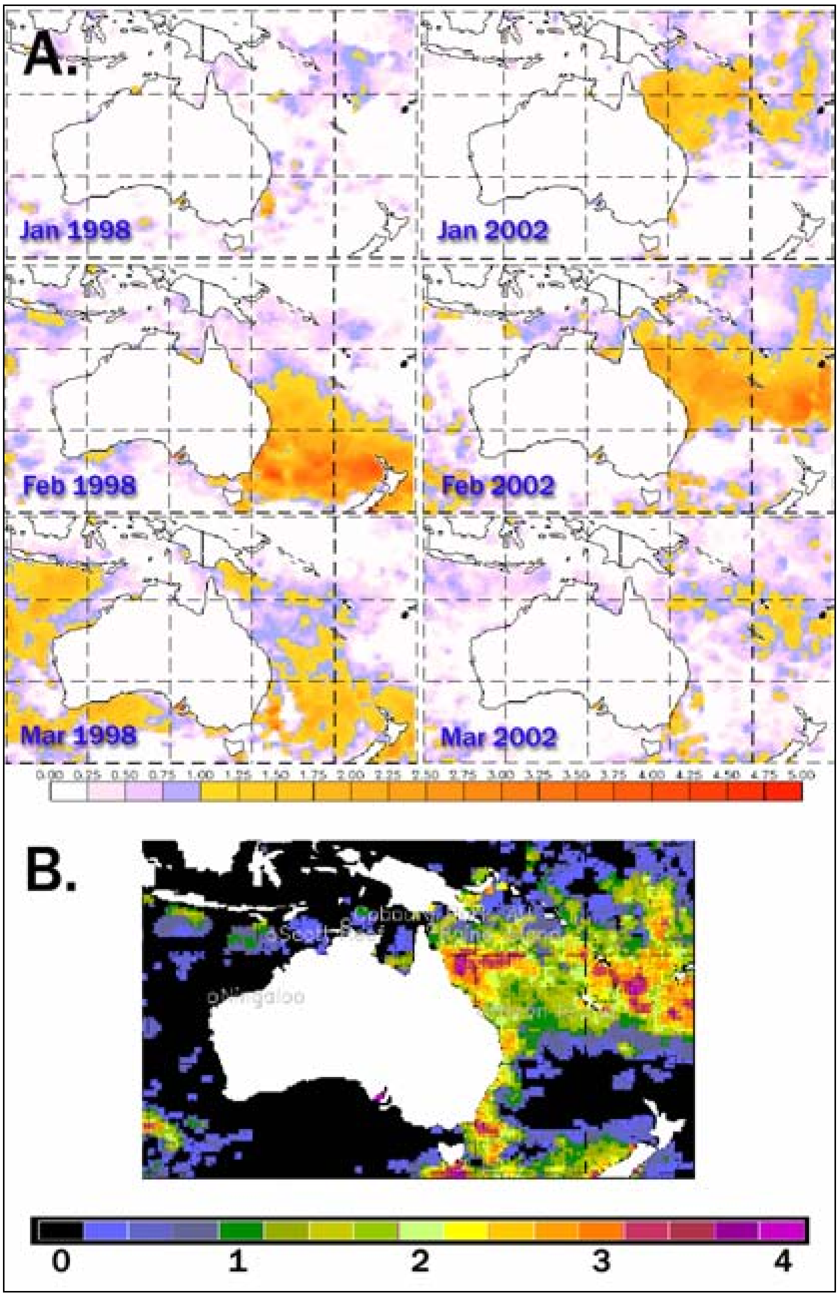


Figure 15. A. Development of thermal anomalies during mass bleaching events on the Great Barrier Reef in 1998 and 2002. Coloured areas indicate excursions of sea temperature above long term mean sea surface temperatures. While satellites only measure the temperature of the top few millimetres of the sea surface, measurements tend to reflect the temperature of the underlying water masses. Images for each month were taken from data gathered around the 10th of each month. B. Degree Heating Months (DHM) for the Great Barrier Reef at the end of the 2002 bleaching event. DHM values are calculated by multiplying the size of an anomaly by the length of time that reefs in an area are exposed to it. Data show DHM values accumulated over the 90 days prior to 23 March 2002.
Source of data: http://www.osdpd.noaa.gov/PSB/EPS/SST/hotspot_archive/ (National Environment Satellite Data, and Information Service NOAA, Washington DC).

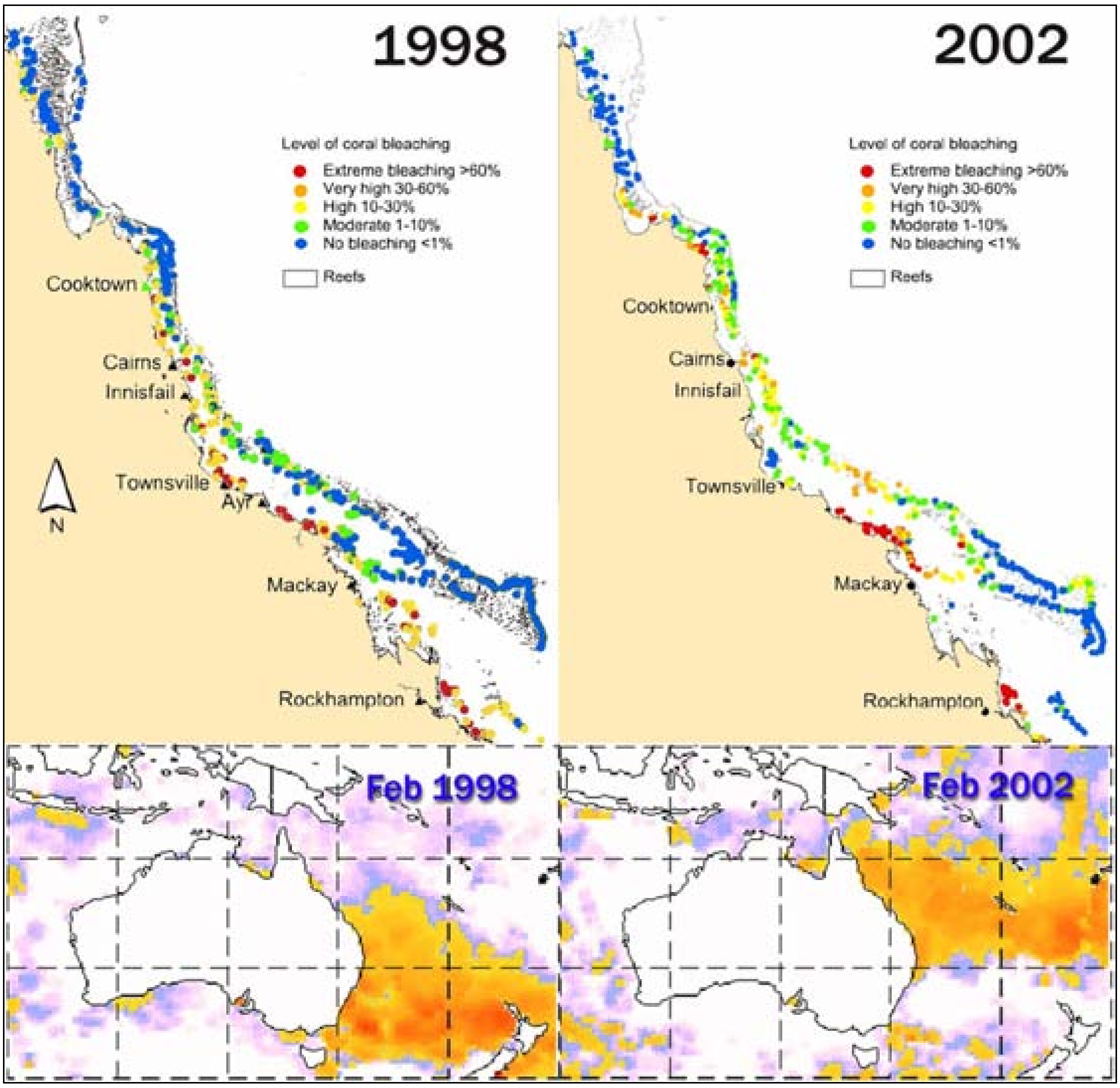


Figure 16. Summary of results of aerial surveys carried out by Ray Berkelmans (GBRMPA, AIMS) in 1998 and 2002 (Figures developed from information posted at www.gbrmpa.gov.au). Shown below each figure are the sea temperature anomalies at the high of the thermal event in each year. See Figure 15 for the development of these thermal events (source: http://www.osdpd.noaa.gov/PSB/EPS/SST/hotspot_archive/; National Environment Satellite Data, and Information Service NOAA, Washington DC).

Recent impacts of thermal stress

In concert with worldwide trends, bleaching has increased in intensity on the Great Barrier Reef over the past 20 years. The last 4 years (in 1998 and 2002) have seen two of the worst mass bleaching events in Australian history. As in previous events, not all parts of the Great Barrier Reef were affected equally within these Reef-wide events. More intense bleaching was seen at inshore sites where shallow water and reduced mixing lead to greater anomalies (Figure 16; Figure 18). 2002 appears to have affected more of the Great Barrier Reef. In 1998, approximately 42% of reefs bleached to some extent and approximately 18% were strongly bleached (Berkelmans and Oliver 1999). Mass bleaching in 2002 affected approximately 54% of reefs to some extent and almost twice as many offshore reefs as compared to 1998 (21% in 1998 as opposed to 41% in 2002; Berkelmans et al. 2003).

Bleaching in 2002 was most intense in the central section (from Mackay to just north of Cooktown), primarily due to the fact that the highest thermal anomalies are centred here (Figure 17). It is also apparent that the 2002 bleaching event saw a larger area affected with high to very high severity bleaching events stretching beyond Cooktown in 2002. Inspecting the distribution of DHM values at the end of the 2002 event reveals that they ranged from 1 to 3 over reef areas. Values may have been higher in inshore reefs although analysis in this regard requires higher resolution satellite remote sensing of temperature. The general trends in the DHM values at this broader scale show that heat stress generally remained lower than that seen in Indian Ocean in 1998.

Interestingly, the results of the Long Term Monitoring Project (LTMP) indicate very little loss of coral cover for offshore reef systems following the 1998 mass bleaching event. Surveys (http://www.aims.gov.au/pages/research/coral-bleaching/Broadscale-bleaching/beb-01.html) conducted in 1999 indicated no net loss of coral cover for offshore reefs. Out of the 47 sites monitored from 1997 to 1998, 8 sites lost 5% or more of their coral cover, 7 sites did not change and 22 sites increased their coral cover by more than 5%. Some other authors did report significant increases in coral mortality following the 1998 event. Berkelmans and Oliver (1999), for example, reported 70% of corals dying down to 6 m on Otter Reef (mid-shelf reef, 18^{o}S). Greater impacts were seen on inshore Great Barrier Reef sites. At Orpheus Island, they also reported that 90-95% of *Acropora* colonies and 60-80% of total coral cover on the reef (including crest and upper reef slope) died within 9 weeks of widespread bleaching. Baird and Marshall (1999) collected detailed information about the effect of the 1998 event on reefs fringing the Palm Islands and Magnetic Island, near Townsville. Of 4,160 colonies surveyed, up to 12% of colonies died at Magnetic Island sites and up to 16% at the Palm Island sites. As found in previous studies, mortality was species specific, with some genera like Millepora (Cl. Hydrozoa) experienced major mortality (85%) and *Stylophora*, *Seriatopora* and *Pocillopora* experienced between 18-30% mortalities.

The impact of the 2002 event on the Great Barrier Reef is still being analysed. In a series of surveys of 27 reefs in April and May 2002, divers found that reefs such as the inshore reefs of the Frankland Islands were almost completely unaffected by bleaching (GBRMPA 2002). In contrast, some other inshore reefs were devastated, with 50% to 90% of the corals on reefs around Bowen having died since the bleaching event in March.

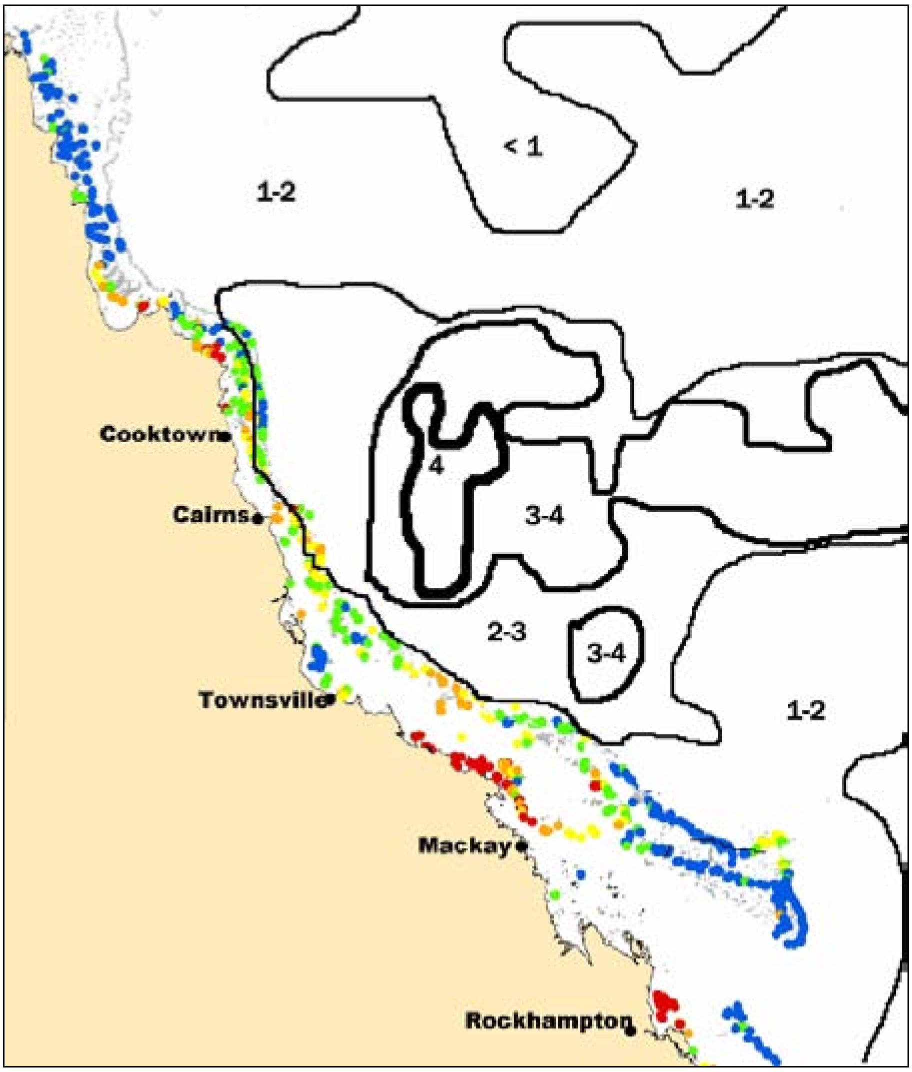


Figure 17. Correlation between broad-scale DHM values and the severity of coral bleaching. Contour lines of thermal stress drawn from Figure 16 and placed over the 2002 bleaching distribution map (Figure 16). Colour code as specified in Figure 16.

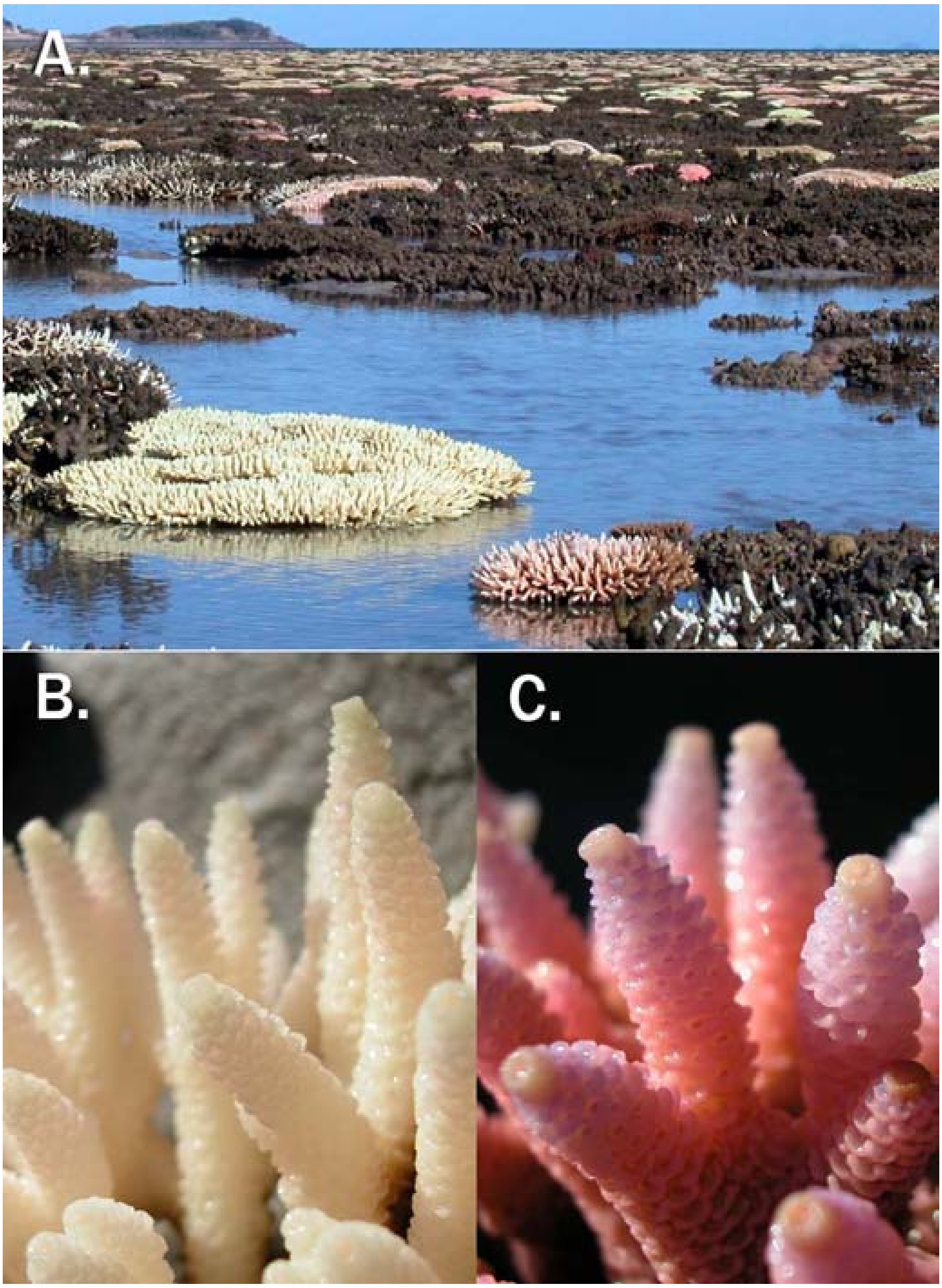


Figure 18. Bleached intertidal corals at Great Keppel Island near Rockhampton in May 2002. Corals were stressed by high sea temperatures in January – March 2002. A. General view of the impact of the record sea temperatures on the coral community. B. All corals bleached either white or C. pink (due to remaining pocilloporin pigments in coral host tissues; Dove et al. 2001). Photos: Ove Hoegh-Guldberg.

The future: Climate change and the Reef

Given the scale of impacts being seen on coral reefs since the mid 1990s, there is substantial scientific evidence that priceless assets like the Great Barrier Reef are under severe threat from climate change as well as other factors such as over-exploitation of key fishery stocks and coastal land use.

Modelling regional climate impacts

How can we tell what the future holds for the Great Barrier Reef? One way, used by Hoegh-Guldberg (1999), is to use information about the past behaviour of coral reefs in the context of future conditions as projected by General Circulation Models (GCM). This approach is not without its shocking outcomes. If one assumes that reef-building corals are like other invertebrates and do not have extraordinary rates of genetic adaptation, then the current thermal tolerances for reef-building corals for corals on the Great Barrier Reef are exceeded annually by the middle of this century (Figure 19). Under these assumptions, corals will bleach more and presumably die more under increasing warming seas. There may be a short period in which populations may see the selection of tougher coral types. However, this period is likely to be short as sea temperatures continue to increase rapidly and the threshold of even these tough species are exceeded. It is important to note that the latter has already occurred when DHM values have risen to 2.5 or more and resulted with the loss of both thermally more tolerant as well as susceptible coral species (Table 6 above).

This approach can be extended as was seen in the previous chapter for reefs outside Australia. As seen for reefs in Australia (Figure 15 and 17) and more generally (Table 6, Chapter 3), simple indices based on the size of a thermal anomaly and the time that corals are exposed to it (Degree Heating Weeks or Months; Strong et al. 2000) can give a fairly accurate projection of the outcome of exposure of corals to stress. The massive changes in sea temperature that are projected even under the mildest IPCC scenarios, suggest that minor variation around these values (due to other factors such as light) will not change the outcome of forecasts like that in Figure 13 (Chapter 3) by more than a decade. This analysis was consequently pursued using GCM data (ECHAM4/OPYC3, Roeckner et al. 1996) for the IS92a scenario (see Figure 6, Chapter 1) for the same three sectors of the Great Barrier Reef used in Figure 20.

The assumptions for this analysis as before are:

a. Adaptation does not occur at rates fast enough to change thermal tolerances and hence today's thermal thresholds will be similar at the three sites for the next 100 years.
b. Bleaching begins for corals exposed to DHM values of 0.5 of more. This is equivalent to two weeks exposure to a + 1^{o}C anomaly above long term sea temperatures at each site
c. Severe mortality events begin when corals are exposed to DHM values equal to or greater than 3.2. This is equivalent to more than 9 weeks at + 1^{o}C anomaly above long-term sea temperatures at each site, or 4.5 weeks at + 2^{o}C anomaly above long-term sea temperatures at each site, and so on.

Additional definitions are:

a. Reefs lose tourist value (i.e. visibly degrade) when bleaching events like that defined in b. occur more than once every two years.
b. Reefs will be devoid of corals when severe mortality events occur more than 3 times per decade. Note: DHM values of 3.2 $\pm$ 0.47 were recorded for the waters of Okinawa, Palau, Scott Reef and the Seychelles in 1998 (Table 6, Chapter 3). All of these reefs lost most of their coral cover in single event, and consequently, it is a fairly safe assumption that three events of this magnitude or greater each decade would largely remove coral cover (Wilkinson 1999).

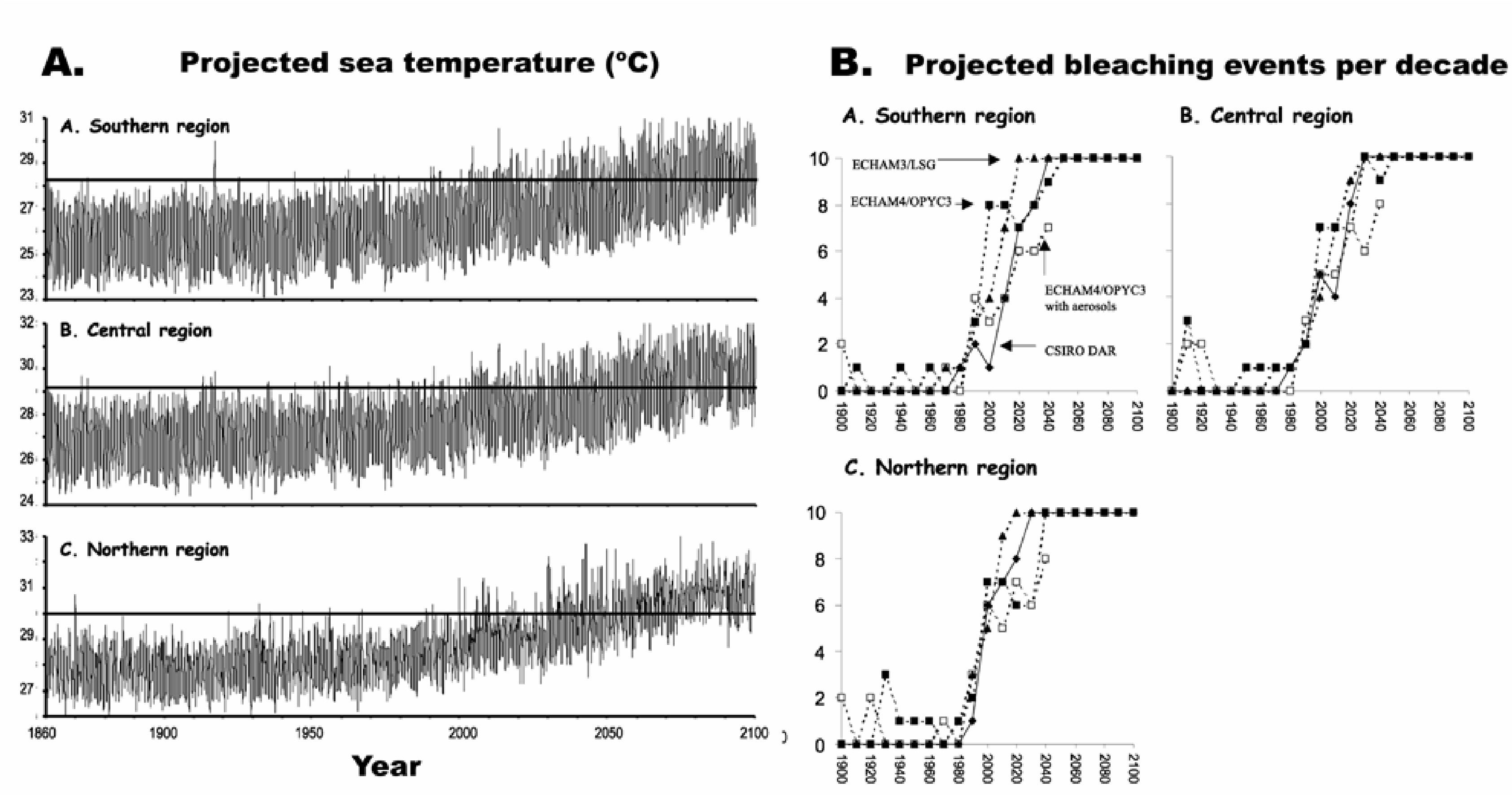


Figure 19. A. Sea surface temperature data generated by the global coupled atmosphere-ocean-ice model (ECHAM4/OPYC3, Roeckner et al. 1996) and provided by Dr Axel Timmermann of KNMI, Netherlands. Temperatures were generated for each month from 1860 to 2100, and were forced by greenhouse gas concentrations that conform to the IPCC scenario IS92a (IPCC 1992). Effects of El Niño–Southern Oscillation (ENSO) events are included. Horizontal lines indicate the thermal thresholds of corals at the southern, central and northern sites (28.2^{o}C; 29.2^{o}C and 30^{o}C respectively). Date were generated for three sectors if the Great Barrier Reef: Southern (23.5°S,149.5°E), Central (18°S,147.5°E) and Northern (11°S,143°E). B. Number of times per decade that predicted temperatures (see part A) exceed coral threshold levels (bleaching events) for (A) Southern, (B) Central and (C) Northern regions of the Great Barrier Reef. Both figures were reproduced from Marine and Freshwater Research Vol. 50 (O Hoegh-Guldberg, 1999) with permission of CSIRO PUBLISHING.

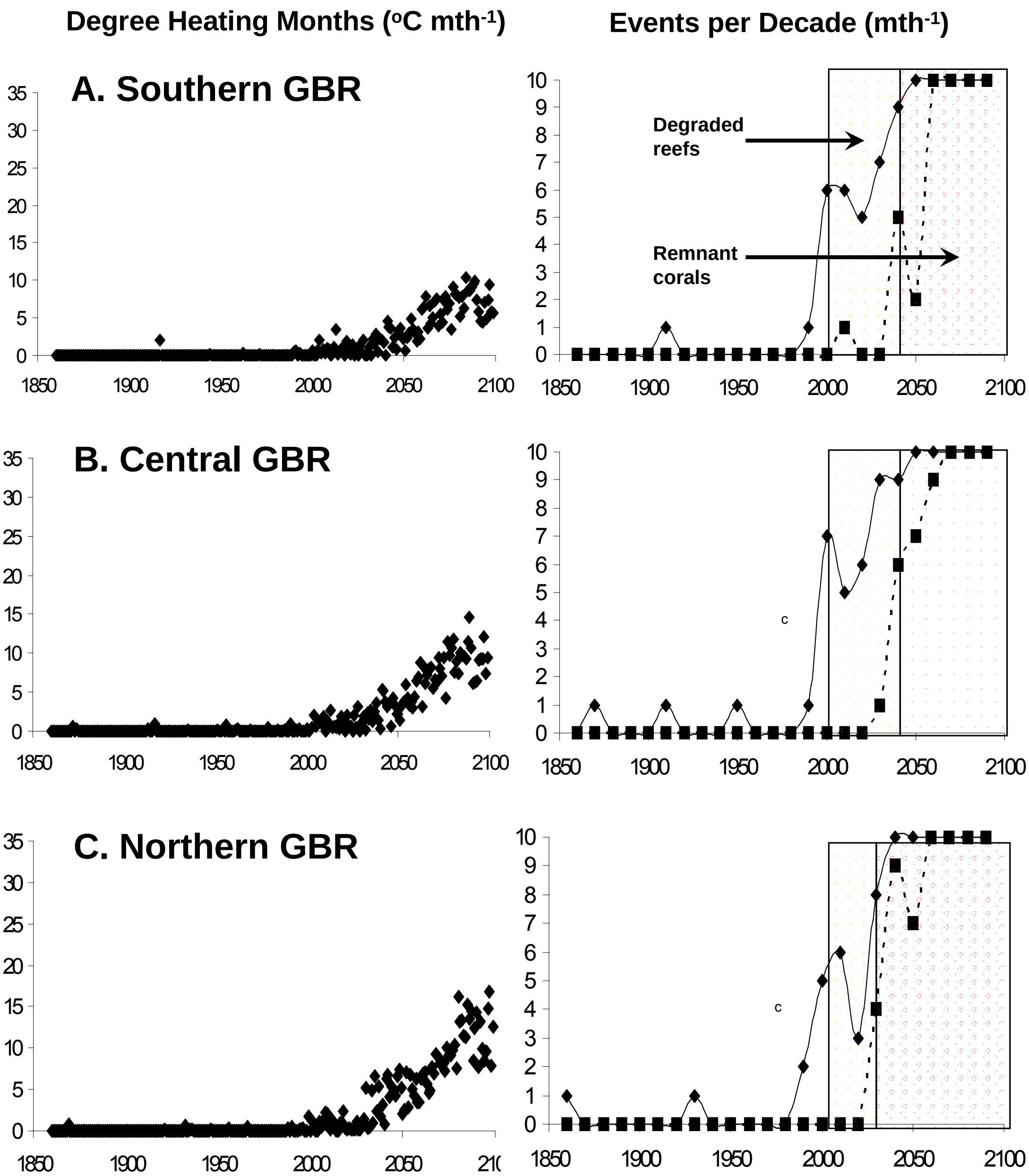


Figure 20. Projected patterns of bleaching projected for reefs along the southern Southern (23.5°S,149.5°E), Central (18°S,147.5°E) and northern (11°S,143°E) sectors of Great Barrier Reef from 1860 up to 2100. Sea temperature data from the ECHAM4/OPYC3 (Roeckner et al. 1996) model (details in Hoegh-Guldberg 1999). Left hand figure in each case shows the accumulated DHM values once they had exceeded 0.5 DHM. Right hand figure shows the frequency of bleaching events per decade over the next century (DHM > 0.5, solid line) and severe events (DHM > 3.2, dotted line). Yellow box shows period in which reefs are in decline (coral cover beginning to decrease). Red box is period in which coral is remnant (< 5%) based on the assumption that coral communities will be unable to survive three severe bleaching events per decade (severe as those seen in Okinawa, Palau, Seychelles and Scott Reef in 1998).

The outcome of this analysis suggests the following. If the projected increases in sea temperature follow the trajectory suggested by the ECHAM4/OPYC3 trajectory for an IS92a scenario, reefs should soon start to decline in terms of coral cover and appearance. With a doubling of CO_2, thermal stress levels will soon reach the levels seen at isolated yet catastrophically affected sites in 1998. When these conditions arrive on reefs on the Great Barrier Reef more than three times per decade, coral cover should have declined to near zero. These dates are on average around 2030-2040 for southern, central and northern sectors of the Great Barrier Reef.

Putting adaptation and climate sensitivity aside, it is hard to argue against the notion that conditions, which have always resulted in massive mortality events, would not decimate coral populations if they arrived every 3-4 years. Coral cover at sites that experienced DHM values of 3 or more decreased by more than 50%. In some cases, coral cover was reduced to less than 5% of its previous values. Recovery of coral cover, even under the most optimal circumstances (low latitude, low human impact) takes at least 10 years. Consequently, the assumption that reefs can sustain up to three of these events per decade is probably highly optimistic.

Climate sensitivity, mortality and loss of tourist value

Critically, the above analysis is derived using the IS92a scenario which is now seen as fairly mild amid the latest scenarios released by the IPCC (2000). To address the objective of this report, several possible IPCC futures (IPCC 2001) require further consideration. Done et al. (2003) have recently undertaken an examination of a wider range of possible scenarios and, critically, apply probability analysis via multiple runs within each model or scenario. Done et al. (2003) use the ReefClim model developed by Roger Jones (CSIRO) and the ReefState model of Scott Wooldridge (AIMS). Done and his co-authors extend the analysis to project how two important aspects of coral reefs, appearance and ecology, are influenced by the changing stress levels on the Great Barrier Reef. This analysis forms an ideal basis for the later parts of this study.

The two scenarios investigated by Done et al. (2003) are at the low (A1T, optimistic) and high (A1FI, pessimistic) ends of scenarios for future climate. Under these scenarios waters warm rapidly by the end of the century, changing by 5^oC in the case of A1FI, and 2^oC in the case of A1T. The authors highlight the size of the change by pointing out that the sea temperatures that are currently typical of Cape York will be at the southern end of the reef by 2050 and 2100 under the worst case (A1F1) and best case (A1T) scenarios respectively (Figure 22).

As pointed out by Hoegh-Guldberg (1999) and reinforced by these authors, the thermal threshold of reef-building corals decreases as one heads southward down the Great Barrier Reef. Done et al. (2003) incorporate the time component of exposure into bleaching versus time curves developed by Berkelmans (2002). This usefully extends the concept of degree heating weeks (Strong et al. 1996, 2000) with a minimum and maximum multiplier of heating stress and exposure time exposure time, and includes two lines that capture what is called the coping range. At the lower edge of this range, no visible impacts are seen, while at the upper edge, corals die. Corals bleach within the range, but, if given enough time, will recover. Critically, this range will also include Sub-lethal impacts discussed in the previous chapter and hence the term "coping" requires some qualification.

On a simple first inspection of these scenarios, it is clear that even under the optimistic scenario, which is similar to the IS92a scenario (Figure 6) used above and by Hoegh-Guldberg (1999), corals will be soon be exposed to regular summer temperatures that will exceed the thermal thresholds observed over the past 20 years. For example, if summer temperatures exceed 28-29^{o}C for even a few weeks, then bleaching eventuates in the Capricorn Bunker group of islands (Heron Island, One Tree Island and other islands; Hoegh-Guldberg 1999, Jones et al. 2000). If, as suggested by both scenarios, these temperatures are reached every summer (by 2030 under A1F1 and by 2050 under A1T), then annual bleaching is almost a certainty, as illustrated for IS92a (not too dissimilar in end point to A1T, Figure 6) in a simpler analysis presented by Hoegh-Guldberg (1999).

The static picture provided by Figure 19 is enhanced by the analysis performed by Done et al. (2003). Analysing multiple runs allows the authors to project the probability of events with differing severity (Figure 22; Table 8). This analysis suggests that the following is likely under the A1F1 and A1T scenarios:

a. Thermal stress exposures of medium and above strengths (> 40 bleaching days in a single summer) are inevitable in coming decades. According to the definition of these impacts (Table 8), this means ecological set-back times of 10 years or more.

b. Under both scenarios, corals (with the same thresholds as today) will experience conditions that cause bleaching every year. This is derived from the fact likelihoods of no exceedance of the thermal thresholds are close to zero (Figure 22 from Done et al. 2003).

c. By 2050, 'catastrophic' exposure (> 100 days) is the most likely outcome for inshore, mid-shelf and offshore reefs under A1F1. Given that the recovery time of such an event (given normal recruitment) is at least 10 years (50 years for full recovery), this scenario would mean a non-coral dominated reef structure by 2050 in the case of all reefs.

d. By 2050, the likelihood of a 'catastrophic' exposure (> 100 days) is at least 10% for the mid and offshore reef sites (see Figure 22 from Done et al. 2003). This is essentially the same as saying that a catastrophic event is likely every 10 years by this point. As time progresses beyond this point, the likelihood gets even greater as sea temperatures rise. Again, recovery times are 10 years or longer meaning that this scenario would probably mean reefs with very low coral cover by this point. Inshore reefs like Magnetic Island would be expected to follow suit perhaps 10-20 years later (2060-2070).

What is clear from this analysis is that the projections of Hoegh-Guldberg (1999), Done et al. (2003, see discussion about adaptation below) and this report are quite similar in the dates at which reefs are likely not to be dominated by reef-building corals. In all cases, conditions contrive (even under the milder scenarios of IS92a and A1T) to be unsuitable for coral survival and hence strongly support the expectation is that reef-building coral cover is likely to be remnant by 2040-50 under all scenarios. Arguments that suggest increases in the mortality of these magnitudes will be sustainable fly in the face of available evidence from 1998, logic and a sound understanding of the population biology of corals.

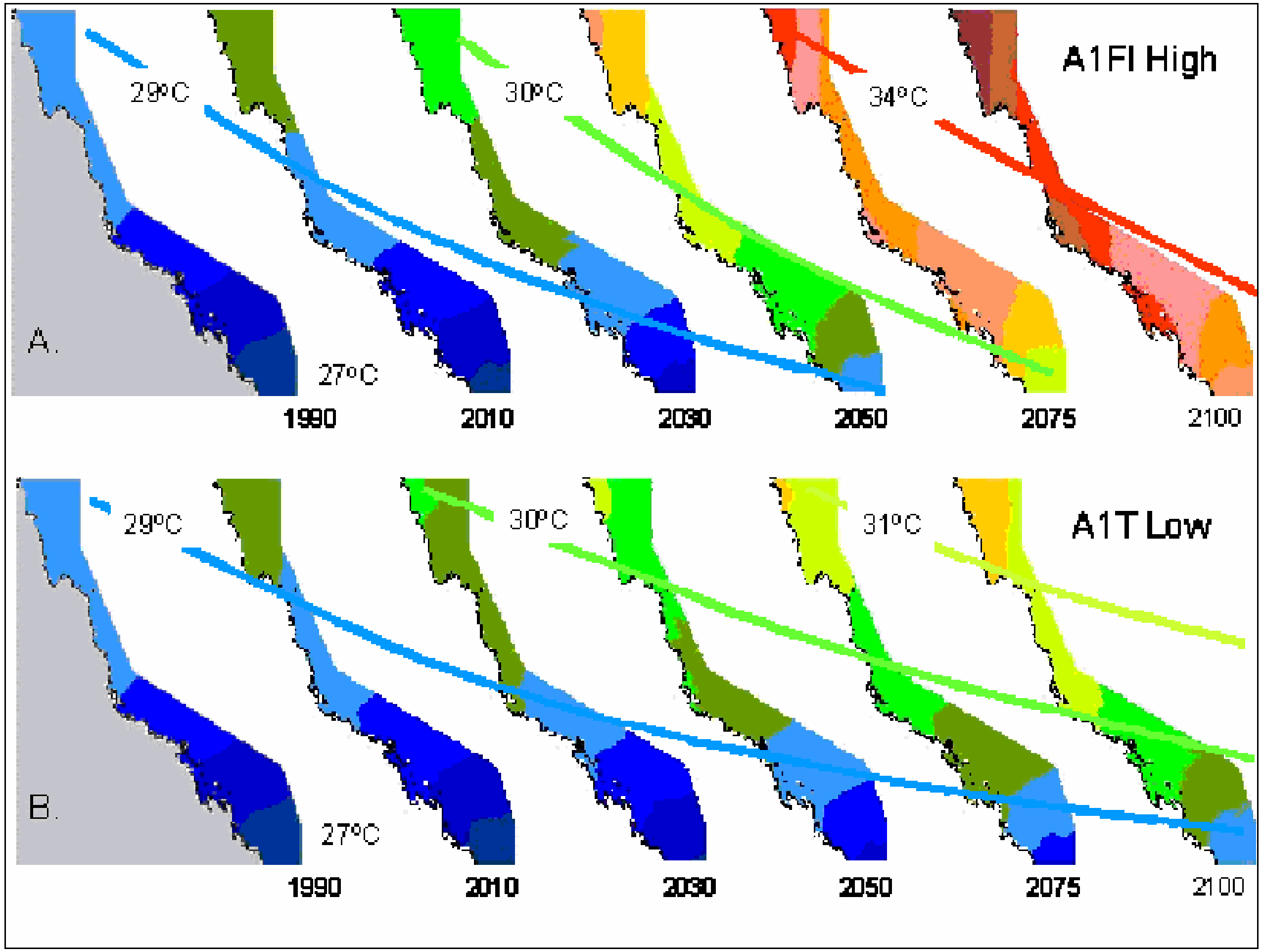


Figure 21. Projected changes in sea temperature from 1990-2100 based on IPCC (2001), and the relationship of mean summer sea-surface temperatures in Australia to the global trend. A. Scenario A1FI High predicts Cape York temperatures at the southern end of the Great Barrier Reef by 2050. B. Scenario A1T Low predicts Cape York temperatures at the southern end of the Great Barrier Reef by 2100. Source: Done et al. (2003).

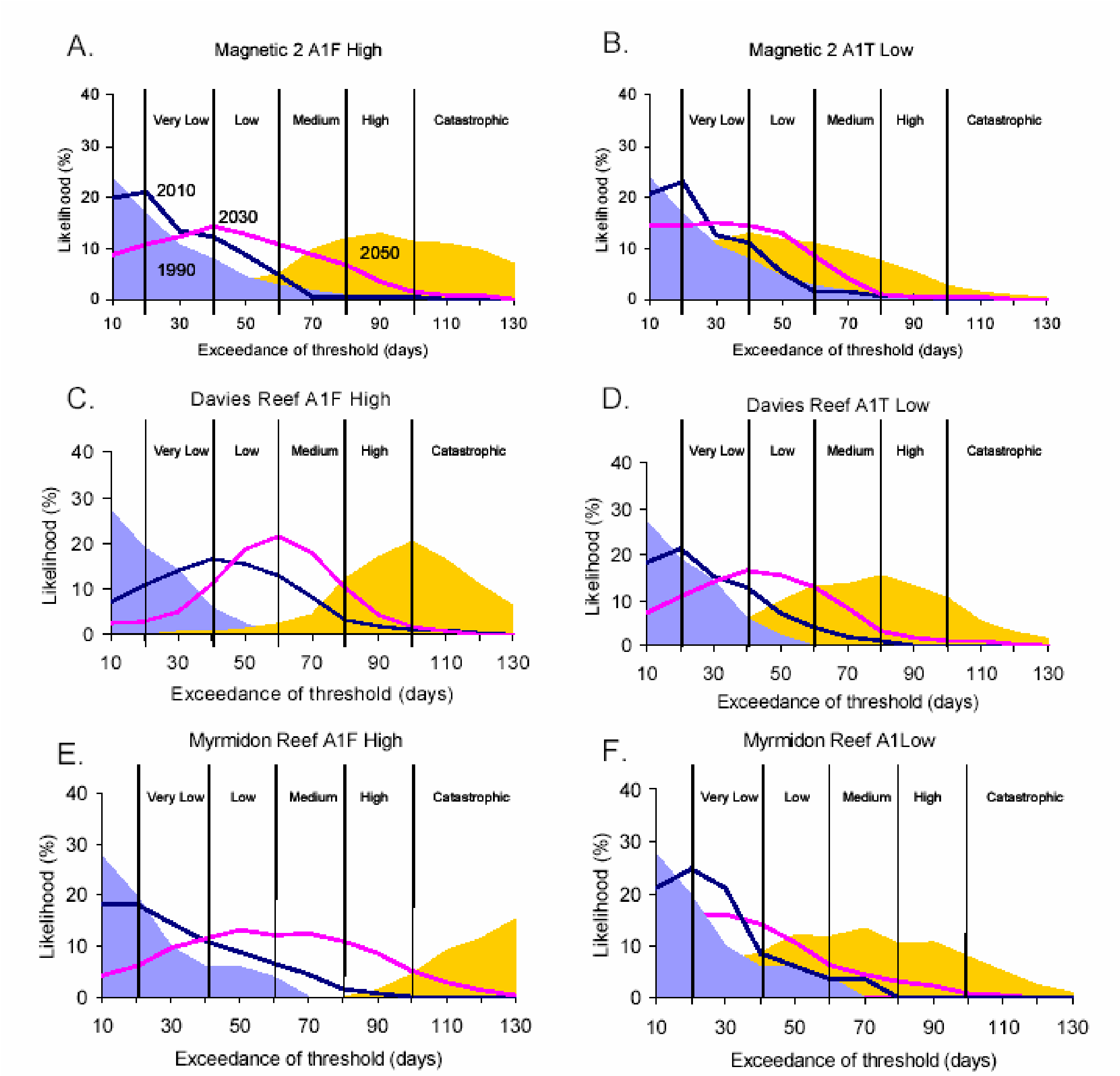


Figure 22. Projections of changes to the probability of thermal events of different intensities (very low to catastrophic) at Magnetic Island, Davies Reef and Myrmidon Reef using "ReefClim" (software developed by Roger Jones, CSIRO and first used by Done et al 2003). Time periods [1990 (baseline), 2010, 2030 and 2050] within the two climate scenarios, A1FI and A1T, are shown. Source: Done et al. (2003).

Table 8. Coral bleaching impact levels on coral communities defined by Done et al. (2003) with associated 'setbacks' in appearance and ecology.

Level 1: Sub-lethal impact

Sub-lethal impact bleaching describes the case when whitening occurs, but no coral tissue is killed. Detrimental effects are, thus, limited to tissue injury, and reduced skeletogenesis, colony growth rate and reproductive output of individuals. It has no effect on the percentage of the reefscape covered in live coral, nor on species composition, relative abundance, or size frequency distribution of corals present. In Done et al. (2003) this is modelled to have zero years of setback (ecology and appearance).

Level 2: Very low level impact

Very low-level impact bleaching describes the case when whitening occurs, and some corals are injured and when ubiquitous, but locally sparse, fast growing vulnerable species die. Ecologically, it may take several years for these species to recruit and grow to the same size as those that died. In terms of visual impact, however, their loss is quickly obscured by growth of survivors, which are in the majority. In Done et al. (2003) this type of impact is modelled as a 3.0-year setback (ecology) and 0.5 year (appearance).

Level 3: Low level impact

Low level impact bleaching is when the same ubiquitous corals are in high relative abundance locally, but their loss is obscured by growth of surviving corals, which are still in the majority. This type of impact is modelled as a 5.0-year setback (ecology) and 1.0 year (appearance) in Done et al. (2003). This term and these model parameters also describe the case when there is conspicuous injury to many of the more visually dominant organisms, but little whole colony mortality among this group. Injuries may take several years to be occluded through the colony's own repair mechanisms, and net reproductive output and live surface will take some years to be reinstated. On the other hand, the relatively minor visual impact will be obscured by growth of surviving corals, which are still in the majority.

Level 4: Medium level impact

Medium level impact bleaching is when fast growing visually dominant organisms suffer moderate to serious death and injury, but there are substantial viable living remnants with high prospects for re-growth. The affected area does not depend on the vagaries of coral recruitment, which may or may not be reliable at that place. In Done et al. (2003), it is modelled as a 10-year setback (ecology) and a 5-year setback (appearance).

Level 5: High level impact

High level impact bleaching is when fast growing visually dominant organisms die en masse, and there are few viable living remnants to initiate re-growth. This area does rely on the vagaries of coral recruitment. This type of impact is modelled as a 20-year setback (ecology) and a 10-year setback (appearance) by Done et al. (2003).

Level 6: Catastrophic impact

Catastrophic bleaching is when ancient visually dominant organisms die en masse, regardless of whether there are viable living remnants to initiate re-growth. All else in its favour (water quality, larval replenishment, optimal grazing rates), it can become dominated by corals in a decade. In Done et al. (2003), this scale of impact is modelled as a 10-year setback (appearance) and a 50-year setback (ecology - although total restoration of a coral community of equivalent age structure may take even longer).

Done et al. (2003) look at the question of how reefs will change and make the important distinction between reefs that are presentable to the visitor versus those that are intact ecologically. They also develop a framework to examine how reefs might change in these two dimensions as stress levels and mortality increase. The integrative model ("ReefState"; Done et al. 2003) assumes reefs will improve over time if unaffected by climate change. If different intensities of events are assigned so-called set-back times, then the interplay between increasing stress and background rates of natural improvement can be modelled. For example, a reef community monitored from 1990 would attain a progression index of +60 years by 2050 but would be set back to its 1990 ecological state by three high level impact bleaching events (each event sets back the ecology of a reef by 20 years; see Table 8). It is quite apparent that the recovery times used by Done et al. (2003) are quite conservative as they (toward the more intense impacts) depend on rates of growth, calcification and recruitment that are associated with healthy reefs. As discussed above, all of these parameters decrease dramatically at higher temperatures. As will be seen, even with these conservative (optimistic) assumptions, major changes in reef appearance and ecology are projected.

The ecological trajectories of the three reefs studied by Done et al. (2003) indicate that major changes are likely to occur on all reefs under the two scenarios. The differences between optimistic and pessimistic scenarios are a matter of a few decades at most. Even allowing for a scope for improvement, the progression index always falls behind the potential and even the 1990 baseline, unless there are high genetic adaptation rates. In most cases, reef progression indices have decreased to at least -50 years by 2040-2050 (Done et al. 2003). According to their definition of reef progression (Table 8), this is equivalent to the ecological set-back of a single "catastrophic" event (more than 100 days in exceedance). Catastrophic events lead to the local death of all corals by thermal stress related mortality (Done et al. 2003). That is, a non-coral dominated community persists at this point in time. This is also probably conservative given that recovery times are likely to be very slow in the heat stressed oceans of the future due to low growth and reproductive rates of remaining corals.

Critical to the present study is how reefs will progress in appearance to these end points. In the absence of any alternative, changes toward the non-coral dominated end-point might be assumed to follow a linear function with increasing stress. While this is very speculative, it probably represents a conservative position given that regular medium to high level impacts (every 10 years) would probably be enough to reduce coral cover completely in advance of the point where seas have warmed to the point where catastrophic events are likely. For this reason, the point where reefs become less appealing for reefs is defined here as the half way point to the complete loss of coral.

Table 9 summarises the dates for loss of coral domination of reefs and of appeal to non-expert visitors using data from Done et al. (2003) and Hoegh-Guldberg (1999). The latter uses the fact that coral populations will not be sustainable under annual bleaching events (Hoegh-Guldberg 1999) or when three thermal events arrive in each decade with of degree heating months of more than 3.2 (Figure 21; Hoegh-Guldberg 2001).

There are several conclusions one can draw from Table 9.

a. Firstly, it is hard to argue from any available evidence that a loss of coral on reefs within the Great Barrier Reef is not highly likely. The thermal stress that corals will see over the next 30-50 years will regularly achieve and exceed the degree heating month values of events like 1998 and 2002. Major mortalities every year such as those that occurred in the Indian Ocean for example are not sustainable in Australian waters.

b. Given the analysis of Done et al. (2003) and the implication that reefs will not be able to sustain catastrophic events more than 3 times a decade, reef-building corals are likely to disappear as dominant organisms on coral reefs between 2020 and 2050.

c. While there is some variability in the impact of climate change according to latitude and proximity to the Queensland coast, the differences in the different trajectories are small. While Done et al. (2003) show that the tougher corals of inshore reefs like Magnetic Island may show delays in response to warming, these differences are at most a couple of decades.

Table 9. Estimated times when coral reefs in the Great Barrier Reef either become less appealing (half way to losing all their coral cover) or no longer coral dominated. Three scenarios investigated: A1F1, A1T and IS92a. Data upon which these conclusions are based are listed in brackets.

	Decade at which reefs likely to become non-coral dominated
A1F1 (Done et al. 2003)	
Magnetic Island	2030-39
Davies Reef	2010-19
Myrmidon Reef	2030-39
IS92a (Hoegh-Guldberg 1999); Figure 21, this report	
Southern GBR	2030-39
Central GBR	2030-39
Northern GBR	2020-29
A1T (Done et al. 2003)	
Magnetic Island	2040-49
Davies Reef	2030-39
Myrmidon Reef	2040-49

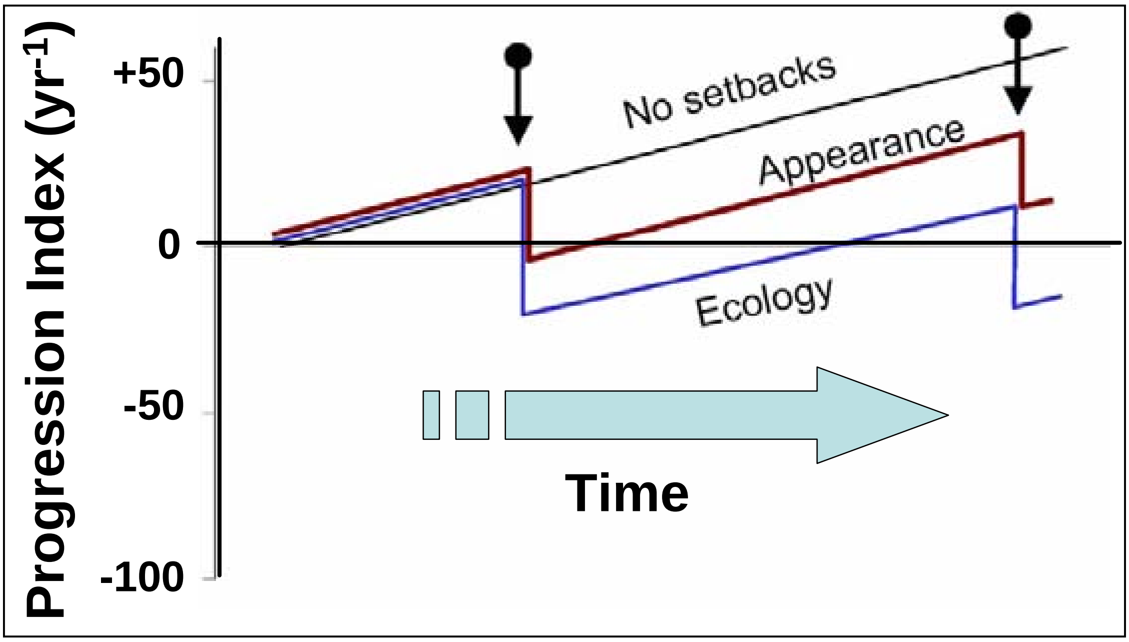


Figure 23. Conceptualisation of the relationship between set-backs in reef quality that either affect appearance or ecology. Without impacts coral reefs increase in progression index. Source: Done et al. (2003).

Other factors affecting climate change outcomes

The preceding analysis has been developed in isolation of a discussion of factors that will clearly affect how reefs respond to climate change. There are two important factors that must be discussed if we are to enhance our understanding of how reefs will respond as climate change continues to increase the stress on the world's reefs. The first is extrinsic and concerns the many other influences that humans have on coral reefs. The second is intrinsic and concerns the possibility that corals will adapt to changes in their environment.

Other anthropogenic stresses

As discussed in Chapter 3, humans are having major impacts on the health of coral reefs across the globe. These impacts range from changes to water quality due to coastal activities to the over-exploitation of key groups of organisms on coral reefs (Table 5). While the reef systems of Australia and the western Pacific generally are rated as among the least stressed and most pristine (Bryant et al. 1998), pressures on reef systems are growing rapidly. In Australia, changes to land use (urbanisation), coastal agriculture and over-exploitation of key fish species are seen as threats to the health of the Great Barrier Reef (Wachenfeld et al. 1999; Jackson et al. 2001; Hughes et al. 2003; Meyers and Worm 2003). The recent WWF report on the state of the Great Barrier Reef summarises these pressures in detail (WWF GBR 2001b) as does numerous reports on water quality on the Great Barrier Reef (most recently Baker 2003 and PC 2003) and the world's reefs in general.

These stresses are critical in determining the rate and extent of the damage caused on reefs like the Great Barrier Reef by climate change. The ability of coral reef ecosystems to recover from the influence of medium to catastrophic thermal events will depend on the background stresses that affect the regeneration of coral reef species. In terms of the model presented by Done et al. (2003), this represented by the background advance of the reef progression index. This allows the reef the capacity to absorb shocks to the ecosystems like the destruction of coral via cyclones and outbreaks of predators like the Crown of Thorns Starfish. In many parts of the world, the influence of humans on reefs has led to deterioration in the capacity of reef systems to absorb perturbations.

Jackson et al. (2001) and most recently Hughes et al. (2003) also highlight the loss of resilience of reefs (the ability to return to a previous state after a perturbation) as another important way that reef systems have been changed by humans (see Folke 2002 on the impact of human intervention on ecosystem resilience). For example, the loss of herbivores through over-exploitation appears to have been responsible for leading to the large scale losses of coral cover from coral reefs around Jamaica and other sites (Hughes 1994). In this case, herbivory controls algal population growth and ensuring open spaces for the recruitment of juvenile corals. On unperturbed reefs both fish and invertebrate grazers undertake this critical role. However, after fish grazers were removed over the 20th century by fishers, one the only grazers left was the sea urchin *Diadema*. This left Caribbean reefs with a reduced capacity to absorb shocks, a fact that was demonstrated when a Caribbean wide virus decimated sea urchin populations in the 1980s. The result of the loss of the only remaining herbivore was that Caribbean reefs rapidly turned from coral reefs to algal dominated ecosystems.

The preceding example is directly relevant to the impacts of climate change on coral reefs. If catastrophic events like some of those seen on reefs during 1998 occur, coral population are pushed down to very low levels and macroalgae (seaweed) dominate the substrate. If high rates of herbivory by fishes and invertebrates are not present, then spaces for new coral recruits are not created and coral migrants are essentially blocked by macroalgal and other benthic species.

Climate change is likely to impact coral reefs heavily over the next 100 years. Their ability to recover quickly from the increasing frequency and intensity of mass coral bleaching events will be critical to the speed to which reefs change. Recent evidence (T. Hughes interviewed in Tooth 2003) is establishing that reefs on the inshore region of the Great Barrier Reef in which fish populations have been removed show much slower rates of recovery after the 1998 bleaching event. Similarly, protected reefs off Tanga in Tanzania, showed almost double the recovery of reefs that were unprotected. Other examples can be found in the most recent report of the Global Coral Reef Monitoring Network report. While not explicitly shown at this point, factors other than fishing pressure (sedimentation, nutrient loading) would be expected to interact to produce effects on the ability of reef systems to recover from coral bleaching and mortality.

The concept of reef resilience is critically important to how society responds to potential impacts of climate change on coral reefs. While reducing greenhouse gas emissions is an urgent priority, equally important is the need to insure that reefs have the highest resilience possible as they face these challenges. The threats listed in Table 5 are all contributing to the rapid decline in both the health and resilience of coral reefs to withstand the impacts of climate change. Management options in which problems like the over-exploitation of fish species and degradation of coastal water quality are dealt with decisively will all contribute to helping coral reefs through this extremely stressful period. The more effectively these options are put in place, the faster any return in historical time and the lower the ultimate extinction rate and loss of coral reef biodiversity. They may also be critical to what outcome is produced when climates on earth eventually stabilize (see next section).

Adaptation

Adaptation of corals to increasing stress levels might vary the thermal threshold of reef-building corals and modify the projected future. Theoretical additions of a putative rate at which adaptation might occur (Hoegh-Guldberg 2001; Done et al 2003) do lead to different outcomes in the above analysis. The problem is, however, that evidence of adaptation at these rapid rates is completely lacking for reef building corals and indeed most organisms that share the long generational that reef-building corals have. Adaptation does happen in geological time as seen by the different thermal threshold at different latitudes or habitats across the world’s oceans (Coles et al. 1976; Hoegh-Guldberg 1999; Berkelmans 2002). But, as argued by Hoegh-Guldberg (1999), these changes probably took several hundred if not thousands of years to occur. It is important not to forget that the single “character” of thermal tolerance is actually the meta-character driven by many gene products that have been tuned by selection to a particular mean temperature and which have to be selected in concert to enable a shift in thermal regime.

As was argued in the previous chapter, evidence for any form of rapid genetic change in coral populations is currently lacking. For example, if adaptation were a rapid force within coral populations, coastal populations of corals should be rapidly re-populating areas in which sediment, nutrient and chemical loads have been increasing. Similarly, coral species that are currently locked geographically to lower latitudes should have evolved characteristics that allow them to live at higher latitudes. That is, coral distributions should not be limited by temperature or any factor because evolution should keep pace with any change or rate of change imposed on them. Clearly these arguments do not hold water in the rapid time scales of the current rapid changes in climate.

Evidence of genetic adaptation to increasing thermal stress is either slim or equivocal (e.g. Glynn et al. 2001, Baker 2001) or unsupportive (Hoegh-Guldberg 1999; Hoegh-Guldberg et al. 2001). In the latter case, mortality rates following coral bleaching events have been increasing rather than decreasing. Ultimately, any selective process will depend on genetic stock that is within an area or is entering an area via recruitment. It will also depend on growth and effective competition of new arrivals with other benthic organisms that may or may not have been promoted by the new conditions. Johnson et al. (2002) have developed a model from 10,000 measurements of coral populations at Davies reef and has used it to investigate how changes in mortality (like those seen during the 1998 event; Baird and Marshall 1999) affect coral cover and the rapidity to which more thermally tolerant clones will spread across a reef when selection acts against more sensitive clones of a putative species. The results of this virtual experiment are striking (Figure 25).

Even under the mild conditions of 1998 (relative to future thermal events) and assuming no change in stress over time, coral cover drops to less than 50% of what it is today by the end of the century. If that stress is increased over time as though a $3^{o}C$ change (by 2100) was occurring, coral cover decreases rapidly to less than 10%. Model runs with more tolerant clones also illustrated the slow rate of genetic adaptation in these systems. Using the most thermally adapted found so far on the reef, Magnetic Island (and assuming that these genes will flow rapidly into Davies Reef), rates at which thermal clones could invade an area can be demonstrated. These rates, however, are much slower than the rate of change and coral cover still declines extremely rapidly (Johnson et al 2002).

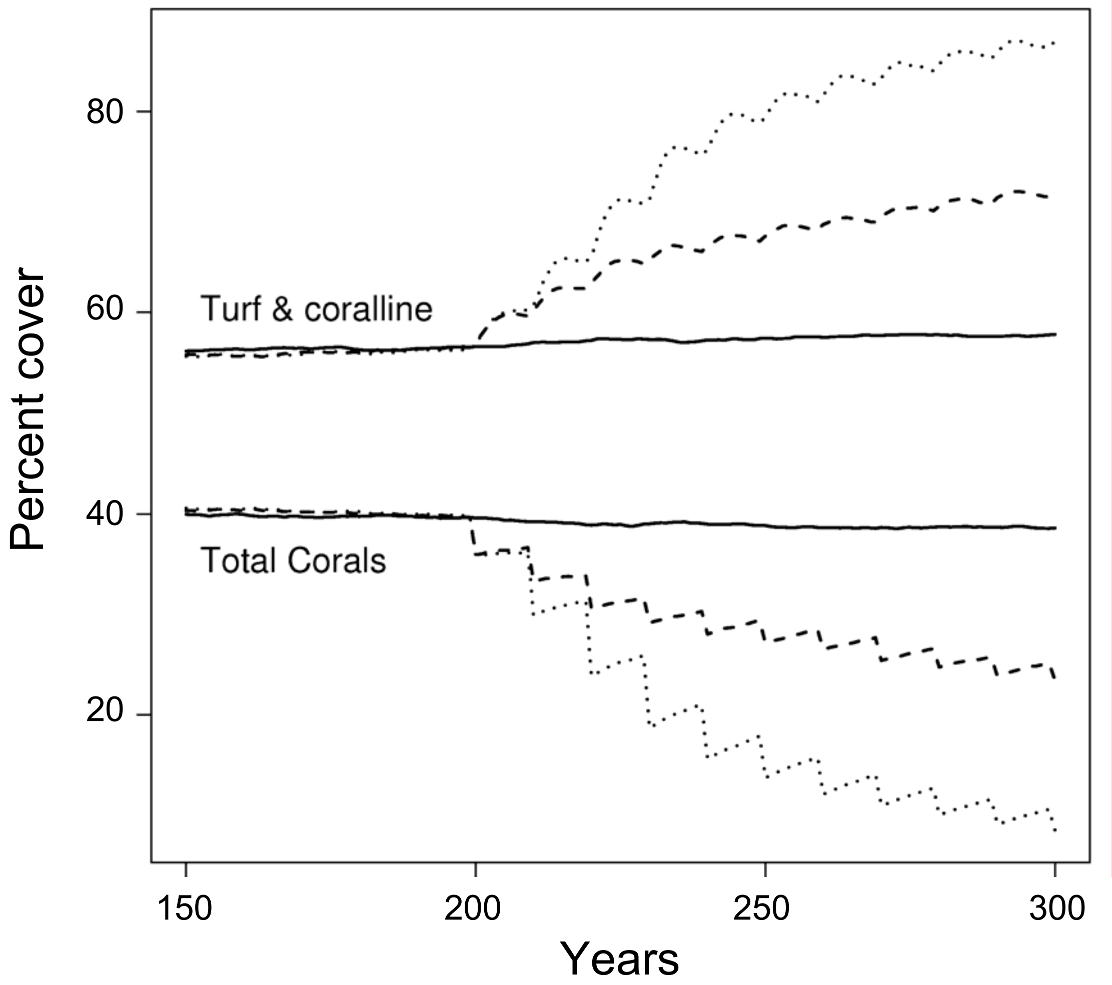


Figure 25. Changes in turf and coralline algae (seaweeds) and coral cover (bottom panel) within a spatial model in which climate impacts are varied (Johnson et al. 2002). Model runs at first with no bleaching mortality included and the biological communities vary around a mean value for coral and algal cover. At 200 years into the run, thermal stress begins in the case of the dashed lines (the solid line continues with no bleaching). The two dashed lines bleaching scenarios are (1) a single 1998-style bleaching every decade (warming events to 31.5 deg C; based on mortality figures from Marshall and Baird), and (2) bleaching every 10 years but with a 3 deg C rise in 100 y. In the latter, the bleaching mortality gets worse every year but there is zero bleaching mortality in the 9 intervening years between bleaching events.

Beyond 2100?

So far, the discussion of the impacts of climate change on the world's reefs has concentrated on the period from now to 2050 or 2100. Perspectives that take in longer time horizons stand to illustrate some of the benefits of scenarios that may not be distinguishable in the nearer future. For example, the families of IPCC scenarios discussed in this report are very similar in terms of temperature profile to around 2030 yet become very distinct in the second half of this century (Figure 6).

According to the long-term forecasts of global temperature (Figure 7C), global greenhouse gas concentrations should stabilize around the end of this century at levels of CO_2 that will range between 450 and 1000 ppm. Going on the geological past, global temperatures will follow closely behind (Figure 3). While conditions for reefs will be hostile during the change, what will happen to reefs once temperatures, carbonate alkalinities and sea levels stabilize?

Figure 26 presents two possible futures. Under milder climate change scenarios (B1, IS92a, A1T) the initial impacts, though great, leave some elements of the coral population in place such that when conditions stabilize, coral populations return. It is important to appreciate that the stabilization temperatures (+2-3^{o}C) are found in some low latitude and inshore habitats (Berkelmans 2002). Therefore, there should be some individuals that migrate over long periods of time from low to higher latitudes. The process of reef growth might be assumed to have a lag phase of 30-40 years in it due to reduced flow of recruits between areas due to low coral stocks and other factors (e.g. those preventing a movement away from the phase shift). It is argued that reefs return with only 70% of the original biodiversity due to the fact that several decades of inclement conditions is likely to be enough to eliminate many coral dependent species. Critical to this scenario are management practices that reduce human impacts on coral reefs to a minimum.

With more severe climate change (A1F1, A2), impacts are dramatic with the loss of some coral species and at least 50% of the organisms that live on coral reefs. The major impact is that organisms with a +5^{o}C temperature tolerance are rare and hence coral stocks with higher thermal tolerance exist only in a few tiny patches (e.g. inshore Saudi Arabian waters). It consequently takes a very long time for coral reefs to even begin to recover coral cover. Temperatures also take much longer to stabilize due to the higher heat load and hence reefs may take several centuries to start to recover.

While these scenarios are high speculative, they highlight several important issues. The first is that the mildest climate change scenarios are the only ones in which coral reefs have any chance of recovering in the near future. Secondly, they highlight the importance of reducing other pressures on coral reefs so as to maximise reef resilience which will be critically important as reefs are allow to recover if stabilization is achieved.

In all of the above scenarios, the "wild card" of how corals will adjust to the vastly reduced calcium carbonate alkalinities of future seas is not resolved. As with other factors like temperature, it is assumed that populations of corals will shift their gene frequencies as sea temperatures stabilize to include individuals that can calcify at these much lower calcium carbonate pools. It is important to point out, however, that this is optimistic given the fact that

that calcifying organisms like reef-building corals do not thrive where salinity (a proxy for the concentration of ions like calcium and carbonate) is low. Similarly, carbonate production has been lower in the past when greenhouse gas concentrations have been higher (e.g. mid-Cretaceous, Wilson and Norris 2001, Wilson et al. 1998). Other factors, such as the growing link between disease and rising thermal stress have equally been left out. These factors would construe to promote the outcomes from rising thermal stress alone.

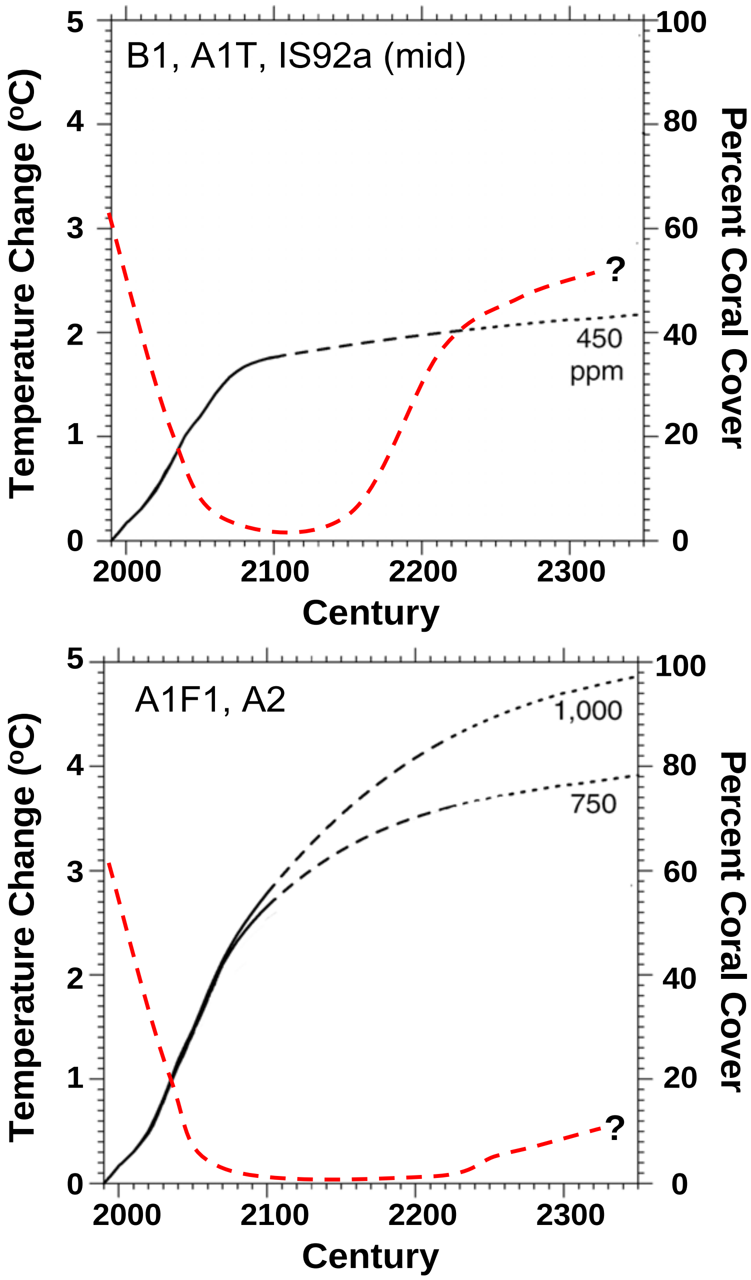


Figure 26. Hypothetical futures for coral reefs beyond 2100. Under milder climate change scenarios (akin to B1, IS92a, A1T) the initial impacts, though great, leave some elements of the coral population in place such that when conditions stabilize, coral populations return. It takes about 50 years for coral reefs to recover quickly after 30-40 years lag time. This takes into account reduced recruitment between areas due to low coral stocks. It is argued that reefs return with only 70% of the original biodiversity. Under more severe climate change (akin to A1F1, A2), the earlier impacts are dramatic with the loss of some coral species and at least 50% of the organisms that live on coral reefs. The major impact is that organisms with a +5°C temperature tolerance are rare today (relegated to small areas of the world, e.g. inshore Saudi Arabian waters). Temperatures also take much longer to stabilize and hence reefs take several centuries to start to recover. These emission scenarios are based on simple model results from the IPCC (2001a) projects following WRE profiles. These are meant as indicative graphs only of the potential impact of stabilized temperatures over the long term.

Biological scenarios for the Great Barrier Reef

One of the main outputs of Section 1 is to indicate when major biological events (such as the decrease in apparent appeal of reefs and the loss of fisheries) might occur. These will drive the economic and social scenarios built later in the report (Parts 2 and 3). It is recognised that placing exact dates on when coral reefs might degrade is speculative. However, most of these dates stem from minimum or most conservative estimates. For example, past mass mortality events (DHM > 2.5) have taken more than 8 years to recover from yet we have suggested that only events that arrive every 3-4 years are going to reduce coral cover to zero. We have also used IS92A model simulations (a world that stabilizes at 500 ppm) which are best case and unlikely scenarios. Even with these conservative estimates, dates at which mass mortality events are occurring every 3-4 years are only a few decades away. It appears highly likely, therefore, that coral reefs will degrade further over the next 40 years based on their behaviour over the past 20 years. Evidence that adaptation can occur at the rates that exceed anything seen in the past is non-existent or equivocal.

Done et al. (2003) concede that stress will continue to increase on coral reefs, even if there is some shift in the tolerance of reefs. They also try to carefully analyse the direction and end point of change. There are at least two potential outcomes that Done et al (2003) associate with a high negative value of their index based study: Community state 3 which is where only the tough coral individuals and species persist, and future hot years may have little additional impact on a greatly reduced coral diversity (and low coral recruitment in the face of very frequent, severe warm events). Or, Community state 4, where reefs are devoid of all or most reef-building corals. In this case, reefs no longer have the capacity to rebuild wave-resistant reef structures that the complex habitats for the enormous biodiversity of coral-dependent organisms. As stated by Done et al. (2003), it clearly matters which scenarios unfolds in the future. States 2 and 3 may be functionally adequate and aesthetically appealing as coral communities, but state 4 would be neither. All outcomes are plausible given our current lack of understanding of key thresholds and the rates of adjustments that may be possible.

Table 10 identifies six sets of biological scenarios for the Great Barrier Reef. Four of these, (A1B, A2, B1, B2) are then used in Part 3 as a basis for the social and economic perspectives in the fully developed scenarios. The most environmentally benign of the scenarios presented in Table 10 is B1, where global average temperature stabilises at around 2 degrees. Yet, even under the B1 scenario, mid-shelf reefs are no longer coral dominated by 2060; and inshore and offshore reefs reach the same state by 2070. However, as noted earlier, under milder climate change scenarios such as B1, coral populations return, though it is argued that they return with only 70% of their original biodiversity.

Table 10. Years after which either reefs have significant less natural appeal and years in which reefs are no longer coral dominated. The assessment of A1F1 and A1T are based on the preceding analysis with an extra 10 years added to the end of the decades listed in Table 9. In order to create values for the four main scenarios explored in this report, the following assumptions (based on expected temperature changes, Figure 6) were used. A1B and B2 are similar to the A1T trajectory and hence this has been adopted for these two. A2 is a little under the A1F1 scenario and hence 10 years have been added to each estimate. B1 lies a bit under the A1T scenario and hence 10 years are added to create the B2 scenario. Given the error around all

trajectories for the first fifty years, these assumptions while approximate are valid for the development of the potential economic and sociological scenarios developed later.

	Year after which reefs have half the coral they had in 1990 and are starting register negative appeal to tourists.	**Year by which reefs are no longer coral dominated.**
A1F1		
Inshore	2025	2050
Mid-shelf reefs	2015	2030
Offshore reefs	2025	2050
A1T		
Inshore	2030	2060
Mid-shelf reefs	2025	2050
Offshore reefs	2030	2060
A1B		
Inshore	2030	2060
Mid-shelf reefs	2025	2050
Offshore reefs	2030	2060
A2		
Inshore	2030	2060
Mid-shelf reefs	2020	2040
Offshore reefs	2030	2060
B2		
Inshore	2030	2060
Mid-shelf reefs	2025	2050
Offshore reefs	2030	2060
B1		
Inshore	2035	2070
Mid-shelf reefs	2030	2060
Offshore reefs	2035	2070

Tourist values in the next fifty years

The impact of the state of any particular coral reef on tourism comes down to whether the accessible natural values that meet the expectations of the visitor. In this way, two points may be seen as important. The first is where coral cover declines below that expected by the visitor as a healthy coral reef. This is equivalent of adding another 50% of the decrease in reef progression values to the estimates of reef state in Done et al. (2003). At this point, it is expected that fish fauna and biodiversity will have declined to a measurable extent ("measurable" defined relative to what the tourist perceives). The second point is where coral has declined to remnant levels (< 5% total areal cover). At this point, reefs will represent a radically different system as far as diving experiences are concerned. They would be expected at this point to be visually shifting into either algal reefs (where herbivores are scarce) or reefs which are dominated by bare, open substrate. These dates are calculated as described above (Table 9) but adding a decade to each calculated date to allow for the most optimistic viewpoint. This was seen as a reasonable decision given similar conclusion of Done et al. (2003).

The other missing component in this analysis, as discussed before, is the role of factors such as eutrophication of tropical waters and over-fishing in affecting the resilience of reefs. These factors will bring the dates forward listed in Table 10. As outlined above, reducing these factors would put the dates back in time. The four scenarios developed in Chapter 12 make different assumptions, which will greatly affect the resilience of the ecosystem.

Fishing on the Reef in 2050

How fisheries will change over the next fifty years is complicated by the lack of information about precise impacts and consequences of changing benthic community structure. These have been compiled and reviewed in Chapter 2. Biologists that study the fish that inhabit coral reefs have documented the tight association of fish species with benthic cover. Some fish settle preferentially from the plankton into living coral only. Others feed exclusively on coral polyps. For this reason, it can safely be assumed that the loss of coral cover will have large scale consequences for any industry or pastime that depends on coral obligate fishes or invertebrates. As discussed above, obligate fishes are already disappearing from reefs that have lost coral cover (Kokita and Nakazona 2001). On the other hand, fish that are herbivorous may increase in numbers as observed for reefs along the shoreline of Tanzania (Lindahl et al. 2001). The main message for industries that depend on benthic populations of fishes is that changes to coral cover are likely to vary fish targeted with the Great Barrier Reef. A precise understanding of exactly how these fish populations will change within the Great Barrier Reef is currently not available and must be a priority for any long-term planning (next 20-50 years) associated with the fishing industry.

Pelagic fisheries such as those associated with tuna and mackerel may also see significant changes. Impacts on pelagic fish populations have already been seen in response to climate changes elsewhere in the world (see Chapter 2). The population dynamics of pelagic fish are highly correlated with climate indices, indicating their extreme sensitivity to climate variability. Again, it is not possible to predict the exact direction of changes as climate changes. However, long-term investments in fishing infrastructure specifically designed to target particular species would seem unwise in the current shifting climate. The lessons outlined in Chapter 2 from the northern hemisphere are particular poignant.

An additional impact that can be expected is the potential rise of problems such as that associated with ciguatera (Lehane and Lewis 2000). As benthic habitats change away from coral domination, it appears that the dinoflagellate flora appears to thrive. This may also be a factor in the rise of other disease organisms. Along changing diet, changes to sea temperature may lead to major changes to the incidence of disease in fishery related organisms. This has been documented for coral communities and invertebrates like sea urchins. There is now strong evidence that the changing frequency of disease is related to changing climates (Harvell et al. 2002).

In terms of setting dates for these changes, it is assumed that the assumptions about relative timing are similar to those of Table 10 and those changes to those elements of the fish populations on the Great Barrier Reef occur linearly with any decline in coral cover. While these functions may have complex shapes, this assumption is in the middle of the range of possibilities.

Conclusions

There is little doubt now that the future of the Great Barrier Reef is being jeopardized by the activities of humans (Hughes et al. 2002; 2003, Pockley 2003). Among these threats are coastal land use, over-fishing and climate change. As with the world's coral reefs, climate change has grown from insignificance 20 years ago to the major threat facing the Great Barrier Reef (Hoegh-Guldberg 1999; Hughes et al 2003). So far (after 0.6^{o}C of global warming), the Reef has probably escaped major lasting impacts from climate change. However, events like 1998 and 2002 remind us that it is the sea temperature of the future that should have us extremely worried. Projected increases in sea temperature in the Great Barrier Reef region are at best 1.5^{o}C by 2100 and are at worst 5^{o}C higher than current sea temperatures. In terms of comparing current conditions with those that will exist on the Great Barrier Reef in the future, sea temperatures that are typical of the northern tip of the Great Barrier Reef will exist at its southern end by 2040-50 (A1, A2) and 2070-90 (B1, B2).

These temperatures will exceed the local thermal tolerances of reef-building corals on annual basis by 2030-60. The calculated thermal stress levels rise to several-fold higher than those seen in 2002 and lead to the highly probable conclusion that reefs dominated by coral will be rare in the Great Barrier Reef region by 2050.

It is important to point out that the rate of change is likely to depend on how we treat reef systems within the Great Barrier Reef Marine Park. The expansion of no-take or green zones will build reef resilience, a factor critical to how reefs will respond to the increasing frequency and intensity of thermal stress events. While some sectors of the fishing industry may see increasing numbers of no-take areas as negative relative to their key activities, there is now a large body of information that shows that protecting fish stocks through no-take zones will lead to increased fish populations in areas adjacent to these areas (e.g. Alcala and Russ 1998a,b).

Differentiating between the four scenarios explored in this report is difficult up to 2040 due to model uncertainties. By 2050, however, the trajectories become distinctly different. Under the potential stabilization of carbon dioxide levels at 450-600 ppm, reefs are likely to recover over 50-100 years as the geographic reassortment of genotypes occurs. It is argued that the genetic stock required to migrate geographically is still available for most of the new thermal habitats. Calcium carbonate alkalinities are also expected not to have decreased to a point where significant calcification is still possible. One hundred years after stabilization, reefs, while much less biodiverse, may have dominant reef-building coral communities. Under scenarios that stabilize at carbon dioxide higher than 600 ppm, reefs may take much longer to return given that the genetic stock for corals that can grow at sea temperatures greater than 33^{o}C are rare on the planet today. It will consequently take longer (if indeed it will happen at all) for warm adapted corals to find new sites within the shifting patterns associated with thermal habitats. The much more devastating effects of these sea temperatures may eliminate so much of the biodiversity associated with reefs that they may take thousands of years to return.

Synthesis to Part 1

The earth's temperature is changing due to changing properties of its atmosphere. It can also be concluded that the distribution and abundance of the terrestrial and aquatic life forms have already changed despite only 0.6°C of warming since 1880. Projections of future climate change suggest that the earth's temperature will change by an additional 2-6°C over the next 100 years. These changes will bring huge changes to the health, distribution and abundance of the earth's biota. Understanding how these changes will impact on human societies and economies is of enormous importance if we are to attempt to minimise the impacts and adapt to the changes.

Foretelling the future gets increasingly complicated as one moves from projections of physical and chemical changes to projections of biological, social and economic change. The importance of at least addressing the possible "envelope" in which the future is contained remains crucial to any attempt to adapt to these future scenarios. In this section, best and worst case scenarios for the most diverse marine ecosystems, coral reefs, were built using past knowledge of the behaviour of coral reefs under stress and scenarios of future climate derived from the Intergovernmental Panel on Climate Change (IPCC 2000). The IPCC scenarios indicate that the conditions of all future worlds will be hostile to coral reefs. Implicit in this are rates of climate change that exceed by 2-3 orders of magnitude any seen before, and carbon dioxide and sea temperatures that exceed anything experienced by coral reefs over the past 500,000 years at least. A synthesis of information on climate and the known tolerances of coral reefs suggest that coral dominated reefs will be rare in the future. How we treat reefs in the meantime will greatly influence the rate at which they degrade. In short, if we treat coral reefs well and massively reduce rates of warming, we have a chance of preserving them into the future. If we don't, we step into a future in which coral reefs have a tenuous future at the very least, or a future in which coral reefs disappear for many hundreds of years at worst.

Just as with the organisms that have to associate with corals to survive, understanding the impacts of climate change on the booming coral reef tourist and fishing industries depends on an understanding of which elements are dependent on the presence of coral on reefs for survival. As some fisheries require the benthic substrates like those seen on today's coral reefs, removing corals will put these industries at risk. Understanding tourist impacts of the loss of coral is perhaps more tricky due to the adaptability of the industry to new markets (Cesar et al. 1998, Cesar 2002). As will be developed in Part 2 (Chapter 8), more than half of the tourists currently visiting the regions along the Great Barrier Reef are "reef-interested", and, as these tend to be relatively big-spending, they represent 70% of the total tourism expenditure in these regions. Therefore calculating when coral reefs lose corals as dominant organisms might be directly related to the health of this sector of the industry. These dates have been calculated for the four scenarios explored. But as will be demonstrated in the scenario development in Part 3 (Chapter 12), tourism unlike fishing is adaptable, resilient and a high-growth industry. Hence the actual impact of the loss of natural values for the ecotourism industry may not prevent further growth of tourism income for the regions along the Great Barrier Reef.

PART 2 – REGIONAL ANALYSIS

Overview

Criteria for economic development should include the main areas it influences, that is, social welfare and the environment. There is a tendency to focus on economic factors or at the most undertake some fairly perfunctory 'socio-economic' analysis.

In the final analysis all economic, social and ecological elements should be taken into account. The aim of Part 2 is to capture this perspective. It provides a bridge to the scenario planning analysis in Part 3, where alternative futures are shaped by the full range of economic, social, ecological, cultural, political and technological influences, which are described regardless of whether they can be expressed statistically.

The theoretical basis is centred on economics but is increasingly embracing social and ecological factors. Welfare has been an integral component throughout the history of economic analysis (Schumpeter 1954:1069-73), though concern over the *distribution* of the economic product is often overshadowed by a fixation with macroeconomic *growth*. Environmentalism as we know it today had no place in economic theory as recently as fifty years ago; Schumpeter (1954:434-35) uses the term in a sociological and political science context. However, it does have roots in the 'externality' and public goods theories of more than a century ago. 'The essence of environmental issues is that they involve externalities and public goods. The combination means that only in rare cases can we appeal to familiar theorems about the splendid welfare results produced by the free market.' (Palgrave 1987). In other words, centre space has been given to what economists even today keep referring to as 'externalities', that is, essentially marginal issues from the point of view of conventional economics.

A notable recent development is the rise of ecological economics, bridging the gap between the two disciplines. The theory, among other applications, is behind practical applications such as the explicit introduction of the environment into national accounting and the development of physical indicators of energy use and environmental degradation, both of which are discussed in Part 2.

The capability of economic theory to provide an analytical framework embracing the environment is encouraging. It is discussed in Chapter 5, which provides a bridge to the empirical analysis in the rest of Part 2. Following the identification of statistical and other sources in Chapter 6, Chapter 7 deals with the economic, social and environmental characteristics of the five regions adjacent to the Great Barrier Reef. The main reef-based industry, tourism, is given a chapter of its own (8), while extractive activities (mainly fisheries) are the subject of Chapter 9.

The final step was to adopt a set of reference projections for the coming 20 years, in the absence of climate change and reef deterioration (Chapter 10). These projections were mainly derived from the Productivity Commission's report on coastal management along the Great Barrier Reef lagoon area (PC 2003).

5. Economic theory and practice

Preamble

That physical scientists work within a theoretical framework is taken for granted by everyone. The evidence in Part 1 could not have been presented without the edifice of scientific theory and method that has been built, literally, over the centuries.

It is important to ensure that the economic analysis of long-term change also has a decent theoretical base. Economists are often perceived as focusing on the short term: the next annual budget in the public sector, the next profit in a commercial environment. While this perspective is important in many contexts, the ecological economics that emerged in the final quarter of the 20th Century takes a longer view and a firm theoretical basis is developing. This chapter has three main sections:

- The development of ecological economics, with its main themes of sustainable development and intergenerational welfare.
- A discussion of total economic value of ecological assets under the heading of 'valuing the invaluable'.
- The introduction of environmental factors into areas such as national accounting, and the development of physical indicators of environmental change.

One point must be made before launching into the next section: This analysis focuses on total regional effects of a warming climate and degradation of the Great Barrier Reef. Each of the five regions adjoining the Reef forms an 'economy'. This approach is in contrast to the analysis of individual projects or activities. Herman Cesar, for instance, is a leading exponent of economic case studies and the editor of a volume on the economics of coral reefs (Cesar 2000). Both types of approach are important and ultimately supplement one another.

Development of ecological economics

Fitting the environment into conventional economic theory

Recent literature abounds with evidence that economic theory continues to provide a solid basis for policy action, including the environment. This includes extensions of conventional theory such as Arrow et al. (2002b), a mathematical paper in a time-honoured economic style firmly rooted in the literature. The paper demonstrates how sustainable development and intergenerational welfare can be built into the traditional theoretical structure. It breaks new ground in applying the theory to 'economies where the government, whether by design or incompetence, does not choose policies that maximise intergenerational welfare. … The theory's reach therefore now extends to actual economies.' (p 2) Kenneth Arrow, it should be added, won the 1972 Nobel Prize for Economics and is the author of a large number of theoretical papers from the 1950s onwards.

Are we consuming too much? A team including noted ecologist Paul Ehrlich (Arrow et al. 2002a) asks: Is our use of Earth's resources sustainable? The paper sets the ecological case against the mainstream economics argument. The basic ecological claim is that population growth contributes to the world living above its means, and so does the growing average demand per person. Conventional economics, on the other hand, acknowledges no limit set by sustainability, or treats it as an externality.

The paper discusses the central concept of g*enuine investment* as the net investment in human and natural capital and manufactured capital goods, *less* disinvestment in environmental capital measured, for example, by estimated change in CO_2 emissions. Data limitations constrain the measurement of genuine investment, and extending the measurement to all environmental assets. Studies generally include commercial forests, oil and minerals, and the atmosphere as a sink for CO_2 – but water resources, forests as agents of carbon sequestration, fisheries, air and water pollutants, soil and biodiversity are often excluded:

> *Under current accounting practices, recorded investment could be positive, even large, while genuine investment is negative. Underpriced environmental natural resources contribute to this phenomenon. Ecosystem services usually are available free to those who use them (fisheries in the open seas; our use of the atmosphere as a sink for pollutants; most services offered by mangrove forests, coral reefs, and watersheds; and so forth). In general, the depletion of environmental assets is not counted properly in economic calculations, and consequently investment projects that are judged to be commercially profitable are not infrequently socially unprofitable.* (p 13)

The authors argue that the simple linear relationships so favoured by conventional economic theoreticians no longer apply. The most serious of the authors' reservations is that massive uncertainties, non-linearities and thresholds are ignored, causing a possibly massive upward bias to the measurement of genuine investment.

Social and ecological resilience

Carl Folke's work on social-ecological resilience and behavioural responses (Folke 2003, in press) represents another branch of ecological economics with roots in the mid-1980s. In many ways it owes more to the complexities of ecology than the comparative simplicity of economic models. The emphasis is on processes of behavioural change and their dynamic and non-linear nature. The approach provides a contrast to the simplified view and application of social cost-benefit analysis, 'which does not take into account the inherent complexities and resulting uncertainties associated with dynamic and interdependent human-environmental systems.'

Resilience is central for the understanding of social response to changes in resource and ecosystem dynamics. Resilience provides the capacity to accept sudden change and cope with uncertainty and surprises while maintaining desirable functions. A non-resilient system is vulnerable. 'In a resilient system, change has the potential to create opportunity for development, novelty and innovation. In a vulnerable system even small changes may be devastating.'

Part 1 (p 30) contains a good example of this, when natural factors interacted with past over-fishing of large herbivorous fish on the reef around Jamaica to allow macroalgae (seaweed) to take over and the coral cover to be almost lost. (Hughes 1994).

Earth's life-support systems contain huge and complex non-linearities and thresholds. Disturbance is part of ecosystem dynamics and development. 'Disturbance opens up patches of opportunity for renewal and reorganisation of the ecosystem for development and evolution.' (p 4). Human activity has actively suppressed and removed disturbance but on the other hand has created new disturbances, thus detrimentally changing the whole disturbance pattern. Managing for resilience is not only an issue of sustaining capacity and opportunity for development, now and in the future, but is also important for environmental, social and economic security.

Endnote on economic theory

The emergence of ecological economics demonstrates that economic theory remains academically sound and in no need of radical change to enable it to incorporate the physical environment. The following three characteristics of the new economics are inter-related but deserve to be spelt out individually:

- The need to portray a dynamic and rapidly changing world is made clear when nature becomes a formal part of the theory. The *process* of change is integral – conventional comparative static models showing an initial and an end stage are insufficient.

- Catering for great complexity – necessitating more complex models of real-world inter-relationships.

- Dealing with non-linearities, thresholds and discontinuities: it no longer makes sense to expect linear relationships and simple normal or lognormal distributions to emulate a complex real world. Forks in the road of the future – where events can develop one way or the other – must be expected. 'Future road forks' – the hazards of projecting past trends – are also close to the heart of scenario planning, as developed in Part 3.

The two sections following, on total economic value and satellite accounts, shed further light on the theoretical and practical issues associated with the derivation of the genuine investment concept advocated in the two papers by Kenneth Arrow and his colleagues (Arrow et al. 2002a and 2002b). The problems remain how to 'value the invaluable' and devise statistics for the missing components that could in principle be assigned a value.

Valuing the invaluable

Total economic value

This study is concerned with appropriate definitions of economic value in relation to a resource such as the Great Barrier Reef Marine Park and World Heritage Area. It includes market-based economic use of the Reef but more importantly the non-market (use and non-use) values, adding to a 'total economic value' (TEV). The World Commission on Protected Areas (WCPS 1998) defines TEV as follows:

> *Total economic value = use values (direct, indirect and option values) + non-use values (existence and bequest values),*

where (quoting WCPS 1998),

- 'direct use values are values derived from the direct use of the protected area for activities such as recreation, tourism, natural resource harvesting, hunting, gene pool services, education and research;

- indirect use values are largely comprised of the protected area's ecological functions such as watershed protection, breeding habitat for migratory species, climatic stabilisation and carbon sequestration. Indirect values are often very dispersed and thus go unnoticed by markets;

- the option values of a protected area refer to options of using the protected area some time in the future. These future uses may be either direct or indirect and may include the future value of information derived from the protected area. Future information is often cited as particularly important for biodiversity as untested genes may provide future inputs into agricultural, pharmaceutical or cosmetic products;

- non-use values are values which humans hold for a protected area which are in no way linked to the use of the protected area. Bequest values relate to the benefit of knowing that others benefit or will benefit from the protected area. Existence values reflect the benefit of knowing that the protected area exists even though one is unlikely to visit it or use it in any other way. Non-use values are particularly difficult to measure.' (WPCS 1998)

Some sources, including the socioeconomic manual for coral reef management (Bunce et al. 2000), argue that it is possible to put a value on non-use values using, for example, the contingent valuation method (p 226), which 'collects information on consumer preferences by asking them what they are willing to pay for a benefit ('willingness-to-pay') or what they are willing to accept by way of compensation to tolerate the loss ('willingness-to-accept').' The manual argues that despite complications of designing and implementing the necessary research and a number of obvious sources of bias, contingent valuation 'is often the only means for estimating the non-use value of coral reefs [and] is therefore often required.' (p 227)

WPCS (1998) discusses a number of valuation techniques but is careful to point out that 'valuation is a developing tool and there are many ways to approach a valuation study' (p 27). Experience shows, however, that the use of these methods results in undervaluing the true ecological value, thus causing the estimated genuine investment to be unrealistically high (Arrow et al. 2002a). Put another way, standard cost-benefit analysis attempting to provide non-market-based estimates is flawed because those questioned to provide the valuations in the absence of a market mechanism don't actually have to pay.

The scale and purpose of the exercise has a bearing on the outcome. In the limited context of managing a protected area it makes sense dealing with the financial value of tourism, recreation and other tangible benefits against the public cost of maintaining an area such as the Warrumbungles or the Grampians– two of the case studies in WPCS 1998 which happen to be located in Australia (Central New South Wales and Western Victoria, respectively).

Herman Cesar gives a comprehensive account of the economic valuation of coral reefs in the opening chapter of a book of essays on the economics of coral reefs (Cesar 2000). After surveying many possible valuation methods, he asks (p 27):

> *Why do economists want to value something as invaluable as coral reefs? The answer could well be: "Because coral reefs are so beautiful that we want to make sure that our grandchildren can enjoy them as well." Yet, we see many coastal populations who are unaware of the goods and services that coral reef ecosystems provide and who are unable to see through the complex linkages of the natural world. We see people using coral reefs unsustainably and even destructively. And we see politicians unwilling to look beyond their short-sighted lenses, and consequently we see a lack of funds for coral reef management, even though the long-term costs of inaction are typically much higher than the funds needed.*

Cesar puts the case squarely into the realm of sustainability and intergenerational equity. Our main point of difference, if any, is whether it is feasible to cost the non-use values associated with the utility to coming generations – something we cannot really have much of a guess at. Measuring the willingness to pay of beneficiaries such as tourists tackles only a minor part of the problem.

In a new publication, Herman Cesar actually values not the Great Barrier Reef as such but the cost of severe coral bleaching in Australian reefs generally (Cesar et al. 2003:19). The figure is $US 28.4 billion or about $A 47 billion at current exchange rates ($A1 approximately equivalent to 60 US cents). The cost is distributed among fisheries, tourism and biodiversity and calculated in Net Present Value (NPV) with a 50-year time horizon at a 3% discount rate. A table in the paper values the worldwide cost of severe bleaching at $US 104.8 billion ($A 175 billion), with Southeast Asia showing the highest damage of $38.3 billion ($A 64 billion). The paper also has a 'moderate' bleaching scenario costed at about one-quarter of the 'severe' scenario, and expresses the hope that concerted efforts of all stakeholders might help us achieve the level of the 'moderate' bleaching predictions.

The basis for these calculations is unknown – how, for instance, does one value biodiversity? What is the basis or range of the calculations 50 years into the future when the range of valuing bleaching events in just one year, 1998, and only in the Indian Ocean, was as wide as $US 700 *million* to $US 8.2 *billion* (Wilkinson et al. 1999)? A range that was calculated, incidentally, using a very different time horizon and discount factor (20 years and 10%)? The latter paper (of which Cesar was a co-author) made the following comments on the 'optimistic' scenario (p 194):

> *In the optimistic scenario the losses are still considerable, but an order of magnitude less than the pessimistic scenario, stemming mainly from loss in tourism (US$ 0.3 billion) and fisheries (US$ 0.3 billion). However, the potential human suffering resulting from the coral bleaching and mortality, of possible malnutrition and increased poverty, as well as unemployment is more than dollar values can express. It is certain that further monitoring and research on both bio-physical and socio-economic aspects is required. However, it can be predicted that the massive bleaching will mean that national economies will be damaged and the international aid community will be called on for far greater support.*

The fact that there is such a colossal range in the estimated damage, coupled with the observation in the quoted passage that the damage goes beyond the impact on the immediately affected industries (tourism and fisheries, coastal protection and 'other services'), really only tells us that the cost is 'very high at best'. Furthermore, to the extent that bequest and other non-use values are taken into account through the NPV analysis, who are we to judge whether we should discount our descendants' valuation at 10% pa over 20 years, 3% pa over 50 years, or at a zero discount rate over centuries?

Another essay in the Cesar volume (Dixon et al. 2000) discusses a contingent valuation survey conducted to infer general visitor perceptions of willingness to pay user fees to visit Bonaire Marine Park in the Caribbean. This can be related to the concept of economic rent, which is defined as an excess profit above normal rates of return that accrue to assets that are scarce and fixed in supply (Dixon et al. 2001). The fundamental environmental resources of Caribbean tourism, 'sun, sand and sea', should benefit the local populations rather than the tourists, who should pay for the benefit of enjoying the beaches, mountains and general ambience. Setting a user fee based on willingness-to-pay provides a simple mechanism – when access to a particular environmental resource can be controlled – for transferring the benefit from tourists to local populations, who own the assets through their governments.

This is a legitimate use of contingent valuation surveys but it falls far short of measuring total economic value. Quite apart from the intergenerational issue, complex ecosystems interact with other ecosystems in ways that remain beyond our state of precise knowledge. It makes little sense to ask samples of respondents to use their limited and possibly biased knowledge to put a value on what they would be willing to pay to preserve a world heritage area (out of their own purse?), or at what monetary value they would be willing to sacrifice (part or whole?) of that area. The alternative is to develop government policies to achieve appropriate standards that look beyond the immediate experiences and financial considerations of individual stakeholders, and are backed by international agreements and conventions.

The Productivity Commission (PC 2003:66-67) notes that the economic indicators in its Great Barrier Reef study only reflect the value of marketed goods and services produced by the main industries in the adjoining regions but does not account for all the value that can accrue to society from the World Heritage Area – particularly when resources are not used. Nor do they reflect all the social costs that can be associated with industry activity. Non-market values include the use of ecosystem services such as the water filtering provided by wetlands and the habitat provided to native species, and non-use values including existence values arising from knowledge that the area is retained in its natural state, and option and bequest values reflecting the future value society may place on the resource.

PC (2003) notes another set of non-market values highlighting the links between the subsistence and cultural values of Great Barrier Reef coastal resources. It quotes the North Queensland Land Council's submission to the Commission's inquiry (p 67):

> *In all coastal regions of Australia, Aboriginal people continue to engage in significant subsistence hunting, fishing and gathering activities in the rivers, seas and on land. For these people, subsistence resources form an important part of the domestic economy. In addition these activities are culturally important and life sustaining.*

One possible avenue towards the elusive goal of total economic valuation is the creation, through government intervention, of markets for ecosystem services (Murtough et al. 2002). These services are the functions performed by ecosystems that lead to desirable environmental outcomes, such as air and water purification, drought and flood mitigation, and stabilisation of climate. If markets can be created through devices such as tradeable credits, for example for forest CO_2 sequestration, this goes part of the way towards closing the gap between identified and total economic value. The Kyoto Protocol defined one tradeable commodity relating to greenhouse gases, expressed as one tonne of CO_2 equivalent. However, it remains difficult to see how this can be related to non-use values for an ecosystem such as the Great Barrier Reef.

Haycock and Driml (2002) survey the existing literature, revealing a vast array of estimates when attempts are made to put a figure on total economic value, including non-market values. They observe that the TEV concept is anthropocentric and ignores an 'intrinsic' value of species and ecosystems, independent of any direct or indirect utility to humans. This value essentially reflects the right of individual species to exist and be protected from human threats to their survival.

The next point in their list of limitations to the TEV framework needs quoting in full:

> *It is extremely unlikely that anyone will be able to estimate feasible dollar values for all components of the TEV. There are obvious limitations involved with assigning monetary values to society's uses of the natural environment. Some attributes are extremely difficult to value, for example the value of photosynthesis (which produces oxygen) or the spiritual value of an area. The complex and interrelated nature of attributes also*

> *means it is difficult to consider them separate goods or services, for example biodiversity underpins all ecosystem services as well as being a value in itself.* (p 12)

It may be argued that all economic valuations are anthropocentric by their very nature; however, admitting to this in-built subjectivity does not mean that we should cease the attempt to extend our concept of economic value to the limits – and we should then recognise that there are elements that cannot be valued. In a comment on a well-known attempt in *Nature* by ecological economist Robert Costanza and his co-authors (1997) to measure the value of the world's ecosystem services, Crowder (1997) cast doubt on the use of neoclassical economic concepts of consumer surplus and willingness to pay to estimate the total value of ecosystem services ranging from one to three times world income. He queried the empirical value of the estimates and conclusions and concluded, 'The accounting of annual benefits or willingness to pay violates meaningful interpretation of prices and economic value.'

Another commentator, in a contribution called *Measuring the Infinite*, puts the central issue succinctly, 'The support value of Biosphere One to human welfare is so large that we simply could not exist in emulators like Biosphere Two.' (Bein 1997). In other words, humanity couldn't exist without functioning ecosystems, and the values consequently do not pass the test of common sense – willingness to pay any finite amount becomes meaningless when the future of humankind depends on the preservation of these systems. Despite its flaws, the wide publicity given to the *Nature* paper has served to draw attention to the fact that concerted action is needed. The arguments in this whole chapter are endorsed by Chowder (1997) when he asks:

> *How do we get world leaders to consider the real value of ecosystems in their economic decisions? What are the limits to economic growth and resource extraction? …While the scale of analysis in the "Nature" article reaches far beyond the methods employed by the authors, perhaps it will catalyze economics to move in the direction of better valuing ecosystem services as inputs to local, regional, and national economies.*

Accounting for the environment

Limitations of satellite environment accounting

The concept of satellite accounts – which extend the conventional national accounting framework to explore new concepts while retaining a connection back to it – has recently been extended to the Australian environment (ABS 2002c). However, non-market values are not included and the resulting adjustments to GDP and related measures are fairly modest.

The idea of satellite accounting for the environment has its origin in 'SNA 93', the United Nations System of National Accounts dated 1993, which embraced the first version of a handbook on a system of environmental and economic accounts (SEEA). An advanced draft of a revised version is available on the Internet (SEEA 2002). The crux – again – is that the market mechanism, which enables prices to be determined, is often absent, especially when the object is a large and complex system. Some environmental and resource changes can be measured, such as depletion of mineral reserves and, on the credit side, discovery of new reserves. The handbook cites a second category of measurable defensive costs, including environmental protection expenditure by industry and government, the organisation and administration of fisheries licensing schemes, and health expenditure related to atmospheric pollution.

The third main feature of environmental accounting is degradation. In contrast to depletion and defensive expenditure, there is no direct way of accounting for it. Damage from environmental degradation can only be measured if it can be defined as costs in the conventional national accounts. However, the damage-cost approach does not attempt to put a value on the total services rendered by the environment. All existence values and many indirect use values are currently left out (p 10-34).

The authors of SEEA 2002 reach the following conclusion on future work on valuing degradation (bolding added – note the caveat that monetary valuation may not be useful even if reliable measurement was possible):

> *The techniques described in this chapter are still being developed and the data requirements to implement them are both extensive and resource intensive and thus generally incomplete. This work therefore should be seen as being in its early stages and is likely to change, perhaps radically, in the medium term. In its present state it may be applied to the valuation in special contexts, for example the analysis of the costs of a toxic waste site or perhaps the impact economy wide of particular emissions.* ***It is not sufficiently well developed to put a monetary value on biodiversity or the threats from global warming, but the threats these pose to sustainability may not be further illuminated by monetary valuation***. (p 9-6)

The theoretical literature, such as Arrow et al. (2002a) which was reviewed in the beginning of this chapter, clearly indicates that these assessments must be carried out before the task of valuation is anywhere finished. The draft SEEA handbook makes another crucial point that environmental costs are not confined to a particular year, and we are therefore environmentally indebted to the future:

> *In making adjustments to current period production or income measures for degradation it is clearly only appropriate to adjust for degradation caused in the present period. This should include an allowance for pollutants generated in this period even though the effects will not impact until later. It should not include the costs of restoring damage caused in an earlier period. … Unremedied degradation which carries forward to a future period is sometimes referred to as 'environmental debt'. Knowing the extent of it is obviously useful, but it is a stock value rather than a flow and as with asset accounts it is possible, in theory at least, to track this through time, seeing how much debt is ameliorated in a year and how much is added to the debt. As with other entries in the balance sheets, the costs of restoration are likely to increase over time also so there is a type of 'holding loss' associated with environmental debt.*
>
> *For additions to environmental debt, increments to stock pollutants should be valued as the present value of damages resulting from these*

> *increments over their lifetime in the environment. This is the methodological basis for the damage figures that are estimated for CO_2 emissions, for instance, where a 200 year residence time in the atmosphere is assumed.* (p 10-36)

Blueprint for a green economy – A possible alternative

The most important contribution of the draft handbook (SEEA 2002) may be the proposition that while there will probably always be controversies surrounding attempts to 'value the invaluable', such as heritage, existence and spiritual values, this may not be the only option. We added the bolding to the following excerpt:

> *One motivation behind many of the calls for 'green GDP' in the early days was the belief that alerting policy analysts to the fact that the economy was damaging the environment by means of adjusting the standard macro-economic aggregates would be sufficient to provoke policy change to avoid this damage. There were, and are, many analysts who feel that this is unlikely to be sufficient and is not in fact the most helpful sort of information to make available to those policy makers concerned to protect the environment.* ***Rather than a green GDP, what is needed is a blueprint for a green economy. It is not the accounting conventions which need to be changed but economic behaviour itself.*** (p 10-41)
>
> *What distinguishes a 'greened economy' model from a more general economic model is the emphasis given to achieving environmental improvement via economic processes. To achieve this, the following inputs are necessary.*
>
> *The first is to establish standards for the use of environmental functions such as those of vital natural resources, environmental waste absorption capacities and life-support systems, biodiversity, air, soil and water quality and the ecological dimensions of sustainability. This is done by means of modelling in physical terms as a result of which environmental standards are determined for use in succeeding stages of the model. These are specified through non-monetary targets relating to maintaining key environmental functions. Physical accounts are essential to organise information concerning the state of the environment and key economy-environmental interface measures or environmental use or 'pressure' indicators relative to estimates of environmental carrying capacities.*

The next step is to identify the measures that would have to be carried out to secure the desired environmental quality level, or of measures for restoring environmental deterioration which actually occurred. …The third step is to calculate the costs necessary to implement these measures. Data on emissions, technology, and costs is required to estimate aggregate abatement and restoration costs. (p 10-45)

'Greened-economy' indicators can be estimated using scenario modelling ex post for a series of years in the past or ex ante for years in the future. (p 10-46)

The Living Planet Index – An example of physical data

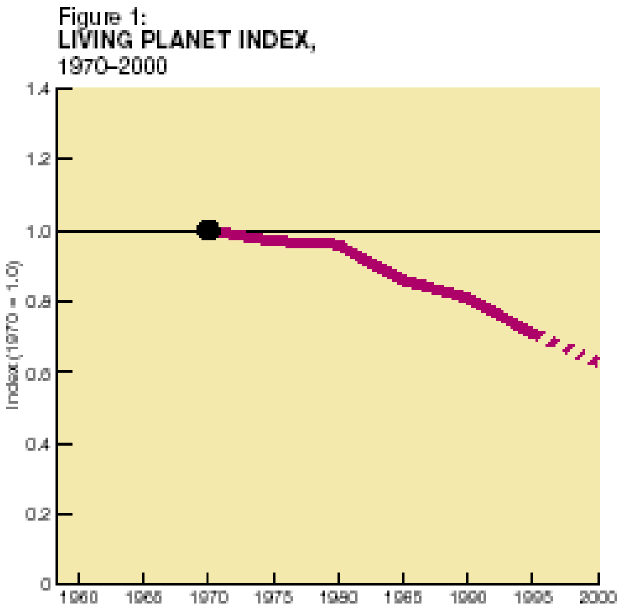


Figure 27: The Living Planet Index is the average of three sub-indices measuring changes in forest, freshwater, and marine ecosystems (see opposite). It fell by 37 per cent between 1970 and 2000. The dotted line indicates the most recent period, for which fewer data are available. (*Quoted from WWF 2002:2*)

The Living Planet Index by the World Wide Fund for Nature shows the state of the world's natural ecosystems (WWF 2002). It highlights the declining biodiversity in the world since 1970. Its display of large declines in environmental quality contrasts with the current state of the art of constructing satellite national accounts for the environment, which identify only a minor net impact. The WWF index also supports the strategic approach proposed for the 'greened economy' (SEEA 2002) of setting standards for using environmental functions rather than attempting to 'value the invaluable'. It is a possible example of the physical accounts advocated for a 'greened economy' by the authors of the draft SEEA handbook – simple in concept if not in execution.

There was a 37% decline in the Living Planet Index between 1970 and 2000 (with accelerated annual deterioration since 1980 indicated by Figure 27). It has three components as explained in the text below the figure:

- The Forest Species Population Index is a measure of the trends in populations of 282 terrestrial bird, mammal, and reptile species living in forest ecosystems around the world. It fell by 15% on average between 1970 and 2000, but practically all this decline occurred since 1990.

- The Freshwater Species Population Index comprises populations of 195 species of birds, mammals, reptiles, amphibians, and fish from lakes, rivers, and wetland ecosystems. This index shows steady decline, especially since 1975, totalling 54% over the 30 years.

- The Marine Species Population Index includes 217 bird, mammal, reptile, and fish species found in marine and coastal ecosystems. Marine populations on average declined by 35% over the three decades and at an accelerated rate since 1980.

Tropical and southern temperate regions appear to lose biodiversity at a faster rate than northern temperate regions. However, WWF notes that this 'does not necessarily imply that northern ecosystems are in a better state than southern or tropical ecosystems, merely that there has been relatively little change in northern ecosystems by comparison over the past 30 years.' (p 3)

The 'triple bottom line'

British author and management consultant John Elkington coined the term 'triple bottom line' in 1997. The three parts are economic prosperity, environmental quality and social justice. His company web site gives the best perspective on the concept we could find (Elkington 2002). Search engine Google shows that the concept has attracted great international interest among business, government and community organisations during the few short years since its inception. It is evidently not just a corporate public relations exercise and is finding its way into the legislation.

The Elkington web site is directed towards business but the concept is readily adaptable to other organisations, and it captures in a way that evidently appeals to business and government the essence of socially and ecologically responsible economic principles. Elkington suggests that the three bottom lines are in constant flux due to social, political, economic and environmental pressures in a complex interdependent dynamic system. In the economic/environmental dynamics, for instance, some companies already promote eco-efficiency, but challenges such as ecological tax reform lie ahead. In the social/environmental sphere, new challenges include environmental justice and the intergenerational equity agenda.

Looking ahead to Part 3, the idea of employing scenario planning techniques is to apply a richly textured approach to the analysis of what the future may bring. The short comment is of course that we don't know the future – but then the businesses that make sweeping decisions based on forecasts of past trends don't know either. A carefully written set of scenarios provides the basis for a comprehensive set of policy recommendations. These scenarios make different assumptions regarding progress on the matters raised in this chapter, including the measurement of environmental costs and the balance between the three components of the triple bottom line.

At the regional analysis stage in Part 2 the logical step is to cover, as far as statistically possible, all dimensions of the 'triple bottom line'. Fortunately we have some information on each, as outlined in Chapters 6, 7, 8 and 9.

6. Statistical and other empirical sources

Introduction

The purpose of this chapter is to list economic and demographic data sources on reef-based and other regional industries and regional economies, and on social characteristics and salient ecological features of the Great Barrier Reef area. There is a reasonable body of data on which to make this assessment; indeed the decentralised nature of the Queensland economy has long encouraged the creation of regional statistics. Five regions adjoin the lagoon: Far North Queensland (Tropical North Queensland for tourism purposes), Northern, Mackay (split into Whitsundays and Mackay for tourism purposes), Fitzroy and Wide Bay-Burnett. Each region is included in its entirety.

The statistical analysis is in Chapter 7 (regional economic, social and environmental data), Chapter 8 (tourism), and Chapter 9 (fisheries and other reef-based industries). Chapter 10 contains a set of base industry projections derived from the Productivity Commission's investigation of water quality in the Great Barrier Reef catchment (PC 2003). The Commission commissioned the Australian Bureau of Agricultural and Resource Economics (ABARE) to analyse and project gross value of production (GVP), gross value added and employment in 2010 and 2020 for nine industries in the five statistical divisions along the Great Barrier Reef (see box). Some are at least partly reef-dependent and the others all contribute to the regional economic base.

ABARE projections

Sugar
Beef
Horticulture
Commercial fishing
Recreational fishing
Aquaculture
Mining
Mineral processing
Tourism

All except tourism and recreational fishing produce goods that are either consumed in the region or exported from it. Tourism adds to the economic base through direct expenditure on goods and services within the region; recreational fishing also influences the base though double counting must be taken into account as discussed in Chapter 9. ABARE was able to commission or otherwise obtain unpublished statistical sources that were inaccessible for this study, and we elected to use most of the projections in the Productivity Commission's report as a starting point from which to measure the impact of the four scenarios presented in Part 3 (see Chapter 10).

The sources

The other main statistical sources for the analysis (other than PC 2003 including the ABARE analysis and projections) are listed below:

- *Basic community profiles* for local government areas for the 1996 and 2001 Census (ABS 2000, ABS 2002a). The main indicators used in the study include: total population counted on the night of the Census (counted at home, visitors from Queensland and other states and territories, and overseas visitors), and industry of employed labour force. Other data include number of Indigenous people and unemployment.

- The standard *Regional Community Report* format set up by the Office of Economic and Statistical Research was used to obtain data for each local government area (OESR 2002b). The information includes population forecasts for each five years to 2021 by the Department of Local Government and Planning, and summary statistics of agricultural production in 1998-99 (gross value of production of crops, livestock disposals and livestock products).

- Estimates of Gross State Product and Gross Regional Product (ABS 2002b, Government Statistician 1998, OESR 2002a) and special tourism satellite accounts for Australia and Queensland (ABS 2002d and OESR 2002a). Unfortunately the quality of previous regional estimates does not match that of the comprehensive research program for 1998-99, especially when it comes to industry detail. This limits the scope for time series analysis and precludes a particular approach to economic impact analysis based on the growth in particular sectors as tourism increases in a region.

- The ABS *Index of Relative Disadvantage*, based on the 1996 Census, provides a social summary indicator published at local government level (ABS 1998b). The publication also shows individual variables such as unemployment, household income per capita, people of Indigenous origin, people with degrees and higher qualifications, and one-parent families with dependent children. The proportion of Indigenous people is a questionable social 'disadvantage'; other variables can be used as proxies such as the unemployment rate to the extent that these communities are disadvantaged. The index does not include wealth, or access to schools, community services, transport and shops (ABS 1998a:15). Neither can it account for factors such as sunshine, balmy climate and alternative lifestyle choices – or recreational fishing opportunities, personal safety and protection from crime (PC 2003:65). An area may attract retired people who bring economic prosperity, whereas the index penalises areas with a high proportion of older people. A Queensland area showing a relative disadvantage compared with the Australian average of, say, 3% may not feel worse off. The index is most relevant for comparison of different parts of a region, or between coastal Queensland regions.

- Social indicators are also available for the 2001 Census, including new ones such as computers at home and Internet access. We have produced a provisional index which tallies well at regional level with the 1996 patterns despite being a crude average of relativities with the total Australian average, unadjusted for auto-correlation between the various indicators. The 1996 index used principal components analysis to account for correlations between the various components.

- The Office of Economic and Statistical Research (OESR 2001) has performed a vital task in compiling statistics of visitor expenditure in Queensland regions from Bureau of Tourism Research records by origin of visitor (intrastate, interstate and international) and purpose of visit (holiday, visiting friends and relatives, business/other) over the period 1985-99. This forms an important part of the work leading to the satellite tourism accounts in OESR (2002a).

- Other more up-to-date tourism statistics are available quarterly from the beginning of 1998 to June 2002 on accommodation establishments (ABS 1998-2002) and monthly from January 1999 to date from the Queensland Regional Tourism Activity Monitor (OESR 2000-02).

- The Tourism Program at James Cook University and CRC Reef Program B2.1.1 (*Understanding Great Barrier Reef Visitors*) provided valuable insights into aspects of the reef tourism market. Another JCU paper, though somewhat dated (Pearce et al. 1997), provided an important component in the process of estimating 'reef-interested' tourism from total regional tourism statistics.

- A new edition of the periodic review of the status of the world's coral reefs (Wilkinson 2002) helps put the Great Barrier Reef in a world competitive perspective.

- Fisheries data include a major report on current condition and trends in fisheries resources from the Department of Primary Industries (Williams et al. 2002), which discusses all important marine fish, molluscs and crustaceans, with some statistics available in a total Queensland context. Fenton and Marshall's three-volume guide to the fishers of Queensland (Fenton and Marshall 2001a, 2001b, 2001c) provides detailed insight into socioeconomic characteristics of operators and employees in each of 22 'town resource clusters' (TRCs), of which 15 adjoin the Great Barrier Reef. While ABARE (PC 2003) has criticised the authors for unduly high estimates of the gross production value of fisheries, the research is notable for its social indicators and for an opportunity to measure the origin of fishers of the reef area. A special analysis of commercial fisheries in the waters adjacent to each of the four northern coastal regions was carried out as part of the study, based on the CD released with the study (Fenton, Marshall and Edgar 2001).

- We formed the view that ABARE is at least partly incorrect in its assessment of Fenton and Marshall's estimates of commercial fisheries as being too high (though it has a point that estimates based on recall rather than records can be distorted). The geographical pattern of the ABARE estimates also looked odd, with little representation given to Wide Bay-Burnett which harbours some of the main fishing ports in Queensland, notably Bundaberg. The initial estimates for commercial fisheries were derived from industry sources rather than ABARE and are actually more in line with Fenton and Marshall (2001a).

- Sunfish Queensland has conducted two surveys of the spending habits and origin of recreational fishers in Mackay/Whitsunday (Murphy 2002a) and Townsville/Thuringowa (Murphy 2002b). These surveys followed a pilot study at Pumicestone Passage (Murphy 2000).

- A recent book on fisheries economics (Hundloe 2002) provided a useful framework as well as specialist contributions to commercial and recreational fisheries (Holland 2002 and Blamey 2002) and an economic perspective on the Indigenous sector (Campbell 2002).

- Key environmental information included PC (2003), the Marine Park Authority's catchment water quality action plan (GBRMPA 2001), the Baker report to the intergovernmental steering committee of the Great Barrier Reef Water Quality Action Plan (Baker 2003), and other sources outlined in Chapter 7.

There is an important dimension of spiritual relationship with land and sea, including the Great Barrier Reef, associated with a large Indigenous population. This is also part of the frame of reference.

7. Regions adjacent to the Great Barrier Reef

Scope of this chapter

This chapter describes the five regions adjoining the Great Barrier Reef in general terms, their economic characteristics, social indicators and environmental issues relevant to the area. Industry-specific analysis is carried out in subsequent chapters: tourism in Chapter 8 and fisheries and other reef-related activities in Chapter 9.

The regions

The Great Barrier Reef World Heritage Area covers 348,000 km^2 from the northern tip of Cape York Peninsula to Lady Elliot Island. The five regions west and south of the Great Barrier Reef are best described in terms of Statistical Divisions as defined by the Australian Bureau of Statistics – with some qualifications each of these areas also corresponds to the local Regional Tourism Organisations (RTOs).

Each Statistical Division consists of a coastal area adjacent to the Reef, and hinterland areas. The latter are highly relevant to any socio-economic analysis because they provide important export industries such as minerals, cattle and beef, and therefore contribute to the economic base of the region. Hinterland industries also have large environmental impacts, contributing to runoff and pollution of the coastal waters of the Marine Park.

- The *Far North Statistical Division* extends from the Torres Strait in the north to Cardwell Shire in the south. It corresponds to the Tropical North Queensland RTO. Cook Shire is the northernmost local government area adjacent to the Marine Park (apart from a small mainland section of Torres Shire at the tip of Cape York). The coastal local government areas running north to south are Cook, Douglas, Cairns, Johnstone and Cardwell. Inland shires include Mareeba and Atherton ('the tuckerbox of the north' on the Atherton Tableland) and a number of other areas. Cairns is the regional centre. Cook Shire extends across the Cape York Peninsula to include Weipa on the Gulf of Carpentaria. Weipa is based on bauxite mining and processing; produce is shipped direct to the aluminium processing plant in Gladstone.

- The *Northern Statistical Division* comprises the twin cities of Townsville and Thuringowa, Hinchinbrook Shire to the north and Burdekin Shire to the south. The hinterland covered by the region consists of Charters Towers and the surrounding Dalrymple Shire. The corresponding RTO is part of Townsville Enterprise Limited and also caters for the rest of the Northern Division. The 130,100 km^2 Burdekin River catchment – the second largest adjacent to the Great Barrier Reef – is within the region except that the tributary Bowen River extends into Mackay Statistical Division and the southern Suttor River and its tributaries into the hinterland of Mackay and Fitzroy Statistical Divisions.

- *Mackay Statistical Division* has been recently extended to include Bowen Shire (formerly in Northern Division). The other local government areas going down the coast are Whitsunday Shire, the City of Mackay, and Sarina and Broadsound Shires. Mirani Shire in the Pioneer River Valley behind Mackay grows sugar cane and could have been included in the coastal local government areas – it is closer than most of Broadsound Shire. Hinterland areas include Nebo and Belyando Shires. There are two RTOs in the Division: the Whitsunday tourist hub and Mackay, which mainly depends on the sugar industry and mining.

- *Fitzroy Statistical Division* has a larger hinterland than the other regions adjacent to the reef. This hinterland contains the 142,500 km^2 Fitzroy River catchment, which has a direct impact on the Great Barrier Reef as well as contributing to the regional economy (the catchment extends into Mackay Statistical Division to the north, as far as the coal-mining area around Moranbah). Coastal areas extend from Livingstone Shire in the north to Gladstone and Calliope Shire to the south. The City of Rockhampton is the largest centre. Two RTOs serve the area: Capricorn, and Gladstone Area Promotion and Development Limited. The latter covers Gladstone and the surrounding Calliope Shire, and Miriam Vale Shire in neighbouring Wide Bay-Burnett Statistical Division.

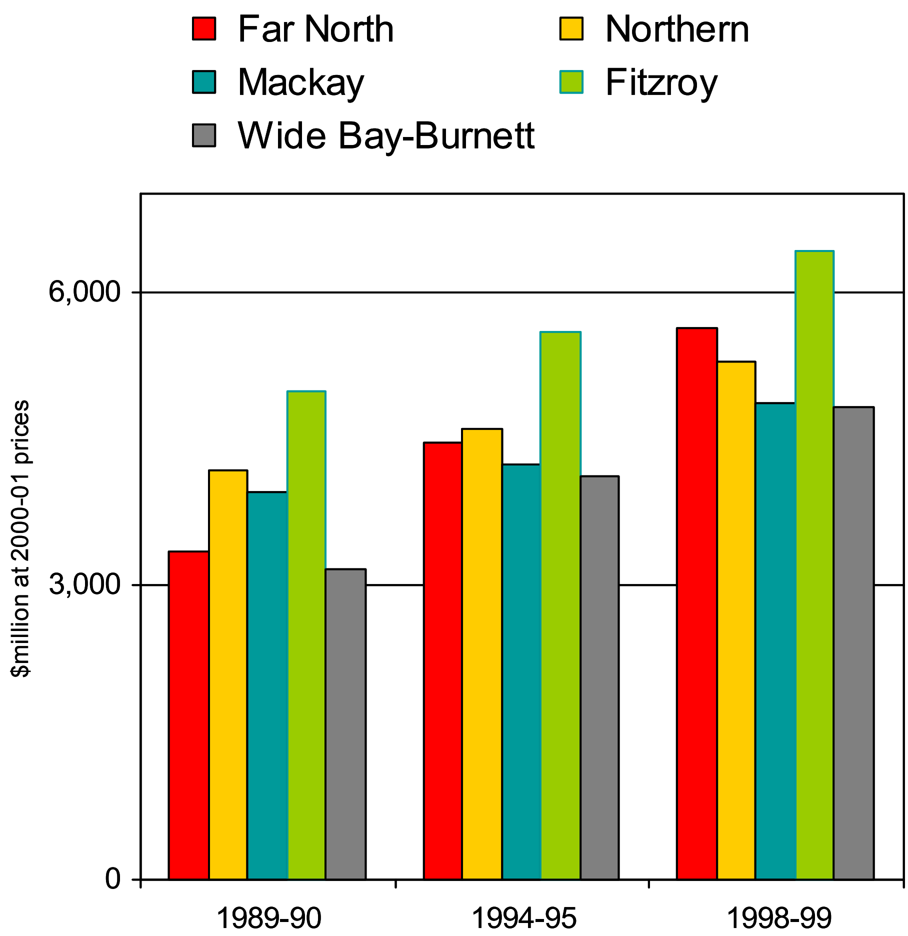
- The *Wide Bay-Burnett Statistical Division* is a large geographical area stretching southwest to Kingaroy and including the town of Gympie (in Cooloola Shire). It contains the Burnett River catchment (33,200 $km^{2).}$ Coastal areas extend from Miriam Vale through Burnett Shire, the City of Bundaberg and Isis Shire to the Cities of Hervey Bay and Maryborough, which share Fraser Island between them. The Bundaberg and Hervey Bay/Maryborough RTOs correspond to the Statistical Division. The inclusion of Wide Bay-Burnett is justified by the area's own perception of itself with large posters meeting the motorist: 'Bundaberg – Gateway to the Great Barrier Reef', and by statistics showing Bundaberg fishers to be active in fishing the waters of the Marine Park (Fenton, Marshall and Edgar 2002).

Regional economies

The recent project in the Office of Economic and Statistical Research of the Queensland Treasury to produce regional tourism satellite accounts for 1998-99 (OESR 2002a) also resulted in improved Gross Regional Product (GRP) estimates. This regional statistical base is second-to-none. Previous GRP estimates for 1989-90 and 1994-95 (Government Statistician 1998) are not fully compatible with the new statistics. It is a reasonable assumption, however, that growth rates estimated in this publication for the first half of the 1990s are valid; the problem is to distribute the growth in the latter part up to 1998-99.

Table A1 (Appendix A) attempts to estimate growth rates for the 1990s by relating regional statistics to the known trend in the total Gross State Product or GSP (ABS 2002b). The Queensland economy grew along a trend of 4.7% per annum between 1989-90 and 2001-02. To be compatible with the previous GRP estimates, point-to-point calculations were substituted for the trend estimate: GSP on this basis increased by an average of 3.9% pa between 1989-90 and 1994-95, and by 4.9% pa between the latter year and 1998-99.

Within this pattern, we estimate that the strongest economic growth in the 1990s occurred in Far North Queensland (6% pa), followed by Southeast Queensland (Brisbane and the Gold and Sunshine Coasts). Apart from Far North Queensland, growth rates appear to have been below the state average along the coast: around 3.5% pa in the latter half of the nineties. Wide Bay-Burnett seems to have had the strongest growth, though other indicators suggest that the region is relatively disadvantaged socially as discussed under social indicators below.



Source: OESR 2002a, ABS 2002b, Government Statistician 1998

Figure 28: Estimated Gross Regional Product at factor cost. Previous years have been adjusted to fit known Gross State Product trends, by estimating the annual change in GRP in each region of Queensland. Fitzroy has the largest GRP of the five regions, while Far North Queensland has the strongest growth (estimated to have continued at 6% pa since 1994-95).

Figure 28 shows the estimated Gross Regional Product for the five regions in 1989-90, 1994-95 and 1998-99. All estimates have been adjusted to 2000-01 prices using the appropriate components of the Gross State Product (assuming that price trends move in parallel in all regions).

ABARE (PC 2003) has produced a base employment estimate for each regional economy for 2000-01 (Figure 29). The text below the chart contains a brief description of dominant industries in each of the regions.

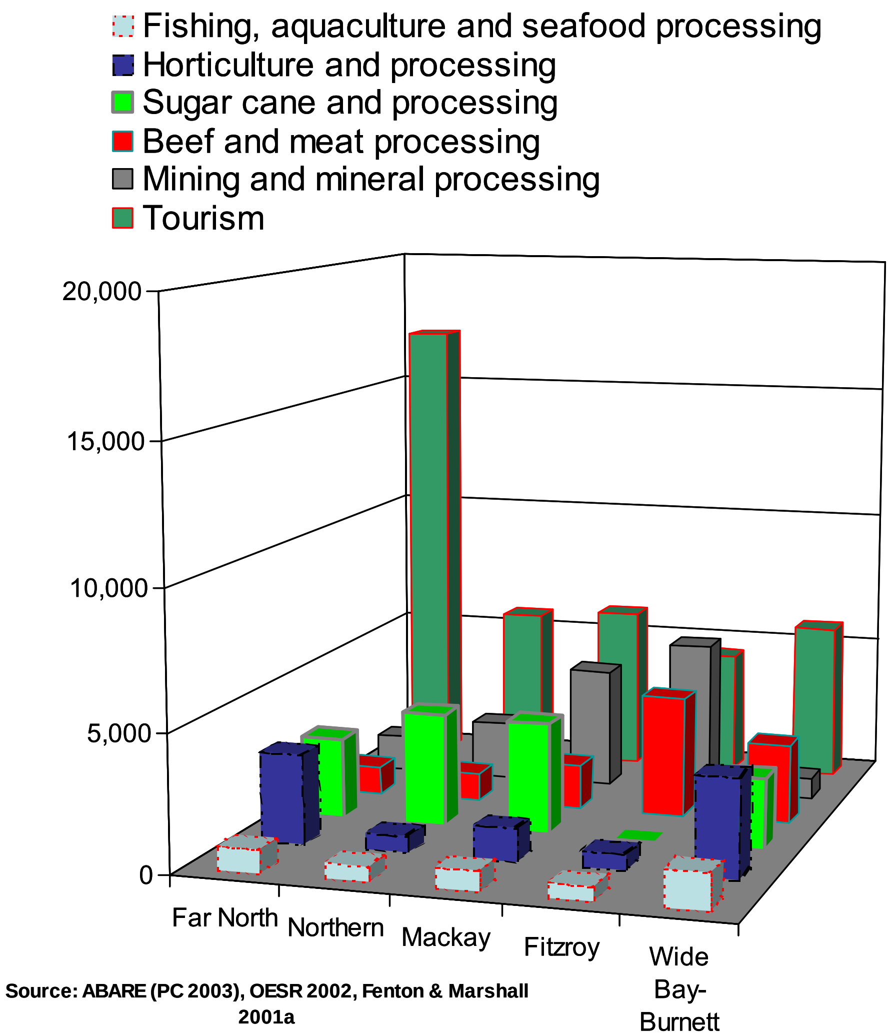


Figure 29: Estimated number of employed persons in key industries in each Statistical Division in 1999-2000. Tourism is the largest industry in terms of employment in each region (row of bars at back of chart). The figures are based on OESR 2002. The maximum estimated number of persons employed in fishing, aquaculture and seafood processing was in Fitzroy (1,325) followed by the Far North (831), where about 17,000 full-time-equivalent persons were employed in tourism. Mining and mineral processing are most important in employment terms in Fitzroy and Mackay, beef and meat processing in Fitzroy, sugar in Northern and Mackay, and horticulture in Wide Bay-Burnett and Far North Queensland.

In employment terms, tourism comes out on top in each of the five regions, though especially in Far North Queensland (its dominance is less in other regions but still striking in terms of gross value of production and value added). The three agricultural industries represented in Figure 29 together managed to exceed tourism employment in only one region: Wide Bay-Burnett.

Even including aquaculture and seafood processing, commercial fisheries provide by far the smallest contribution to the regional economic base – though these industries did provide employment for about 1,200 people in 2000-01 according to Table A1. This employment was concentrated at opposite ends of the Great Barrier Reef: Far

North Queensland and Wide Bay-Burnett. The estimates do not include recreational fishing, which adds little or nothing to the regional base as discussed in Chapter 9.

The number of employed persons in the five regions increased from 392,000 persons in 1996 to 408,000 in 2001 (Tables A3 and A4). Workforce growth was modest: 0.8% pa. The Northern Statistical Division showed the strongest average annual increase of 1.7% (Table A5). Wide Bay-Burnett had the second-highest rate of employment growth (1% pa). Of the three remaining regions, even Far North Queensland managed only 0.5% pa in the five years to 2001.

The growth and level of primary and secondary industry employment provides one indicator of the importance of these sectors as a generator of regional economic base. Employment in rural industries (agriculture, forestry and fishing) increased marginally in most regions, averaging 0.5% pa with Mackay and Fitzroy at the extremes (-0.2% and 1.9% pa, respectively). In 2001, 9.5% of the workforce along the Great Barrier Reef was employed in rural industries according to Table A6 – with the highest proportions in Wide Bay-Burnett (14.5%) and Mackay (10.8%).

Mining employment declined most of all industries, by an average of 3.6% pa for the five regions (Table A5). Only 2.9% of the total employed workforce was in mining in 2001 (Table A6); Mackay and Fitzroy had the largest proportions of 7.7% and 4.8%, respectively.

Manufacturing employment increased by 0.7% pa with a mixed regional growth pattern. There were declines in Far North Queensland (-0.5% pa) and Mackay (-0.8% pa) – both with a large component of sugar mills. On the other hand, manufacturing employment increased in Fitzroy (1.7% pa), Northern (1.3% pa) and Wide Bay-Burnett (1.1% pa). The manufacturing component of the total employed workforce varied from 11% in Fitzroy and Wide Bay-Burnett through about 9% in Mackay and Northern, to 7% in the Far North.

The main growth industries between 1996 and 2001 were (Table A5):

- retail sales: 2.7% pa in total and rates between 3.3% and 2.1% pa in the five regions, highest in Northern and lowest in Fitzroy;

- government administration and defence: 2.4% pa for all Great Barrier Reef regions but varying greatly from 5.2% pa in Far North Queensland and 2.5% in the Northern region to minus 1.5% pa in Fitzroy);

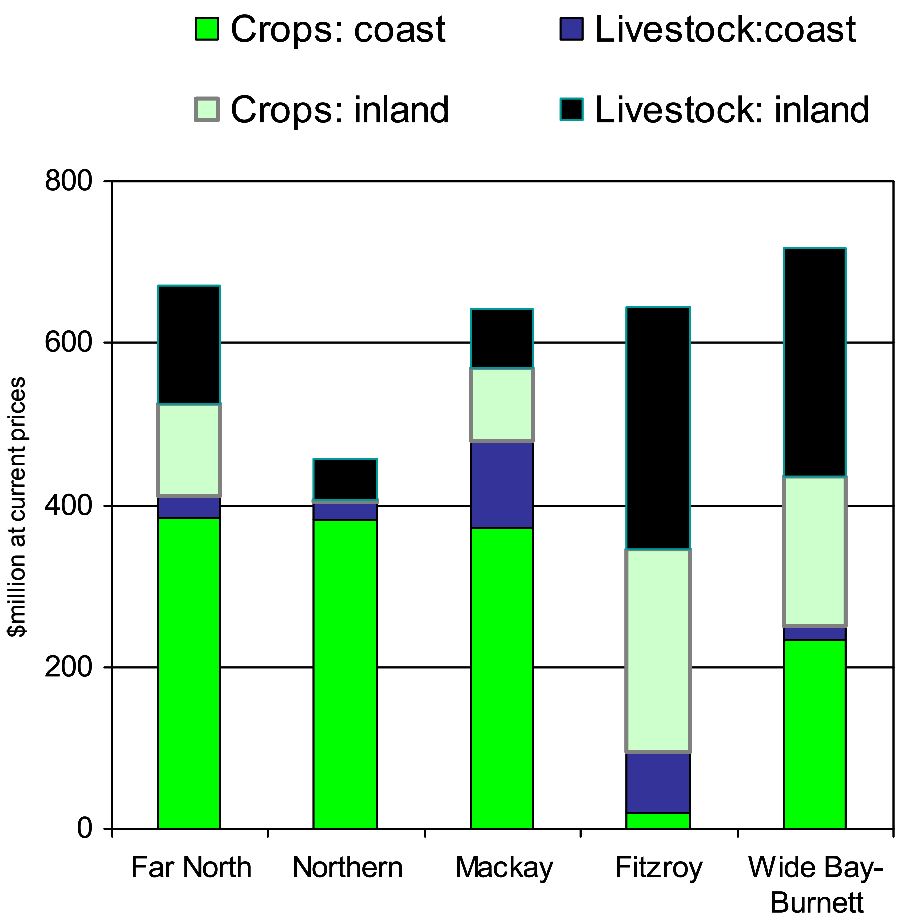
- education: 2.3% pa overall and significant in all regions but declining in magnitude from north to south: 3.2% pa in the Far North, 2.3% pa in Northern, 2.2% pa in Mackay, 2% in Fitzroy and 1.8% in Wide Bay-Burnett;

- property and business services, health and community services, and personal and other services showed average employment growth rates of 1.4% or 1.5% pa., with some regional differences as shown by Table A5.

On the other hand, two industries showed consistent declines:

- According to the statistics, employment in communication services declined by an average 2.5% pa with the highest annual decline of 5.7% in Fitzroy and the smallest decline in the Northern region (-0.7%). This sector also declined in total Queensland, from 24,042 to 23,016 persons (-0.9% pa). This outcome in a supposedly dynamic growth sector caused us to examine the share of communications in the total Queensland Gross State Product, to find that it actually lost share between 1995-96 (3.1%) and 2000-01 (3.0%).

- The finance and insurance sector showed a decline in employment of 2.1% pa along the Great Barrier Reef. The Northern region did relatively best (-1.1% pa), while falls between 2.3% and 2.5% pa occurred in the other four regions. State-wide, employment in this industry increased by 1% pa from 42,336 to 44,562 persons, which suggests that centralisation of these services had an adverse impact on regional employment. The fact that the region containing the largest centre in provincial Queensland showed the smallest decline seems to support this.



Source: OESR 2002b

Figure 30: Gross value of production of agricultural products in 1998-99 totalled between 640 and 700 million dollars in four regions, and $460 million in the Northern Statistical Division. The chart distinguishes between coastal and inland local government areas. Crops dominated by sugar cane are important for all coastal areas except Fitzroy, especially the three northernmost regions (Mirani Shire in the Mackay region might have been added as a coastal area). Livestock production and disposals are most important in the Fitzroy and Wide Bay-Burnett hinterlands, which also benefit from significant inland grain and other crops.

Finally, we note from Table A6 that the patterns in service industry employment do not differ greatly. One reason for this is that these industries mainly serve the local population. Percentages significantly above average provide an indicator that services may be exported beyond the region. So it may be argued that the following features strengthen the economic base of a particular Great Barrier Reef region:

- Government administration and defence in 2001 accounted for 10% of the employed workforce in the Northern region and 8.2% in the Far North, compared with only 3-4% in the other regions.

- Education was more evenly distributed but reached about 8.5% of the employed workforce in the Northern, Fitzroy and Wide Bay-Burnett regions, compared with 7% in the Far North and 6.5% in Mackay. The differences would be largely attributable to the main James Cook University campus in Townsville and Central Queensland University campuses in Rockhampton and Bundaberg, providing net export income in the form of tertiary educational services for the regions in question.

- Accommodation, cafés and restaurants employed 9.5% of the workforce in Far North Queensland and 7.1% in Mackay Statistical Division, which includes the Whitsunday tourism region. The industry employed about 5% of the Northern, Fitzroy and Wide Bay-Burnett workforces in 2001. It is identified in Chapter 8 as a statistical 'marker' of individual tourism areas.

Agricultural production totalled $3.1 billion in 1998-99, roughly equally split between crops ($1.6 billion) and livestock production and disposals ($1.5 billion). The Figure 30 describes how coastal local government areas are dominated by crops, especially sugar cane, while the cattle industry occupies the hinterland.

Regional social indicators

Turning from economic to social statistics, two main indicators were identified: the Index of relative disadvantage and the distribution of the Indigenous population.

Index of relative disadvantage

The Index of relative disadvantage is based on the 1996 Census (ABS 1998b), and goes some way towards describing differences in social health, though it leaves out a number of dimensions that cannot be derived from the Census – conceivably, physical and other indicators could be added for small areas, though this would be beyond the scope of this study. We have calculated a provisional index for 2001 based on crude average measures rather than principal components analysis, which takes correlations between variables into account. The indices are remarkably similar to 1996; the main difference is that the new provisional index also sees Wide Bay-Burnett as the most disadvantaged area, only more so (Figure 31).

Table A8 (Appendix A) shows that Wide Bay-Burnett was relatively disadvantaged in 1996 in terms of aged population (the proportion aged 65+ was 14% compared with an 11.2% average for Queensland), 16-year olds still at school (70.7% compared with 78.4% for Queensland), people with degrees and higher qualifications (4.2% compared with an average of 8.6% for Queensland), labour force participation rate (54.9%, compared with 63.2% for Queensland), an unemployment rate of 15.1% compared with a state average of 9.7%, and weekly per capita income ($222, compared with $293 for Queensland). For all these indicators, Wide Bay-Burnett showed the most unfavourable reading among the five Great Barrier Reef regions, though this may not be quite correct given that the area attracts retired people, who actually add to rather than detract from the regional economic base.

At the other end of the scale, Mackay Statistical Division had the lowest aged population (8% aged 65+), the highest labour force participation rate (67.3%), the lowest regional unemployment rate (7.5%), and the highest income per capita ($332 per week).

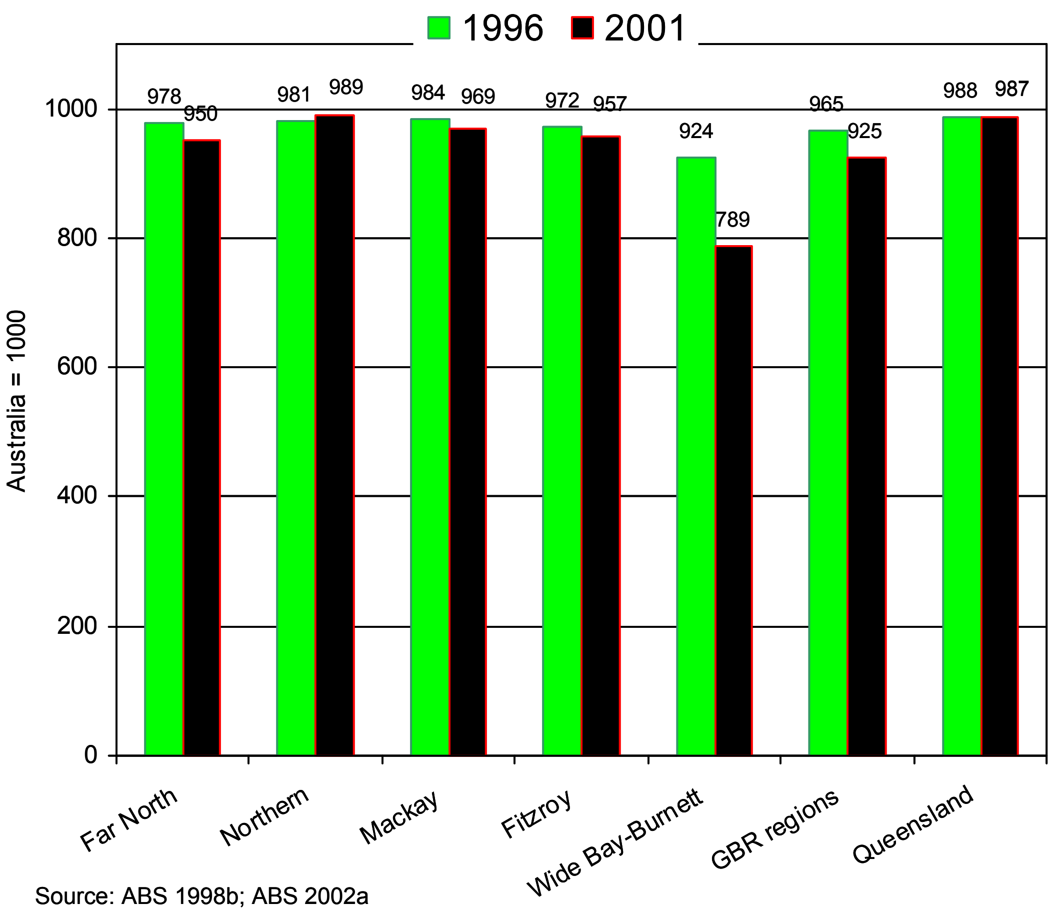
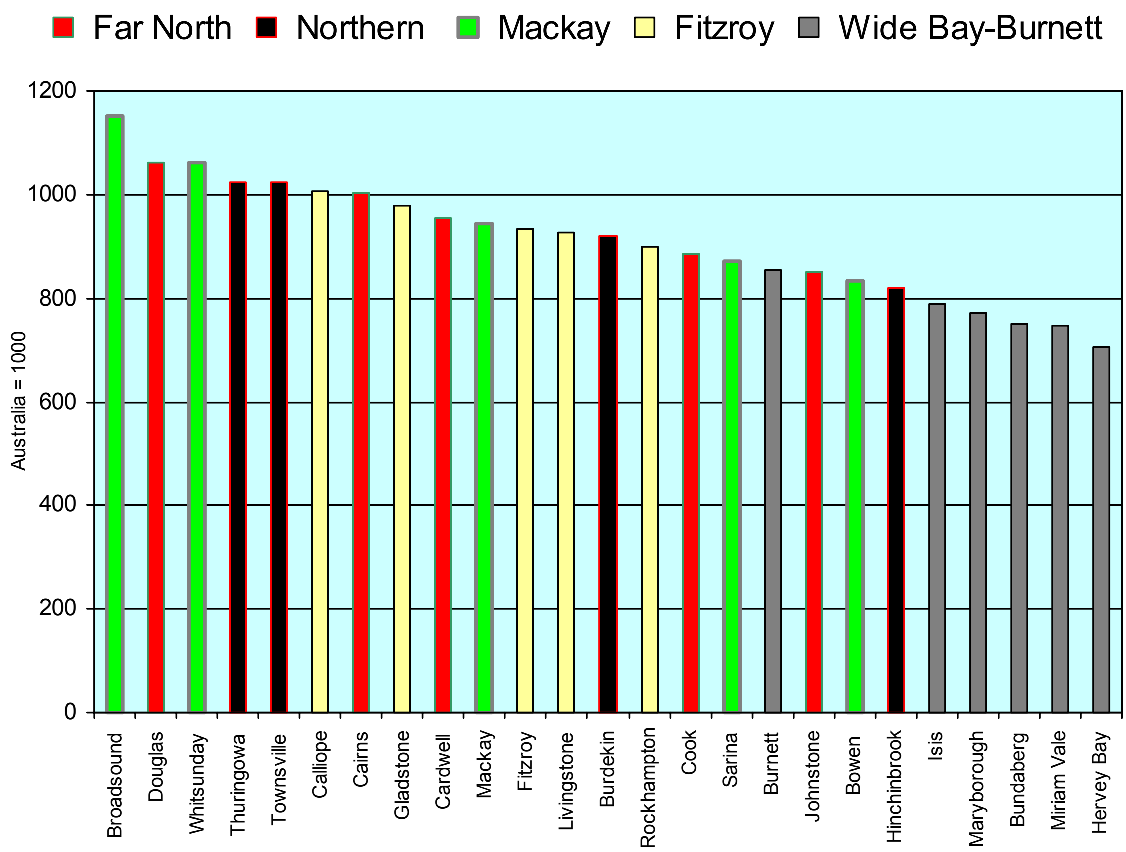


Figure 31: 1996 Index of Relative Disadvantage (based on principal components analysis) and provisional index for 2001 (based on crude averages). Indices are related to the Australian average 1,000). The black bars for 2001 are based on the ratio to the overall Australian average for population 65+, proportion of students completing year 12, did not move last five years, computers at home, Internet access, couples with dependent children or students, one-parent families with dependent children or students, unemployment rate, and labour force participation rate. All ratios were made to point in the same direction by inverting the positive indicators (such as completing year 12, computers at home, Internet access and labour force participation rate).

In 2001, persons aged 65 years and over accounted for 16.2% of the population in Wide Bay-Burnett compared with 10.5% to 11% in the four other Great Barrier Reef regions, and 12.3% in Queensland (Table A9). The labour force participation rate was 52.9% in Wide Bay-Burnett and between 63.7% and 64.6% in the other regions, and 63.1% on average for Queensland (Table A10). The unemployment rate was 11.6% in Wide Bay-Burnett, 7.5% to 8% in the other four regions and 8.2% for Queensland as a whole (Table A10). This suggests that Wide Bay-Burnett has some genuine social disadvantages compared with the other regions.

In conclusion, the social disadvantage of the four northern Great Barrier Reef regions, relative to total Queensland, was probably about the same in 1996 and 2001, given the provisional nature of the 2001 index. Wide Bay-Burnett seems to be genuinely more disadvantaged in both 1996 and 2001, though the latter year may give an exaggerated impression of further disadvantage since we were unable to conduct a full principal components analysis of 2001 Census data within the scope of the study.



Source: ABS 2002a

Figure 32: Provisional index of relative disadvantage 2001 for coastal local government areas along the Great Barrier Reef. Each region has its own co lour code. High index values are found for the tourism areas of Douglas and Whitsunday Shires, and for some major urban areas: Townsville/Thuringowa, Cairns, and what might be termed Greater Gladstone (Gladstone City and Calliope Shire). There are wide variations in the provisional index among areas within a given region (even if we ignore inland areas as here). The concentration of all local areas of Wide Bay-Burnett with the major urban centres at the bottom is, however, remarkable. See text for comments on Broadsound Shire and comparisons with 1996.

The provisional index for 2001 shows two major tourism areas (Douglas and Whitsunday Shires) and some major urban areas (Townsville, Cairns, Gladstone followed by Mackay) to be socially most advantageously positioned among local government areas along the Great Barrier Reef coast (Figure 32). The pattern is similar to the details published for 1996 (ABS 1998b), though the index for that year shows less variation due to the more sophisticated data treatment. The highest index values in 1996 were for Douglas and Whitsunday Shires (both 1,014), while Cairns led the cities with 1,012 (the urban 'Part A' only), followed by Townsville Part A with 998, Thuringowa Part A (996), Gladstone City and Calliope Shire Part A (984), Mackay Part A (980), Rockhampton and Fitzroy Shire Part A (967), Maryborough (938), Bundaberg (932) and Hervey Bay (917). Following these findings for 1996, there were no real surprises in the findings for 2001 on this score.

Intra-regional patterns were also similar. Among areas not mentioned above, Cardwell (967) led Johnstone (959) with Cook trailing (a score of 855 excluding Weipa) in the Far North, and Burdekin (982) doing better than Hinchinbrook (933) in the Northern Statistical Division. Broadsound (999) led Sarina (942) and Bowen (905) in what is now the Mackay Statistical Division. The high 2001 index value for Broadsound was due mainly to a small proportion of older people, a very low proportion of single people with dependents, a very low unemployment rate and a high labour force participation rate (Tables A9 and A10).

In the Fitzroy Statistical Division, the 1996 indices for Livingstone Shire and Fitzroy Shire (non-urban Part B) were similar: 979 and 975, respectively, and both slightly ahead of urban Rockhampton (967), as in 2001. In Wide Bay-Burnett, non-urban Burnett Shire at 905 trailed Isis Shire's 914 (as distinct from the provisional finding for 2001), but both topped Miriam Vale (878) as in 2001, and in both years the index was low for all these areas compared with other Great Barrier Reef coastal areas.

The pattern of social disadvantage therefore appears to be reasonably consistent along the Great Barrier Reef coast, suggesting that some tourism-dependent locations have relatively much to lose in a worst-case scenario for the Reef, while others are already in a relatively weak position. The latter include Wide Bay-Burnett, though it would not be as dependent on reef-based tourism as areas further north. Among the tourism-dependent locations, those relying most on international visitors are identified in Table A9 as Douglas Shire (21.9% overseas visitors on Census night), Whitsunday Shire (12.7%), Cairns (8.4%) and Cardwell Shire (7.1%). The next highest ratio was in Cook Shire (3%). The only other examples of above-average overseas visitation were Hervey Bay (2.5%), Johnstone Shire (2.2%), Townsville (2.2%) and Miriam Vale (2.1%) – the Queensland average was 1.9%.

Another set of social indicators

Mark Fenton's and Nadine Marshall's analysis of commercial fishers in Queensland (Fenton and Marshall 2001a) is notable for its socioeconomic analysis. Based on a survey that the authors estimate represents 41% of the commercial fishing industry, it created a considerable number of social indicators. The analysis was based on 23 'town resource clusters' (TRCs), 16 of which are located along the Great Barrier Reef coast from Cooktown in the Far North to Maryborough in Wide Bay-Burnett.

Table 11 contains selected indicators from the Fenton and Marshall analysis. The first column of gross value of production (GVP) indicates relative size of TRCs: Cairns was the largest followed by Bundaberg, Townsville, Gladstone and Mackay.

According to ABARE (PC 2003), the estimates are incompatible with Queensland Fisheries Service statistics and exaggerate the true levels. However, other fisheries industries estimates are more in accordance with Fenton and Marshall, including a table on the web site of the Queensland Seafood Industry Association based on a 1988 paper by C J Bishop of the Griffith University Institute of Applied Environmental Research (http://www.qsia.com.au/stats/econ.htm). While obviously dated, it shows total value to fishers in the Great Barrier Reef regions of $209.5 million in 1988, compared with $270.2 million in total Queensland (78%). Total employment in the five regions along the Reef was 4,238, compared with 6,262 in the State (68%, with some out-of-State employment included in the grand total though the main difference is due to relatively high labour productivity for Brisbane-based fishers).

Fenton and Marshall found a similar but slightly lower pair of ratios: 73% for Great Barrier Reef regions of total State GVP, and 62% for employment (see footnote to Table 11). The higher proportions in the QSIA table are biased upwards by the inclusion of the Northwest with Far North Queensland – the Karumba, Weipa and Thursday Island town resource clusters are excluded in Table 11.

Table 11: Selected socioeconomic indicators for commercial fishers, 2000

TRC[1] and Statistical Division[2]	Total commercial fishers		Owner-operators			Commercial fishing businesses		
	GVP ($000)	Number of employees	Years in home town	Own house	Completed Year 12	Mean years owned	Gross value production	Personnel per business
Cooktown	1,502	42	17.2	33.3%	33.3%	7.6	100	2.8
Port Douglas	4,729	26	21.5	25.0%	8.3%	12.4	139	1.8
Cairns	53,195	787	21.7	42.9%	7.1%	13.4	277	4.1
Innisfail	12,611	40	21.3	53.7%	11.1%	15.6	94	3.0
Far North	**72,037**	**895**	**21.5**	**43.4%**	**8.4%**	**13.6**	**192**	**3.4**
Lucinda	3,427	68	25.8	50.0%	23.5%	16.0	95	1.9
Townsville	35,487	428	22.4	40.4%	21.8%	12.5	232	2.8
Ayr	798	27	28.3	57.1%	14.3%	12.2	50	1.7
Northern	**39,712**	**523**	**22.8**	**37.2%**	**19.8%**	**12.8**	**194**	**2.6**
Bowen	10,563	217	24.3	40.4%	15.4%	10.7	151	3.1
Airlie Beach	333	35	23.3	62.5%	50.0%	18.2	24	2.5
Mackay	28,220	464	26.0	53.1%	2.0%	13.5	237	3.9
Mackay	**39,116**	**716**	**25.5**	**49.8%**	**6.0%**	**12.8**	**193**	**3.5**
Yeppoon	7,183	214	25.8	53.7%	10.0%	18.0	70	2.1
Gladstone	28,436	354	17.3	44.0%	16.0%	10.9	218	2.7
Fitzroy	**35,619**	**568**	**19.0**	**46.0%**	**14.8%**	**12.3**	**153**	**2.4**
Bundaberg	37,065	829	21.8	48.7%	14.3%	12.4	121	2.7
Hervey Bay	19,874	377	19.3	37.2%	19.3%	14.6	179	3.4
Maryborough	1,815	61	25.8	52.9%	11.8%	18.0	50	1.7
Wide Bay-Burnett	**58,754**	**1,267**	**21.1**	**44.9%**	**15.9%**	**13.3**	**129**	**2.8**
Total GBR[3]	**245,238**	**3,969**	**21.9**	**44.2%**	**12.6%**	**13.1**	**172**	**3.0**

[1] Town resource centre defined in source

[2] Averages derived using total gross value of production (GVP) as weights

[3] GBR proportion of total Queensland commercial fisheries GVP: 73%, total employment: 62%.

Source: Fenton and Marshall (2002a), Table A, p iv.

The distribution of total Gross Value of Production among statistical regions in Fenton and Marshall (2001a) is likely to be largely valid, given that the methodology was the same for all regions and any design bias presumably uniform. With the exception of Wide Bay-Burnett, where the ABARE estimate is implausibly low, the patterns show some similarities between the two sources. The two first columns of Table 11 show Fenton and Marshall's regional estimates of GVP and employment, respectively: the Far North leads with a GVP of $72 million followed by $59 million for Wide Bay-Burnett and between $35 million and $40 million for the three other regions. The employment pattern was different with Wide Bay-Burnett (mainly Bundaberg) employing over 1,200 persons, the Far North about 900, Mackay 700, Fitzroy about 570 and the Northern region 520. Table 11 makes it possible to calculate average GVP per business, which falls the further south one travels along the Great Barrier Reef: Far North $277,500, Northern and Mackay both around $193,000, Fitzroy $153,000 and Wide Bay-Burnett $129,000.

ABARE estimates of regional commercial fisheries, 1999-00

Statistical Division	GVP ($m)	Employees	GVP/business
Far North	55	232	$ 711,000
Northern	19	84	$ 679,000
Mackay	21	48	$ 1,313,000
Fitzroy	18	82	$ 659,000
Wide Bay-Burnett	7	195	$ 108,000
Total GBR regions	**120**	**641**	**$ 562,000**

Average business assumed to have three employees including own

Source: PC 2003:267-277

The left-hand box shows that no such consistency exists in the ABARE estimates. The average GVP per business ($562,000) exceeds Fenton and Marshall's Great Barrier Reef average of $186,000 by a factor of three, assuming an average employment of three persons as in Fenton and Marshall (2001a). The regional pattern of averages looks odd, in particular Mackay's $1.3 million compared with $108,000 in Wide Bay-Burnett. The prime problem is, however, that the average gross value of production is three times higher in the ABARE estimations than in the Fenton and Marshall survey. While GVP is only half as high according to ABARE, GVP per business is a mere 16%. This difference cannot be explained away as memory bias in the Fenton and Marshall study. It is noted that the Fenton and Marshall use full-time peak seasonal employment as their main indicator but also quote an off-peak season figure that is about 13% lower – however, this only explains a small part of the discrepancy.

Three of the selected indicators in Table 11 concern the status of the owner-operator: the length of time he (between 98% and 99% are male) has been resident in his home town, whether he owns his house and his level of secondary education (completed year 12). Three other indicators relate to the business: years in operation, mean GVP, and average number of personnel per business (including owners). These are just a sample of the indicators developed by Fenton and Marshall; while relating to a fairly small industry, the analysis assumes additional importance because fisheries may be under threat due to climate change, and because they provide quality products which are in considerable demand from a spectrum of Australian and international markets.

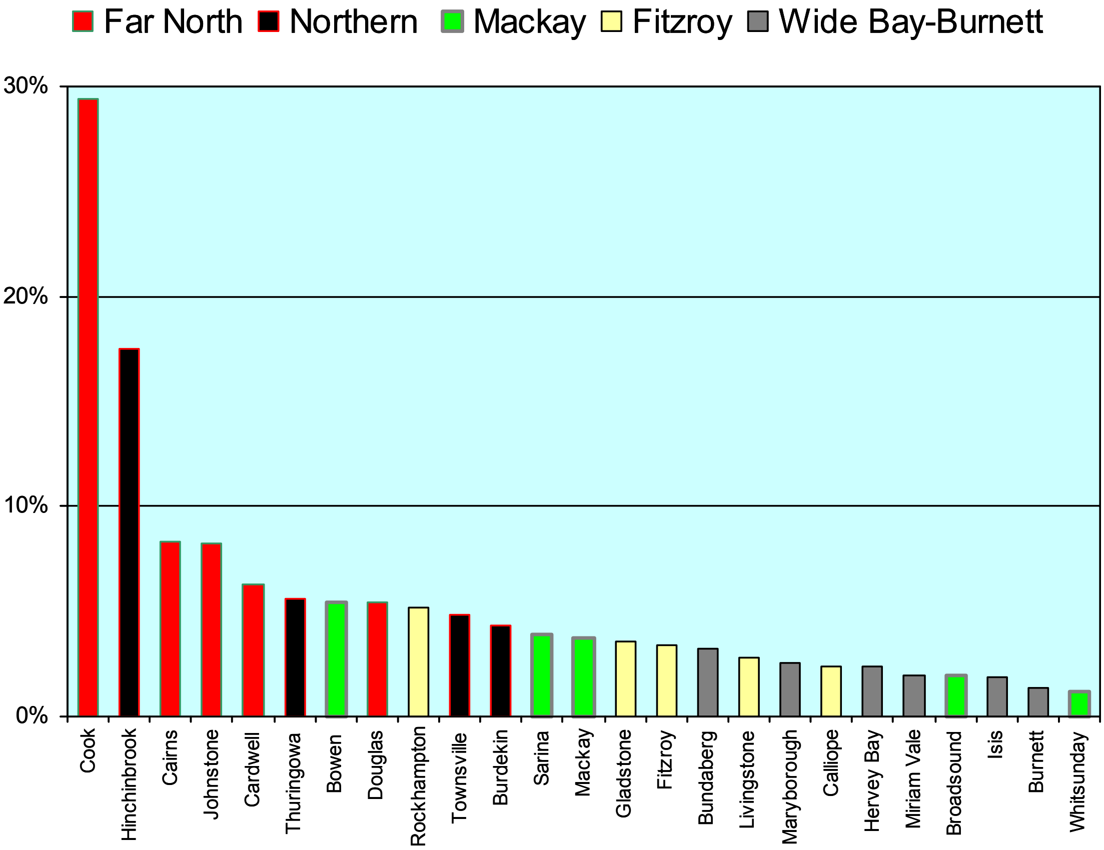
Table 11 tells a story about an industry of small businesses, with the largest concentration at either end of the Great Barrier Reef (Cairns and Bundaberg). Operators are long-term residents of their home towns who have been in the business for an average of about 13 years. They are moderately well educated (other statistics show that most left school after Year 10), and many own their own house.

Other indicators are shown in Chapter 9, which contains an analysis of fisheries in waters adjoining the regions along the Great Barrier Reef, from the compact disc database of the Fenton and Marshall research (Fenton, Marshall and Edgar 2002).

Indigenous people

Figure 33 shows the proportion of Indigenous people in each coastal local government area along the Great Barrier Reef, coded by region.

Far North Queensland had the highest proportion of Indigenous people (11.8%) and the highest proportion of Torres Strait Islanders of any Australian region; 40% of the



Source: ABS 2002a

Figure 33: Proportion of Aboriginal and Torres Strait persons in coastal local government areas along the Great Barrier Reef, 2001 Census. Each region has its own colour code, as in the previous chart. The Indigenous proportion is highest in Far North Queensland (11.8%, and reaching 22.2% in the remainder of the Statistical Division not shown above). The Indigenous proportion was 6.1% in the Northern region, where Hinchinbrook Shire including Palm Island showed the highest ratio. Other regions were closer to the Queensland average of 3.1%: 3.3% in Mackay, 4.3% in Fitzroy and 3% in Wide Bay-Burnett. The average Indigenous component for the five Great Barrier Reef regions was 6%.

total number of Indigenous people in Cairns are Islanders.

Aboriginal and Torres Strait Islander people accounted for 6.1% of the total population in the Northern Division, 3.3% in the Mackay Statistical Division (with the second-highest proportion of Islanders among the five regions), 4.3% in Fitzroy and 3% in Wide Bay-Burnett.

Growth in Indigenous population

Region	1996	2001	Per annum
Far North	25,752	28,909	2.3%
Northern	9,803	11,598	3.4%
Mackay	4,323	4,696	1.7%
Fitzroy	7,090	7,836	2.0%
Wide Bay-Burnett	5,590	7,066	4.8%
Total Great Barrier Reef	52,558	60,105	2.7%

Source: ABS 2000 and 2002a

Between 1996 and 2001 the Aboriginal and Torres Strait Islander share of total population increased in all regions, except the Far North where it declined from 13.2% in 1996 to 11.8% in 2001. The growth in the number of Indigenous people varied from 4.8% pa in Wide Bay-Burnett and 3.4% in the Northern region, to 1.7% in Mackay, 2% in Fitzroy and 2.3% in the Far North. The average annual growth in all Great Barrier Reef regions was 2.7%, as shown in the right-hand box.

The regional environment

Overview

The explicit inclusion of the regional environment completes the perspective needed for the scenario building in Part 3.

Two recent workshops provide an overview focusing on the environmental health of the Great Barrier Reef itself before describing the range of actual and potential external threats.

Conservation of coral reef ecosystems	**Priority:**	**1**

Actions to cope with climate change: The only avenue to solve this issue is to reduce the rate of climate change immediately. This will involve an estimated reduction in greenhouse emission to 20% of today's figure over 20 years. This will lead to a maximum (then decrease) +1.5^{o}C above present sea temperatures. This would allow reefs some chance of recovery from the damaged condition that a +1.5^{o}C excursion would lead to.

Barriers to adaptation: The barriers to changing CO_2 levels are:

- general lack of incentive for public
- lack of political leadership and knowledge
- commitment to wrong long term strategy
- lack of strategic thinking at all levels.

Synergies to adaptation: Reducing CO_2 and replacing it with other sources of renewable energy will lead to new industries within Queensland – if we get in soon enough, a stimulated economy will eventuate. Get in too late and the reverse holds.

Knowledge gaps: Careful economic study of such industries as "biofuels", "solar", geothermal and hydrogen cells. These need immediate attention. Need to increase understanding of short term management strategies for coral reefs, which will help reefs survive the very stressful next few decades. Need to know to more about what else is removed when corals are moved out of the ecosystem. Need much more knowledge about impacts of climate change on other marine organisms – indirect impacts of loss of corals, direct impacts on other biota.

Source: Workshop organised by Australian Greenhouse Office, August 2002. Excerpt from workshop session 3.

Table 12: In August 2002, the Australian Greenhouse Office organised a series of workshops in Cairns to identify environmental issues along the Great Barrier Reef. Participants were drawn from local industries and communities as well as from scientists and administrators. The table shows an excerpt relating directly to the Reef developed during workshop session 3. Workshop findings on associated ecosystems (seagrass beds, mangrove, estuary, pelagic and seafloor) and other matters are mentioned in the text. The workshop also dealt with land-based ecosystem and tourism issues, and with agriculture and human health.

Table 12 presents the main consensus statement from the first of these workshops, conducted in Cairns in August 2002. It was part of a series of workshops organised by the Australian Greenhouse Office with participation by a broad range of industry and community representatives, administrators and scientists. The primary focus was on climate change. The strong consensus of this diverse group was that there is an urgent need to reduce greenhouse gas emissions now to help the reefs to survive the very stressful conditions expected over the next few decades, and that the main barriers to adaptation are lack of public incentive and political priorities which allegedly ignore the need for long-term strategic thinking. The formulation is taken verbatim from the notes prepared by the Australian Greenhouse Office.

The workshops also considered the conservation of other ecosystems which interact with the coral reefs in the Great Barrier Reef Marine Park. The following points are part of the participants' other consensus statements:

- It is not well understood how *seagrass bed* ecosystems function, but we need to focus on protection including removal of threats from deteriorating water quality.
- The same applies to *mangrove and estuary* ecosystems. Little is known about how these are likely to react to climate change.
- There is a need to reduce pressures on *pelagic and seafloor* ecosystems from trawling and line fishing, and to modify equipment to reduce impacts.
- Associated with all ecosystems in the Marine Park, *iconic species conservation* is a key issue. These species are mainly *charismatic megafauna* – dolphins, whales, dugongs, and green, loggerhead and flatback turtles – which add greatly to the attractiveness of the Great Barrier Reef as a tourism destination. See further below under the heading of fisheries and the Representative Areas Program.

In October 2002, a group of leading Australian and international scientists met in Townsville on the invitation of Professor Terry Hughes to consider coral reef research and management. The resulting 'Townsville Declaration' (Hughes et al. 2002, Pockley 2003) is the strongest and most authoritative statement yet on the fragility and risky future of the Great Barrier Reef World Heritage Area ecosystems under climate change and the urgent need to maximise their resilience by curbing pollution and overfishing. It is reproduced in full in Figure 34. The contributing scientists (identified by number under the various items of the Declaration) were:

1 Dr. David Bellwood (Fish Ecologist), Director Centre for Coral Reef Biodiversity, James Cook University, Australia
2 Dr. Margaret Card (Environmental Manager). Environmental Protection Agency, Townsville, Australia
3 Dr. Sean R. Connolly (Ecological Modeller & Marine Ecologist), James Cook University, Australia
4 Dr. Patty Debenham (Marine Science Communicator), SeaWeb, California, USA.
5 Prof. Carl Folke (Ecological Economist), Swedish Academy of Sciences/Stockholm University, Sweden
6 Prof. Rick Grosberg (Evolutionary Ecologist), University of California, Davis, USA.
7 Prof. Ove Hoegh-Guldberg (Coral Physiologist/Ecologist), University of Queensland, Australia
8 Prof. Terry Hughes (Coral Ecologist), James Cook University, Australia
9 Prof. Jeremy Jackson (Ecologist and Geologist), Scripps Institution of Oceanography, USA.
10 Dr. Joanie Kleypas (Geologist/Ocean Chemist), National Center for Atmospheric Research, USA.
11 Dr. Janice M. Lough (Climatologist), Australian Institute of Marine Science, Australia
12 Dr. Paul Marshall (Marine Park Manager), Great Barrier Reef Marine Park Authority, Australia
13 Dr. Magnus Nyström (Ecosystems Ecologist), Stockholm University, Sweden
14 Dr. John Pandolfi (Coral Reef Paleontologist), Smithsonian Institution, USA.
15 Dr. Peter Pockley (Science Writer & Broadcaster), NSW, Australia
16 Dr. Brian Rosen (Coral Paleontologist/Biogeographer), The Natural History Museum, UK.
17 Prof. Joan Roughgarden (Ecological Theoretician and Marine Biologist), Stanford University, USA.

Figure 34: The Townsville Declaration on Coral Reef Research and Management

Overfishing and pollution have driven massive and accelerating decreases in abundance of coral reef species and have caused global changes in reef ecosystems over the last two centuries. If these trends continue, coral reefs will decline further, resulting in the loss of biodiversity and economic value (8, 9, 14).

Outbreaks of coral bleaching have greatly increased in frequency and magnitude over the past 30 years, and are tightly linked to increases in temperature. A similar increase has occurred in coral disease (7, 8, 9).

Projected increases in carbon dioxide and temperature over the next 50 years exceed the conditions under which coral reefs have flourished over the past half million years (10, 11, 14, 16).

The accelerating rate of environmental change diminishes the evolutionary capacity of many coral species to adapt (6, 8).

Global warming is not an all-or-none scenario for coral reefs. Reefs will change rather than disappear entirely. The challenge is to work out how, why, and what the consequences will be in relation to the other problems faced by coral reefs (1, 3, 6, 7, 8, 16).

Current management strategies need to be vigorously implemented and complemented by strong policy decisions to reduce the rate of global warming. International and national integration of reef management strategies is an urgent priority (2, 5, 13).

Marine protected areas are currently the best management tool for preserving coral reefs, especially for extractive activities such as fishing. To be effective, 30 – 50% of the available reef area should be no-take (no fishing) for long-term protection of coral reefs and their services (2, 3, 9, 17).

No-take reserves are a powerful tool, but they can only work if combined with effective management of surrounding areas. This requires a strong focus on supporting reef resilience, which involves reducing pollution, protecting food webs and managing key functional groups (such as herbivores) as insurance for sustainability (1, 2, 3, 5, 6, 9, 12, 13).

Coral reefs are the global canaries, as they are already showing rapid responses to climate change at the global scale. Scientists, managers and policy makers can use reefs to examine the effectiveness of international attempts to understand and respond to the impact of global warming (1, 7, 11).

The maintenance of reef structures requires that rates of reef growth balance rates of erosion. Future changes in ocean chemistry due to higher carbon dioxide may cause dissolution or weakening of the limestone that makes reefs (1, 3, 10, 14,16).

Coral reefs support social and economic development and therefore need to be sustained. To achieve this goal there is a clear need to reduce the rate of global warming (5, 17).

18 October 2002

The major external environmental threat to the Great Barrier Reef is water quality, which has been the subject of major investigation as reported below under a general heading followed by regional detail. Other issues discussed in turn in the sections following relate to current use of the Marine Park (fishing and tourism), and potential threats (exploration and mining, and shipping accidents).

Water quality – general

The most important recent development is the Federal and Queensland Governments' Reef Water Quality Protection Plan released on 5th December 2003 which aims to stabilise and reverse the decline in water quality entering the World Heritage Area within 10 years.

Two recent major inquiries relate to coastal management. The Productivity Commission's report on regional industries and measures to address declining water quality (PC 2003) noted that water quality in rivers entering the Great Barrier Reef lagoon has declined because of diffuse pollutants, especially sediments, nutrients and chemicals from cropping and grazing lands in relatively small areas of the adjacent catchments – around 80% of sediments exported to the lagoon is generated within less than 30% of the catchment area. This pollution threatens inshore reefs and associated ecosystems. The most significant pollutants are soil erosion on grazing properties, and the overuse or misuse of fertilisers and chemicals by cropping industries.

The brief of the Productivity Commission's inquiry was to concentrate on terrestrial runoff, and it explicitly states (PC 2003:151) that other threats to reefs and associated ecosystems are beyond the scope of its study. 'Other pressures include marine accidents and oil spills, overfishing, outbreaks of crown-of-thorns starfish (which feed on coral), global atmospheric changes (which can influence water temperatures, sea levels, and climatic patterns such as the frequency and size of cyclones), and **coral bleaching**.' These other factors clearly aggravate the findings of the Commission's report and must be considered by policy makers when formulating abatement options.

The second study was for the Intergovernmental Steering Committee of the Great Barrier Reef Water Quality Action Plan, by a panel of nine scientists (Baker 2003). It is a detailed review of massive evidence of land-sourced pollution from fertilisers, pesticides and sediment runoff, and its impact on water quality.

As the present study was nearing completion an article appeared in the authoritative British journal *Nature* (McCullogh et al. 2003) presenting new evidence of the long-term impact on coral health of sediment fluxes from the Burdekin River. The research was timely enough to form an input into the Baker report mentioned in the previous paragraph. The group of coral organisms known as *Porites* can live for 300-400 years, which make them ideal objects for the study of environmental change. The authors applied a mass spectrometry technique specifically adapted for coral studies, using barium as a tracer.

Barium is released from fine-grained suspended particles (clays) when sediments enter a low-salinity estuarine zone, such as the Burdekin River delta. It is carried by flood plumes into the lagoon and is absorbed into coral skeletons in proportion to the ambient seawater concentration. The authors analysed the ratio of barium to calcium (Ba/Ca) in a 5.3 metre coral core from the Havannah Reef near Palm Island, which provided a record from about 1750 to 1985. Shorter cores from Havannah and the nearby Pandora Reef extended the record to 1998.

The key finding was a striking difference in Ba/Ca ratios before and after European settlement of the Burdekin area in 1862, attributable largely to the introduction of hoofed animals. Floods carry the greatest suspended sediment loads from loss of groundcover, because the greatest damage from erosion occurs during periods of drought. Prominent examples are the runoff events of 1927, 1936, 1968, 1970 and 1988, which were all preceded by droughts. The authors conclude (p 270):

> *Fine-grained suspended sediments are likely to have the most deleterious effects on coral reefs. These sediments can be readily transported and dispersed throughout the inner to mid-shelf regions of the GBR, and are more chemically reactive, being the major source of terrestrial P and other important nutrient elements. Reducing sediment fluxes to coral reefs must be a high priority if corals are to survive the damaging combination of direct anthropogenic impact and rapid climate change.*

The most recent national environment report (Thom 2001) finds, among many other factors, that pressures on Australia's coral reefs continue unabated from downstream effects of land use and other human activities.

The Great Barrier Reef Marine Park Authority (GBRMPA 2001, GBRMPA 2002) states that decades of scientific research and evaluation unequivocally establish that land use activities in catchments adjacent to the Marine Park are contributing directly to a decline in water quality. Its water quality action plan (GBRMPA 2001) shows increases in pollutants of 300-900% for sediment loads, 300-1,500% for phosphorus, and 200-400% for nitrogen since about 1850, while pesticides are now detectable in coastal sediments. 'Even more worrying is the fact that almost all pollutant loads are increasing annually and showing no signs of abatement.' (GBRMPA 2001:i).

Water quality issues – regional patterns

The Great Barrier Reef Catchment Water Quality Action Plan (GBRMPA 2001) identified reefs at risk from catchment-based threats and identifies catchments in terms of their potential risk to the world heritage values of the Reef. The Reef Water Quality Protection Plan (the State of Queensland and Commonwealth of Australia, 2003) updates this earlier risk assessment. To appreciate this specifically in relation to coral bleaching, it must be borne in mind that the Great Barrier Reef is generally physically much closer to the coast, and therefore to the pollutants, in the north than in the south. The coral will also be under more stress from temperature increases near the coast. Deterioration of southern reefs (Fitzroy region) could be delayed up to two decades compared to northern reefs.

This general geographical rule is not without exception, the most important relating to the Whitsundays. The following is part of a consensus statement by a group of scientists quoted in the Productivity Commission's report (PC 2003:254):

Areas at risk are near-shore reefs and seagrass beds south of Port Douglas and within 20 km of the coast. The areas of most concern are those between Port Douglas and Hinchinbrook as well as Bowen to Mackay. A major proportion of the GBRWHA (including the outer reef) is not likely to be threatened by terrestrial runoff.

The areas nominated as being most at risk from terrestrial runoff thus include the greatest tourism areas around Cairns and Port Douglas and in the Whitsundays.

The Far North region includes the Johnstone River basin which is identified in the Reef Water Quality Protection Plan as a high biophysical risk to the Great Barrier

Reef. Two other river basins, the Mulgrave-Russell and the Tully, are identified in the Plan as a medium-high risk.

In the Johnstone River catchment, GBRMPA 2001 identified the following issues as of concern:

- agricultural land is prone to erosion due to high intensity of cropping, long duration rainfall, and steep slopes;
- high contributions of nutrients (particularly nitrates) and pesticides from cropping lands; and
- loss of about 65% of coastal wetlands.

In the *Northern Statistical Division*, the Burdekin River basin is identified as a high biophysical risk to the Great Barrier Reef and the Herbert River basin is identified as a medium-high risk.

The Burdekin River catchment area is dominated by beef cattle grazing, however, the floodplains are dominated by intensive fertilised cropping, particular sugar cane. GBRMPA 2001 identified the following areas of concern:

- approximately 73% of the catchment has been cleared, mostly for grazing; erosion is widespread;
- between 70% and 80% of coastal wetlands have been lost; and
- high contributions of sediment and phosphorus, particularly after intensive rains break long-dry periods.

The *Mackay Statistical Division* extends from Bowen to Broadsound Shires and includes the Whitsunday Islands and associated tourism region. The Plane Creek basin is identified as a high biophysical risk to the Great Barrier Reef. Three other catchments are identified in the Reef Water Quality Protection Plan as medium-high risk: the Proserpine, O'Connell and Pioneer River basins. All four catchments discharge high to very high quantities of nutrients (particularly nitrates) and pesticides into the Great Barrier Reef lagoon, primarily from cropping lands (sugar cane). Loss of vegetation, modifications to floodplains, erosion and proximity to inshore reefs and seagrass beds (dugong habitats) make these catchments of high priority for protection and restoration actions.

The *Fitzroy Statistical Division* contains the Fitzroy River basin, the largest along the Great Barrier Reef. It is identified as a high biophysical risk to the Great Barrier Reef. The catchment is dominated by grazing lands. The Fitzroy River system contains multiple dams and weirs, and cotton and horticultural expansion may occur with the approval of a proposed new mega-dam on the Dawson River.

Finally, the *Wide Bay-Burnett Statistical Division* includes the Burnett River catchment, which the Reef Water Quality Protection Plan identifies as medium-high risk. The dominant land use is grazing and these lands have been extensively cleared. The floodplains have been modified by intensive fertilised cropping, predominantly sugar cane. Soil salinity is a serious emerging problem associated with saltwater intrusion due to overuse of ground water for irrigation.

The above assessments concern themselves mainly with the impact of pollution by rural industries due to runoff into the Great Barrier Reef lagoon. They do not explicitly mention the direct impact of climate change on the industries themselves. It is likely, however, that increasing incidence of drought and other effects of climate change will have a negative impact on the resilience of these industries, which will limit their ability to deal with pollution problems. The list of issues associated with particular catchments suggests that this loss of resilience is reef-wide and could affect all major rural industries: sugar cane, fruit and vegetables, and grazing.

The following sections briefly describe environmental issues associated with fisheries and tourism, and the potential threats from a possible policy change allowing exploration and mining in and near the Marine Park, and the movement of ships between Reef and coast. For mining, the regional implications would depend on the actual sites (with Fitzroy currently most at risk because of an existing project), while the areas at greatest risk of a shipping disaster are in the north where the Reef is relatively close to the mainland.

The Representative Areas Program and fisheries

As described on GBRMPA's web site, the World Heritage Area contains, among other unique features, six of the world's seven species of marine turtle, the largest green turtle breeding area in the world, one of the world's most important dugong populations, and a breeding area for humpback and other whale species. Its diverse systems include over 3000 km^2 of seagrass meadows, 2000 km^2 of mangroves including 54% of the world's mangrove diversity, 2904 coral reefs built from 359 species of hard coral, 2200 species of native plants which is 25% of Queensland's total native plant species, more than 1,500 species of fish, 1,500 species of sponges equalling 30% of Australia's diversity in sponges, 800 species of echinoderms (e.g. sea stars) which is 13% of the world's total species, over 5,000 species of molluscs and over one third of all the world's soft coral and sea pen species (80 species). It also features spectacular landscapes such as the Whitsundays and Hinchinbrook Island.

In fact, the discussion in Part 1 of the current state of knowledge of the biodiversity of the Marine Park suggests that each statement on species numbers in the previous paragraph should read 'identified species'. The Representative Areas Program was initiated to protect all this (GBRMPA 2002c).

The background for the Program was that as various protection measures for different habitats were adopted within the World Heritage Area, there was a growing understanding that marine park managers should identify and protect representative examples of the diversity of habitats and processes upon which all species depend, rather than focus on individual species or specific habitats. A representative area is an area that is typical of the surrounding habitats or ecosystem at a chosen scale. The physical features, oceanographic processes and ecological patterns within a representative area reflect those of the surrounding habitat.

Only 4.6% of the Marine Park is highly protected ('green zones') at the time of writing. The final zoning plan that was tabled by the Australian Minister for Environment and Heritage the Hon Dr David Kemp on 3rd December 2003 includes a comprehensive and representative network of no-take zones throughout all 70 bioregions that comprise the Marine Park.

The importance of the Representative Areas Program increases even further when we take the climate-induced threat to the coral into account. As already mentioned, the long-term health of the Reef can only be achieved through the reduction of greenhouse gas emissions. As demonstrated in Part 1 it will take many years to reverse the upward trend in temperatures, and it is essential over the next 25 years or so to manage the Great Barrier Reef to secure maximum resilience as an insurance policy against virtually complete destruction.

As Part 1 also shows, there is now overwhelming evidence that reducing fisheries pressure on fish that perform important functions (such as grazing and predation) will have positive effects on the ability of reefs to recover from future shocks from climate change. The final zoning plan tabled in Parliament protects 33% of the Marine Park in "no-take" zones. This goes a long way to providing the protection and hence increased reef resilience required for the Reef to have a chance of surviving climate change.

Marine reserves or no-take zones actually enhance adjacent fisheries. One study (Roberts et al. 2001) confirms theoretical predictions that marine reserves can play a key role in supporting fisheries. Within five years of creating five small reserves in the Caribbean (St Lucia), catches were 46% to 90% higher than before, the increase depending on type of fishing gear. Reserve zones in the Merrill Island National Wildlife Refuge in Florida have supplied increasing numbers of record-sized fish to recreational fisheries since the 1970s. Translated to the grander scale of the Great Barrier Reef Representative Areas Program and assuming for the moment that other factors remain equal, the inference is that the total catch is unlikely to be reduced in proportion to the reduction of legal fishing areas.

While overfishing is or should be controlled mainly by statutory fisheries management plans under the Queensland Fisheries Act 1994, physical habitat destruction by the prevalent trawling activities in the area requires other remedies. These include the research, development and introduction of improved methods to reduce and eventually eliminate damage to the sea bed and large volumes of bycatch.

The regional impact of fisheries restrictions is widespread, mainly associated with the home port of fishers. The research by Fenton and Marshall (2001a) suggests that it may be particularly keenly felt in Wide Bay-Burnett, where Bundaberg appears to be the home of about 16% of the fishing fleet, and in Far North Queensland. The fishing ports next in importance according to Fenton and Marshall are Cairns, Townsville, Gladstone, Innisfail, Mackay and Yeppoon as detailed in Chapter 9.

Environmental impact of tourism

A recent comprehensive study carried out for CRC Reef (Harriott 2002) states:

'Impacts of marine tourism can be broadly categorised as ecological, social and cultural. The major types of marine tourism impacts include:

- coastal tourism development (population pressures, construction activities);
- island-based tourism infrastructure (marinas, sewage discharge, construction);
- marine-based tourism infrastructure (pontoons, moorings, fish feeding);
- boat-induced damage (anchoring, ship grounding, litter, waste discharge);
- water based activities (diving, snorkelling, reef walking, fishing);
- wildlife interactions (seabirds, turtle-watching, whale-watching).'

Cairns and the Whitsundays according to Vicki Harriott account for 85% of tourist visitations in areas comprising only 7% of the Marine Park. Hence, the impact of tourism is relatively low in the rest of the Great Barrier Reef. The main management problems associated with tourism are therefore concentrated on the Cairns and Whitsundays regions, including:

- Coastal and island-based sewerage and other pollution associated with increasing tourism infrastructure;
- Anchoring of tourist and recreational boats (whereas pontoons are generally found to have minimal impact);
- Careless behaviour of a minority of divers swimming too close to fragile branching corals.

Education and training remain important components of tourism management. The Environmental Management Charge introduced in 1993 for each visitor to the Reef contributes to the funding of research, education and Marine Park management (p 7).

Harriott (2002:35) concludes:

> *'The impacts of marine tourism within the Great Barrier Reef Marine Park are generally localised and of small magnitude compared with those of other environmental concerns (overfishing, inshore water quality, crown of thorns starfish, coral bleaching). Commercial tourism operators have strong motivation to protect the reef resources on which their industry is based. … Apart from the local tourism impacts within the Marine Park, which are generally well managed, there has been concern that rapid expansion of tourism can increase pressure for coastal and urban development, with potential indirect and cumulative effects on the Great Barrier Reef World Heritage Area.'*

Mining the Great Barrier Reef

Marine basins next to the Great Barrier Reef World Heritage Park are believed to contain up to 5 billion barrels of oil, making the region Australia's richest offshore oil field (Cumming 2002). In 1967, mining and petroleum exploration leases covered four-fifths of the total Reef area. The last of these leases – covering a total of over 190,000 km^2 – were not relinquished until 1990 (Dickie 1998).

While there is a total ban on exploration and mining in the World Heritage Park, oil exploration proposals for adjacent areas are still being developed, such as a proposal lodged with Environment Australia in December 2000 from the Norwegian TGS-NOPEC Geophysical Company, in an area only 50 km from the eastern boundary of the Marine Park, between two reefs in the Coral Sea (WWF GBR 2001a). The then Federal Environment Minister, Senator Robert Hill, subsequently decided that the proposed seismic testing in the region could have a negative impact on threatened marine species and the marine environment and invoked the Environment Protection and Biodiversity Act – a move strongly supported by the Queensland Government.

The risk persists, however, that exploration and drilling may one day take place in areas adjacent to the Great Barrier Reef Marine Heritage Area, under a future regime without the commitment of the present Federal Government and Opposition. The Australian Democrats in 2002 attempted to introduce a Private Member's Bill to extend the boundaries of the current Marine Park to prevent an offshore oil industry adjacent to the Reef. The Federal Shadow Minister for the Environment and Heritage, Kelvin Thomson, introduced another Private Member's Bill in February 2003 to extend the Marine Park to the Exclusive Economic Zone (EEZ) to prevent exploration and mining activities permanently both on and off the Reef (Thomson 2003).

On top of the possible exploration and drilling for conventional crude oil, shale oil projects pose another real threat. Stage 1 of the Stuart project, a research and development plant, has been erected near Gladstone. While it appears to be facing some difficulties with Canadian partner Suncor pulling out in April 2002, Stage 3 of the project, if it came to fruition, would involve mining inside the Great Barrier Reef Marine Park (Greenpeace 2002). A former chairman of the Great Barrier Reef Marine Park Authority, Ian McPhail, told Environment Minister Senator Hill in 1998 that 'the environmental risk of mining for oil shale deposit is likely to be greater than that associated with oil exploration and drilling' (Dickie 1998). Greenpeace 2002 calls the process 'unbelievably polluting. Huge amounts of energy are required to mine and produce this form of energy. The carbon dioxide emissions from the process are up to 60% higher than they are for the production of conventional crude oil.'

Shipping hazards

Shipping transits along the inner route of the Great Barrier Reef from its northern to southern extremities are commonplace events. Commercial ports within the region include Cape Flattery, Cairns, Mourilyan, Lucinda, Townsville, Abbot Point, Mackay, Hay Point, Port Alma, Gladstone and Bundaberg (AMSA 2001). Approximately 6,000 ship movements of large vessels in excess of 50 metres in length occur within the region every year. Most of these vessels use the inner route. The rest enter into or depart from the Reef through the Grafton, Palm and Hydrographers Passages, to the ports of Cairns, Townsville and Mackay, respectively.

Most vessels using the Great Barrier Reef routes are bulk carriers (42%) carrying export cargo such as coal, bauxite, nickel ores, raw sugar, alumina and silica sand. The major bulk ports are Hay Point, Abbot Point and Gladstone. Between 5% and 10% of ships are oil tankers, mostly on northerly transits, either in ballast or carrying refined product to Queensland ports north of Brisbane. The remaining trading vessel traffic consists of container vessels (24%), general cargo (22%) and other types.

Numerous types of recreational and commercial fishing vessels also ply the Queensland coast on a regular basis. It is estimated that there are some 1,500 tourism vessels and 25,000 commercial and recreational fishing vessels operating in the Great Barrier Reef (AMSA 2001).

GBRMPA (1998b) calculates the risk of a large oil spill in Australian waters in any five-year period at 37% (84% in any 20 years). The Torres Strait and the northern section of the inner shipping route have been identified as having the highest risk of shipping accidents in Australia. It is also the route for which recommendations for compulsory pilotage has been most vigorously pursued. The Australian Marine Safety Authority was commissioned to review ship safety and pollution prevention measures in the Great Barrier Reef (AMSA 2001) and proffered a detailed set of recommendations, of which the following are indications only:

- Better coordinated management through a Great Barrier Reef Shipping Management Group consisting of AMSA, the Commonwealth Department of Transport and Regional Services, Queensland Transport, and GBRMPA – that is, the authorities that are currently in charge of various aspects of shipping.

- The responsibilities of the management group would include: ensuring ongoing clarification of roles; preparing a shipping management plan as part of a three-year rolling program; reporting regularly to the respective ministers; and developing a study of the economic, environmental and social impact of shipping in the Marine Park and Torres Strait to assist with the long-term management of the industry within the region.

REEFPLAN is a special oil spill contingency plan for the waters of the World Heritage Area (port authorities have their own plans as well). The Queensland Government is responsible for initiating oil spill responses through Queensland Transport. However, if the spill is of major magnitude, local resources are insufficient. Furthermore, the use of oil spill dispersants is significantly limited by the sensitivity of the reef and inter-tidal communities. The actual impact of a spill will vary with the local environment and the type of oil. 'However, significant impacts can be expected on a regional scale in the short to medium term.' (GBRMPA 1998b)

Synthesis

This chapter has brought together the main economic, social and environmental information for the five Great Barrier Reef regions. These are essential inputs into the scenario planning in Part 3, which seeks to take all relevant factors into account in the description of possible futures. In summary, the following thumbnail sketches apply to the five regions:

- *Far North Queensland* is both the most advantaged and potentially the most vulnerable region. Being home for the largest and most lucrative parts of the tourist industry (refer Chapter 8), it has displayed the highest rate of economic growth. Fisheries are also relatively important in the Far North. Sugar cane and horticultural industries contribute significantly to the economic base of the region. People in the region tend to be socially advantaged compared to other regions, especially the tourism centres of Cairns and Port Douglas. Indigenous culture is an important and visible part of the social fabric in the region. Ecologically and economically, the region stands most to lose if the attraction to visitors deteriorates as a result of widespread coral bleaching.

- The *Northern Statistical Division*, dominated by Townsville, relies relatively less on tourism and gains resilience from other industries – it also shares prominence in the cane growing area with Mackay. While tourism remains the main source of employment, and the Reef remains important for the economy, the region would not be as vulnerable as the Far North to losses due to coral bleaching.

- The *Mackay Statistical Division* includes the second-largest Great Barrier Reef tourism industry, based on the Whitsundays, and is therefore more vulnerable to climate change. However, the economy of the region as a whole is based on sugar cane and coal mining as well as tourism, which makes it more resilient to change than the Far North.

- The main export industries contributing to the economic base of the *Fitzroy Statistical Division* are cattle and mining. Tourism is a major employer, but contributes relatively less to the total economy than the regions further to the north. Reefs along the Fitzroy region are generally better protected than further north, due to distance.

- Finally, *Wide Bay Burnett* presents a mixed picture. While tourism is also a major employer in this region, the combined number of people employed in horticulture, beef and sugar exceeds that in the tourism industry. It is uncertain whether this has an influence on social conditions, but most local government areas in the region score relatively highly on the scale of social disadvantage. Along with Cairns, Bundaberg is the 'fishing capital' of the Great Barrier Reef, which adds an element of social vulnerability, though fisheries provide relatively little employment in the total picture.

8. Tourism

Introduction

This chapter analyses the available evidence on the most important reef-related industry, tourism. Two main objectives are to analyse the tourism satellite accounting data for 1998-99 which provide a valuable new benchmark for the contribution of tourism to the regional economies, and to identify a 'reef-interested' component from that new base.

Statistics

This study benefits substantially from the work of the Office of Economic and Statistical Research to develop first a time series of regional visitor expenditure from 1985 to 1999 (OESR 2001) and subsequently (OESR 2002a) regional satellite accounts for tourism, referred to as Tourism Gross Regional Product (GRP). These statistics provide the backbone for this chapter.

Other data sources include up-to-date statistics of visitor accommodation (ABS 1998-2002) and the Regional Tourism Activity Monitor or R-TAM compiled for Tourism Queensland by the Office of Economic and Statistical Research (OESR 2000-02). Important data on visitor numbers were found in Tourism Queensland's *Regional Summaries* (TQ 2002). Comparison of the 1996 and 2001 Census (ABS 2000 and ABS 2002a) provided an interesting snapshot of the change in visitor numbers over the five-year period. The Productivity Commission's report on water quality (PC 2003) provided a set of regional reference projections for the future analysis in Part 3.

One inquiry was frustrated by unfavourable timing and personnel changes but gives rise to an interesting hypothesis. The executive director of the Association of Marine Park Tourism Operators (AMPTO) offered to distribute a quick email survey to selected members. These operators were asked to rank nine key concerns (box jellyfish, coastal pollution, coral bleaching, crown of thorns starfish, irukandji jellyfish, less opportunity to observe biodiversity, regulation of access to Reef, shipping disaster in inner passage, and special tourism taxes and charges).

Among operators in Tropical North Queensland, coral bleaching came out as a strong number one (followed by crown of thorns starfish and coastal pollution). Operators in the Whitsunday region were much less polarised in their opinions and coral bleaching scored a distant sixth position (crown of thorns starfish and coastal pollution were the key concerns). While the response was insufficient for statistical significance, we recommend that GBRMPA conduct a comprehensive survey of operator concerns.

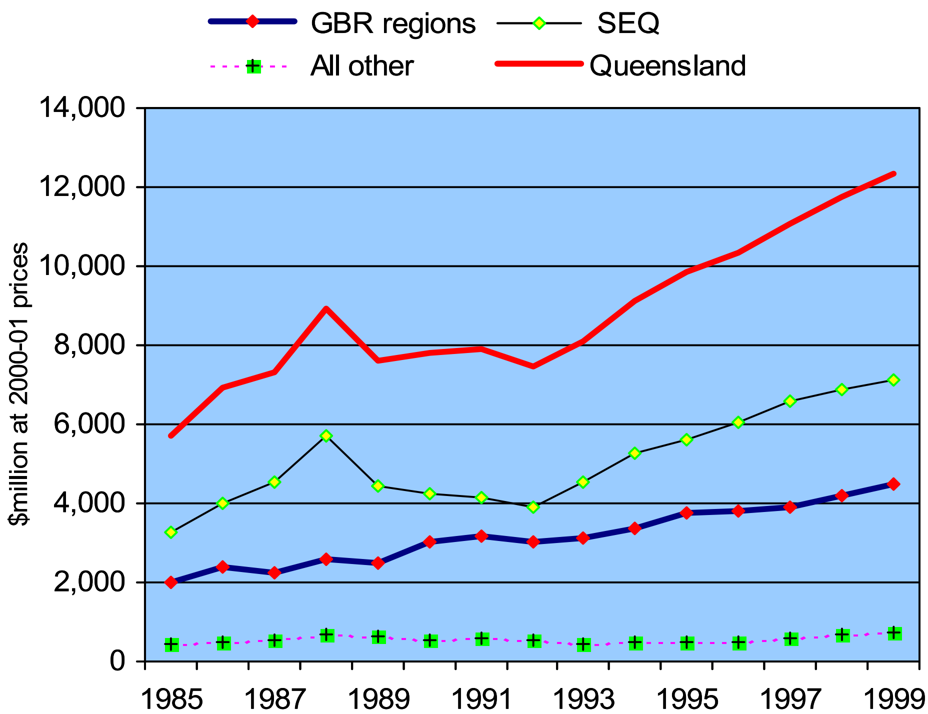
The final data source was the Tourism Program conducted through CRC Reef, mainly by James Cook University staff. This program and previous work provided insight into reef-based tourism as such – an important aim in this study.

Other data sources could have been consulted, including GBRMPA's Environmental Management Charge which captures information on passenger days for people visiting the Reef but needs to be supplemented by information on vessels, trip types and points of departure, and price data. With the new availability of macroeconomic regional statistics from the tourism satellite accounts, it is no longer necessary to build the statistics from the bottom up as in previous studies of reef-based tourism (Driml 1999, KPMG 2000, Innes and Gorman 2002). As will be demonstrated at the end of this chapter, the top-down approach results in significantly higher estimates of tourism associated with the Great Barrier Reef.

Appendix B contains the statistical tables discussed in the following sections. Graphs derived from these tables illustrate the presentation below.

Growth

Total visitor expenditure in constant 2000-01 prices increased by 4.5% per annum in Queensland from 1985 to 1999 (Table B1). This rate was significantly exceeded in Far North (Tropical North) Queensland, which recorded an annual growth of 8.2%, equivalent to doubling every nine years. Above-average growth also occurred in the Whitsunday regional tourism area (6.2% pa) and in Wide Bay-Burnett (6% pa). Lesser growth rates in the Northern, Mackay and Fitzroy regions reduced the total regional Great Barrier Reef average to 5.4% pa, still in excess of the Queensland average – and of the 4.4% annual rate recorded for Southeast Queensland (Brisbane and the Gold and Sunshine Coasts).



Source: OESR2002a, ABS 2002b (implicit deflator)

Figure 35: Total visitor expenditure in main areas of Queensland: Southeast Queensland (Brisbane, Gold and Sunshine Coasts), tourist regions adjoining the Great Barrier Reef (Tropical North Queensland to Fraser Coast), and all other (Darling Downs and Outback regions).

Total visitor expenditure in the Great Barrier Reef regions trails Southeast Queensland, which accounts for over half the state total (Figure 35). The share of the Great Barrier Reef regions has fluctuated significantly (Table B1): it fell from about 35% in the mid-eighties to 29% in 1988, then rose to over 40% in 1991 and 1992 but then drifted down towards 36% by 1999, more or less the level of 15 years previously. The Southeast Queensland share was largely a mirror image; the main feature was a fall of almost 12 percentage points between 1988 (63.7%) and 1991 (52.7%).

In constant dollar terms, visitor spending in Southeast Queensland declined from $5.7 billion in 1988 to around $4 billion in 1991 and 1992. This contrasts with the Great Barrier Reef regions, which saw continued growth between 1985 and 1999 apart from a plateau around $3 billion to $3.1 billion between 1990 and 1993. Total visitor expenditure along the Great Barrier Reef reached $4.5 billion in 1999 compared with less than $2 billion in 1985. Figure 35 show these differences.

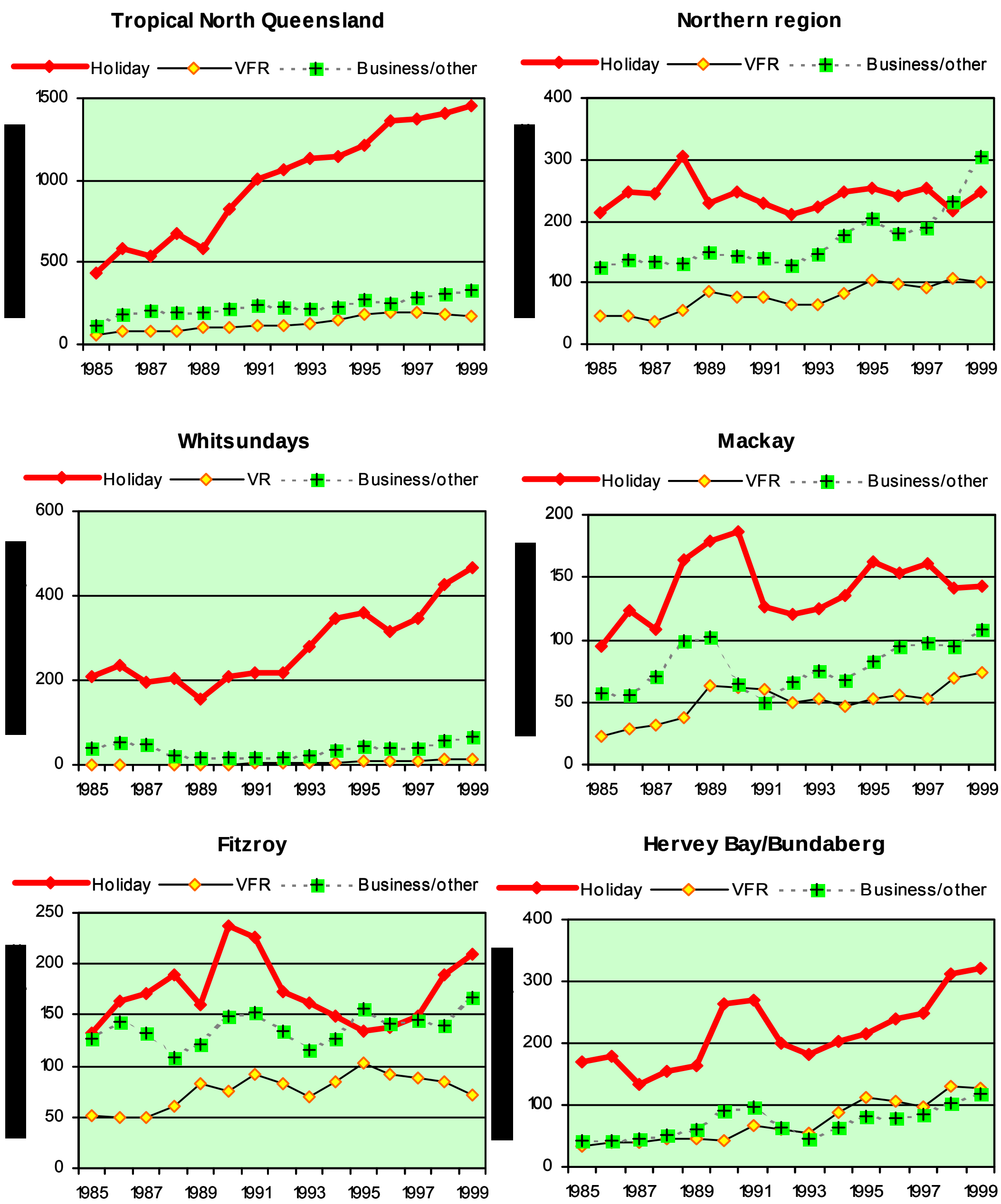
The late eighties and early nineties were turbulent times on the Australian business scene, which may provide some explanation for the fluctuating fortunes in Southeast Queensland. The trends, backed by observation and interviews with tourism organisations and individual operators, suggest that the tourism industry along the Reef may be more resilient and less prone to external shocks.

The journey towards an estimate of reef-based (or reef-interested) tourism necessitates an analysis of the groups making up total visitor numbers. It is fair to assume that people visiting for business reasons, to study and for other purposes are not primarily interested in the Reef. Some of course may be, but they would be the exception. Among those called 'tourists' most visit to have a holiday, but the so-called VFR group (industry jargon for 'visiting friends and relatives') is a significant minority.

The level of expenditure depends a great deal on what definition is adopted. Total visitor expenditure in the Great Barrier Reef regions in 1999 was $4.5 billion in constant 2000-01 prices (Table B1). Of this amount, business and other visitors spent about $1.1 billion, leaving just over $3.4 billion as spending by what the Office for Economic and Statistical Research defines as tourists. Holiday-makers accounted for $2.84 billion of tourism spending, VFR for the remaining $550 million (Table B2).

The structure of visitor spending varied enormously from region to region (Figure 36). This can be quickly summarised as the share, in 1999, of holiday-makers' spending (Table B2) relative to total visitor expenditure (Table B1). The Whitsunday regional tourism area tops the scale with 88% of total spending by holiday-makers, followed by 83% in Tropical North Queensland, 79% in Wide Bay-Burnett, 67% in Mackay, 63% in Fitzroy and 53% in the Northern region.

The trends over the period covered by the chart in the various components are also revealing. The most persistent upward trends related to holidays in Tropical North Queensland and the Whitsundays, the two foremost tourist regions. By 1999, expenditure by holiday-makers was close to $1.5 billion in the Far North and was approaching $500 million in the Whitsundays. The third reasonably persistent trend was in the Hervey Bay/Maryborough and Bundaberg regional tourism areas, combined into Wide Bay-Burnett in this report. In the other three regions, holiday expenditure could hardly be termed a growth industry despite an upward drift in Fitzroy since the mid-1990s.



Source: OESR 2001

Figure 36: Type of visitor. Business and other visitors are assumed to visit for reasons other than the Great Barrier Reef. It is also relevant to distinguish between those tourists who state they are holiday-makers and those who visit friends or relatives (VFR). Pearce et al. (1997) suggested that VFR people are not interested in the Reef or national parks generally.

Table B2 shows trends in total tourism expenditure in each region between 1985 and 1999. These trends were calculated without regard to the fluctuations that took place during these years, but do provide a reasonable thumbnail sketch. The annual growth in the two top tourism regions, Tropical North Queensland and Whitsunday, was higher, at 9.0% and 6.7%, respectively, than when business and other spending is included (8.2% and 6.2%). The converse was the case in the Northern region, where total visitor expenditure increased by 2.7% pa but tourism expenditure by only 1.4% pa. The growth trend is also slightly reduced in the Mackay region when business and other visitors are excluded (from 2.9% to 2.7% pa), while it remained unchanged in Wide Bay-Burnett (6% pa) and Fitzroy (1.2% pa).

People visiting friends and relatives provided the only growth in total tourism expenditure in the Northern and Fitzroy regions (lower panel of Table B2). A study which will be explored at the end of this chapter (Pearce et al. 1997) finds that the VFR group is not particularly interested in the Reef or other national parks, whether the individuals concerned originate in Queensland, other states or overseas. However, Figure 37 (and the appended Table B3) shows that the most attractive tourist regions in Northern and Southeast Queensland had more than their share of VFR in 1999. Relative to the resident population in the region, spending by the VFR group in the Whitsunday region was almost twice the Queensland average and exceeded the finding for Brisbane by a factor of 2.6. Quantitatively more important, since the resident Whitsunday population is small, VFR spending relative to the resident population in the Tropical North was twice the Brisbane level.

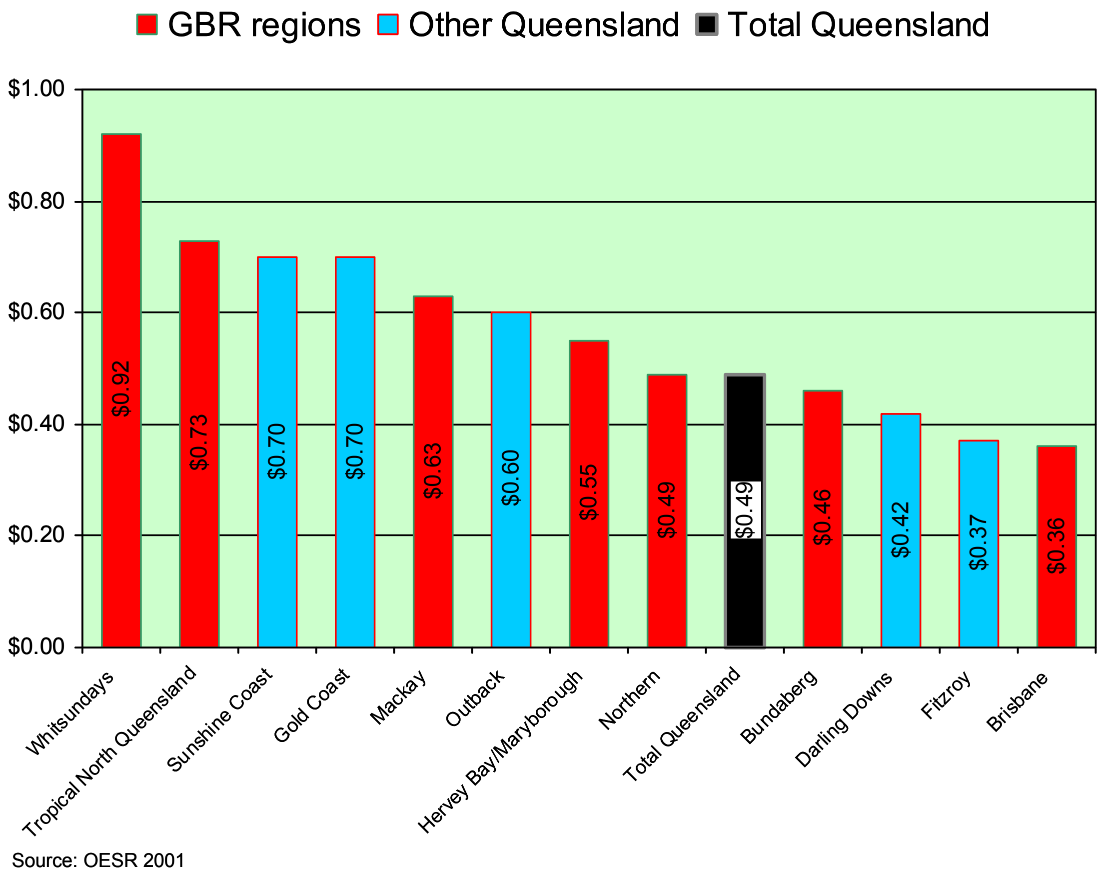
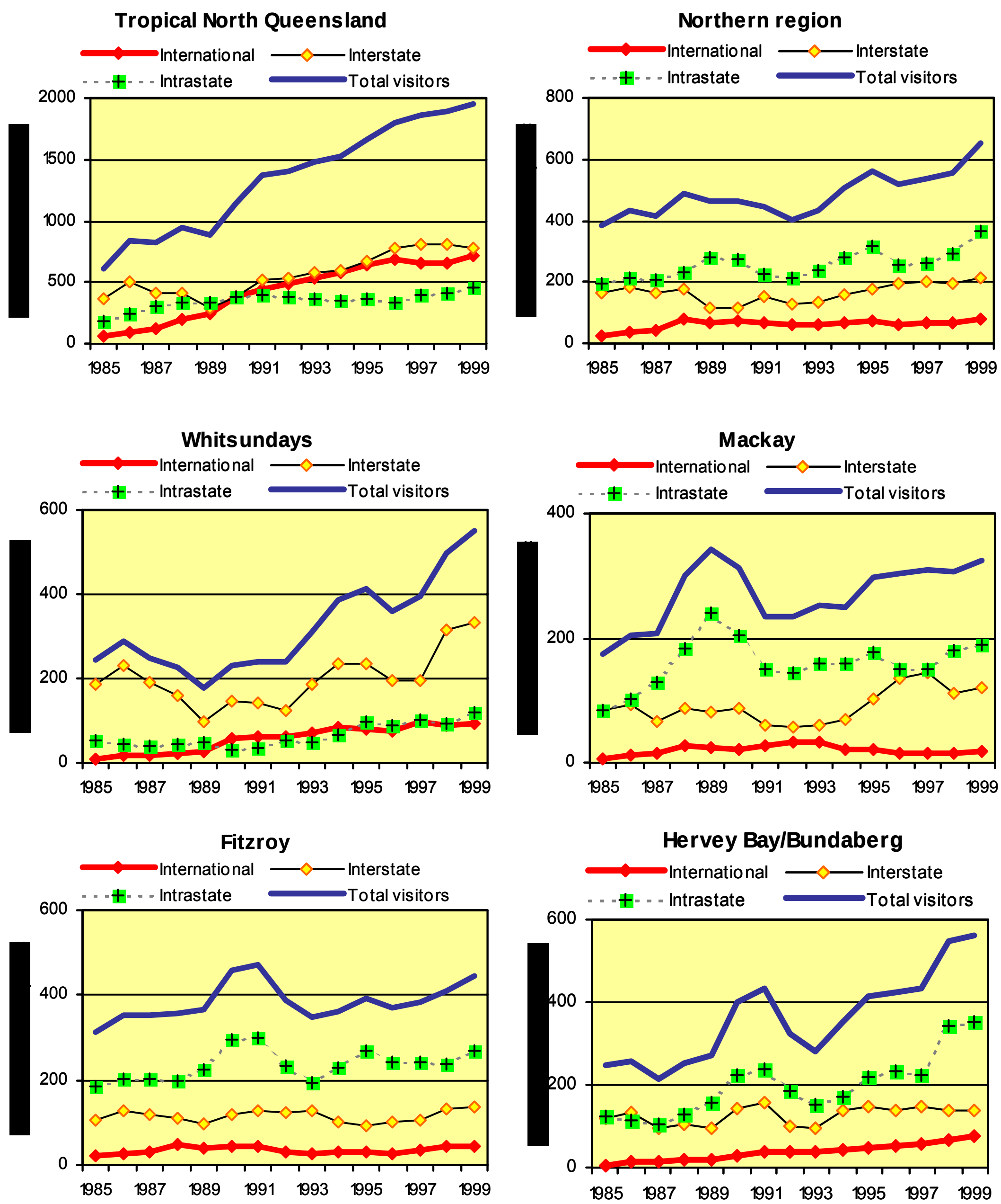


Figure 37: Average expenditure per tourist visiting friends and relatives per person resident in the tourism region. The two strongest tourism regions along the Reef show averages twice as high or more than those with the lowest average levels of spending per VFR person. While some research suggests that people visiting friends and relatives are not interested in ecotourism, this may be a conservative assumption.

These people apparently take the opportunity to combine visits to friends and relatives with visiting an attractive area, one that contains a famous Reef. Omitting the VFR group in the estimation of reef-interested tourism is conservative – but that is in principle what we will be doing for lack of further information.



Source: OESR 2001

Figure 38: Growth and origin of visitor expenditure in coastal tourism regions adjoining the Great Barrier Reef. Tropical North Queensland corresponds to the Far North Statistical Division, the Mackay and Whitsundays regions make up the Mackay Statistical Division, and the Hervey Bay/Maryborough and Bundaberg tourism regions equate Wide Bay-Burnett Statistical Division.

The OESR data make the vital distinction between intrastate, interstate and international visitors though they do not subdivide these groups into holiday, VFR, business and other visitors. Figure 38 shows regional trends in each group, while the statistics are shown as three-year averages in Table B4. The three components vary considerably from region to region (see also Table B8):

- The international component is by far the strongest in Tropical North Queensland, where it accounted for 36% of total visitor expenditure in 1999 compared with 20% in the Whitsundays area, 13% in Wide Bay-

Burnett, 12% in the Northern region (presumably with a hefty business travel component), 10% in Fitzroy and 5% in the Mackay tourism region. The average international proportion for all Great Barrier Reef regions was 22%, and for Queensland 20%.

- Interstate visitors spent the largest proportion of total visitor expenditure in the Whitsunday region (59%), followed by Tropical North Queensland with 42%, Mackay 40%, Northern 35%, Fitzroy 30% and Wide Bay-Burnett 27%. The Great Barrier Reef regional average was 40% and the average for Queensland considerably higher (47%).

- The proportion of visitors from within Queensland fell in two distinct groups. They comprised the majority in Fitzroy and Wide Bay-Burnett (60% in each), Mackay (55%) and Northern (53%). They accounted for only 22% in the Far North and the Whitsunday regions.

Returning to the distributions of tourist expenditure in the regions facing the Reef, Tropical North Queensland has been hovering around the 50% mark for the past several years (48% of the Great Barrier Reef total in 1999). The Northern region shows a falling share, to 10% in 1999. The Whitsundays have enjoyed an increasing share since 1991, from 9% to 14% in 1999. Mackay is down to 6% and Fitzroy to 8%, while Wide Bay-Burnett shows recent gains to 13% (Table B5).

Tourism gross regional product

An Australian perspective

The recent work on national tourism satellite accounts provides useful background. ABS (2002d) contains four years of estimated tourism GDP and tourism employment statistics (Table B6). It shows the tourism GDP to average 4.5% of total GDP between 1997-98 and 1999-2000 and then increase to 4.7% in 2000-01 on preliminary figures. Tourism employment remained constant at 6% of total employment in each of the four years. The definitions in the national satellite accounts, and in the Queensland accounts described below, distinguish between employment generated by tourism and employment generated by other economic activities. There is no double counting.

Finally, while labour productivity is relatively low in the tourism sector, it appears to have risen by an average of 3% pa during the brief period over which these statistics have been compiled: tourism GDP per person employed at constant 2000-01 prices increased from $52,400 to $57,700 between 1997-98 and 2000-01. It was still well below the $73,700 average for total GDP.

Queensland and the Great Barrier Reef

Australia's tourism GDP in 1998-99 was $28 billion (Table B6). Queensland's tourism GSP in the same year was $6.3 billion or about 22.5% of the Australian total. The combined tourism GRP for the Great Barrier Reef regions was $2 billion (Table B7) or about 7% of Australia's total tourism GDP – a substantial proportion for what is sometimes considered a remote area.

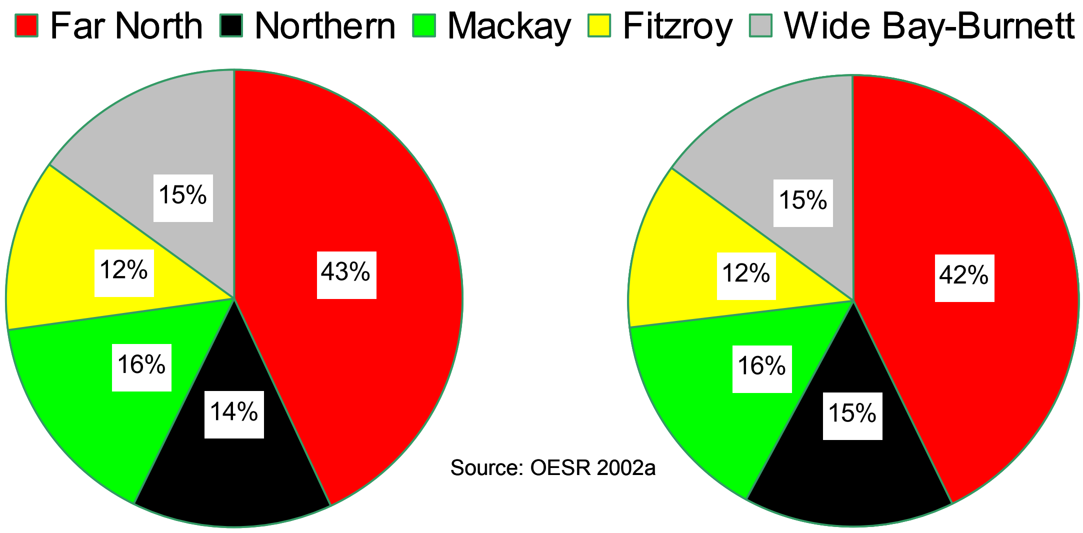
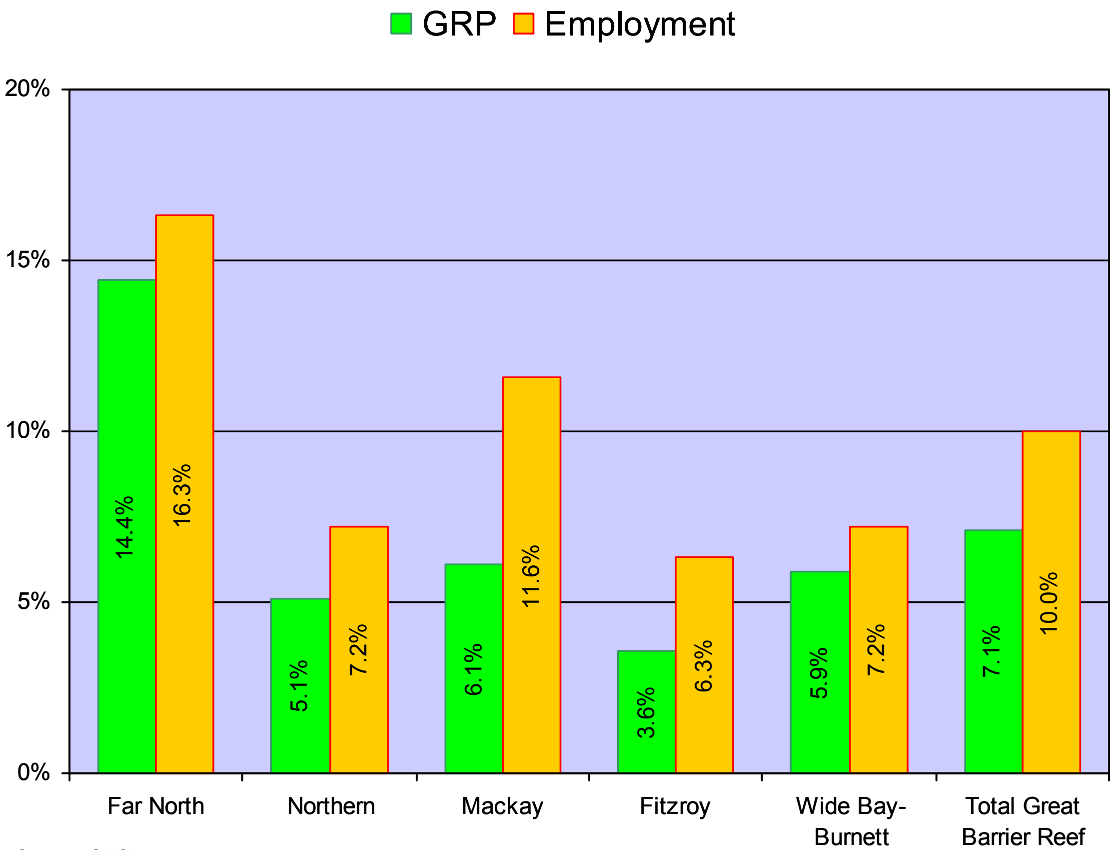


Figure 39: A: Distribution of Tourism GRP among Great Barrier Reef regions in 1998-99.
B: Distribution of full-time equivalent tourism employment, 1999.

Tropical North Queensland, as is by now well established, accounts for the largest share of the total tourism GRP for the Great Barrier Reef area (43% in 1998-99). The rest was fairly evenly shared among the other four regions, with the smallest share to Fitzroy. There was little difference between the distribution of tourism GRP and the distribution of tourism employment among the five Statistical Divisions (Figure 39).

Tourism contributed 7% of the total gross product in the five Great Barrier Reef



Source: OESR 2002a

Figure 40: Tourism contribution to total gross regional product, 1998-99, and total full-time equivalent employment, 1999.

regions in 1998-99, and provided 10% of the employment (Figure 40). Reflecting the relatively labour-intensive nature of tourism, its contribution to employment was higher in each region than the contribution to GRP, especially in Mackay because mining is an important industry in that region and very capital-intensive (OESR 2002a:32), so high value added is achieved with relatively modest labour input.

Tourism in Tropical North Queensland again contributed by far the greatest proportion of total regional gross product, followed, in value terms, by Mackay (including the Whitsundays) and Wide Bay-Burnett.

Relative to total visitor expenditure (Table B1), the level of tourism GRP in 1998-99 (Table B7) in the five Statistical Divisions along the Great Barrier Reef comprised 45%. GRP is lower because the cost of producing tourism product is deducted from the total visitor expenditure figure. The relativity also varies regionally depending on where the cost occurs: while Far North Queensland and Townsville showed about the same relativity as the average (44%), the tourism GRP in Mackay/Whitsundays was only 36% of total visitor expenditure, while it was higher than average at 54% in Fitzroy and 55% in Wide Bay-Burnett.

Other industry indicators

A Census indicator of tourism growth

The 1996 and 2001 Census publications show the population as it was counted, including visitors to the area and excluding residents temporarily absent on Census night. This provides an opportunity for conducting a spot check on the change in the number of visitors between 1996 and 2001. Being a snapshot, it only provides information about the difference between two dates, 6 August 1996 and 7 August 2001. Nevertheless the results are revealing (Table B9 and Figure 41).

At least as far as these dates show, the number of intrastate visitors to the Great Barrier Reef regions declined between 1996 and 2001, as did the number of interstate visitors. On the other hand, the number of overseas visitors increased at an average annual rate of between 11% (Whitsundays and Wide Bay-Burnett, with Northern not far behind but perhaps largely due to business and student visitors) and 2% (Mackay excluding Whitsundays). The implicit growth rate for Tropical North Queensland was almost 7% per annum. The differential regional growth rates are quite startling but cannot be further elaborated; the low growth rate for Mackay would be at least partly due to the dominance of the neighbouring Whitsundays as a tourist region.

The implicit annual rate of growth in the number of overseas visitors to all five Great Barrier Reef regions was 7.6%, compared with annual declines in intrastate and interstate visitors of 0.8% and 1.1%, respectively (Table B9). The rest of Queensland showed a similar pattern: 6.6% annual growth in the number of overseas visitors, 0.5% in intrastate visitors, and an annual fall of 0.7% for interstate visitors.

A tourism industry activity marker

Persons employed in accommodation, cafés and restaurants can be defined succinctly as members of the hospitality industry. The ratio of hospitality industry employment to total persons employed is available for each local government area. It once again picks out those local areas that depend most on tourism, in fact, quite dramatically so (Figure 42). Three groups can be distinguished:

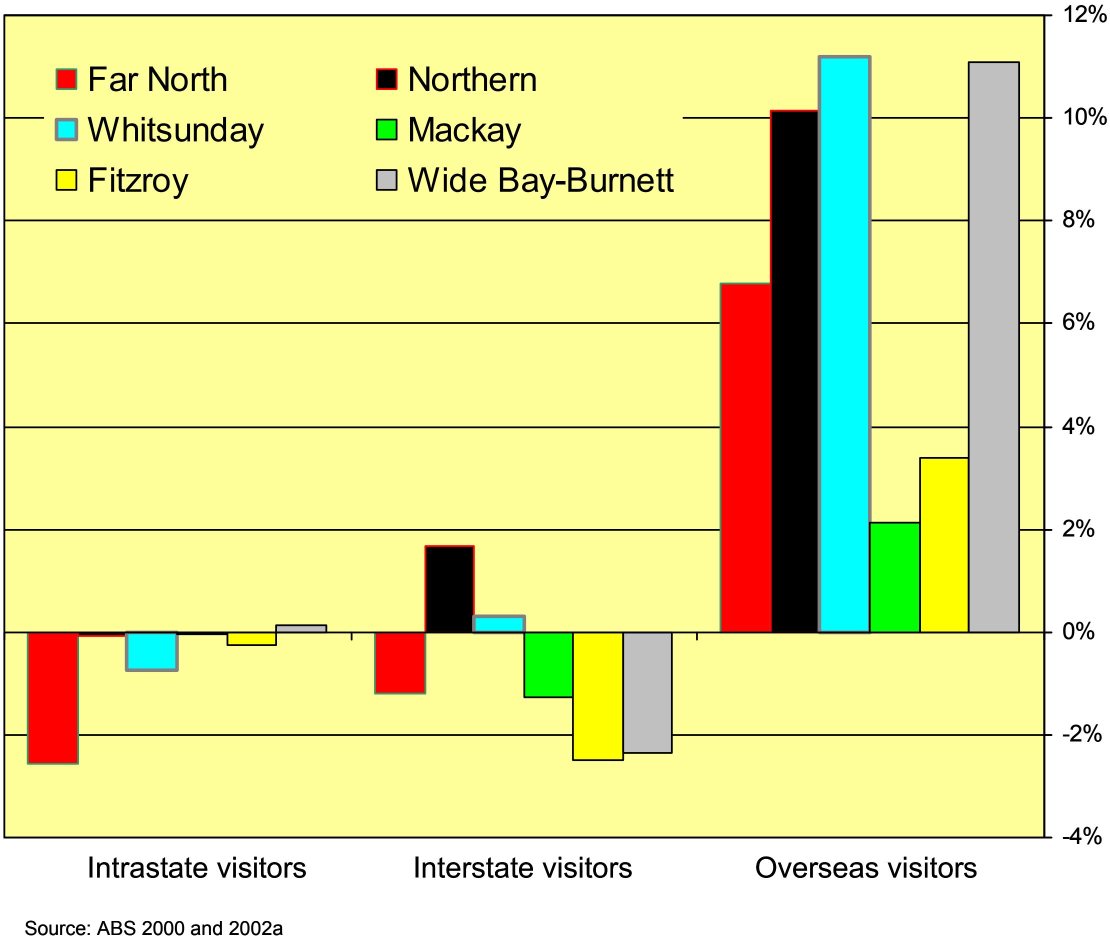


Figure 41: Implicit annual rates of change, visitors on Census night, August 1996 to August 2001, GBR regions

- Douglas and Whitsunday Shires, which are in a class of their own.
- Cairns, Cardwell and perhaps Cook in Tropical North Queensland, Hervey Bay and Miriam Vale in Wide Bay-Burnett, and Livingstone Shire on the Fitzroy coast including Yeppoon and Great Keppel Island, which all have an above-average dependency on tourism. Cairns, of course, is quantitatively the most important area with 5,865 persons in hospitality jobs in August 2001 compared with 1,455 in Douglas and 1,761 in Whitsunday Shire (Table B10).
- All the rest, with hospitality accounting for 5% or less of total employment, for which no significant or above-average dependency on tourism can be identified.

Regional Tourism Activity Monitor

The Queensland tourism industry has developed some good indicators in recent years, including the Regional Tourism Activity Monitor (R-TAM), based on voluntary records from operators. Some of the published information is summarised in Tables B11 and B12, including average room expenditure, length of stay and occupancy rates for various classes of hotels in Cairns, Port Douglas, Townsville and the Whitsundays, and for capacity utilisation of a range of tourist attractions and reef-based tours and cruises. For example, it puts the number of bareboat passengers in the Whitsunday

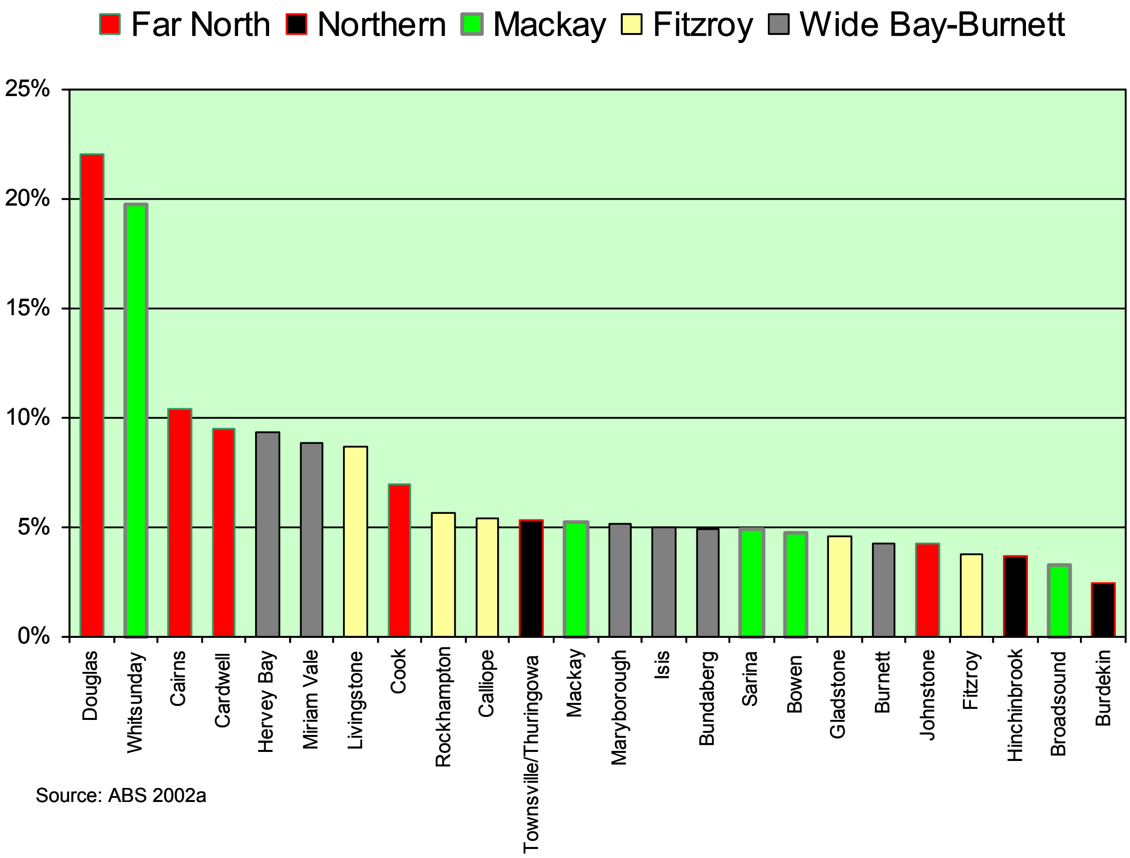


Figure 42: Persons employed in hospitality industry relative to total number of employed persons, 2001 Census

region at about 42,000 for 2002, similar to the number of passenger *days* in a previous investigation (KPMG 2000), and the number of passengers on crewed charter boats at 53,600 (December Quarter estimated). While there is little published evidence available to help digest these figures, R-TAM provides a promising start to producing a broader range of data for the analysis of the reef-based tourism industry.

Accommodation statistics

The Australian Bureau of Statistics produces quarterly small-area data on accommodation establishments throughout Australia (ABS 1998-2002). This includes number of establishments, employment, number of guest nights, and takings. The following points were derived from Tables B13 to B16 in Appendix B:

- Of 7,900 guest nights in the year ended June 2002 (2001-02), 4,360 were in Tropical North Queensland (55%). Seventeen island resorts from Lizard to Lady Elliot Islands accounted for 1,180 nights (15% of total nights). Individual establishments in the Great Barrier Reef region (the 17 establishments) are also part of the respective regional totals (Table B13).

- Recent trends have been unstable. The number of guest nights declined by 1.1% in 1998, picked up by 4.9% in 1999, declined again in 2000 (by 2.5%) and showed a 0.9% growth in 2001. There was a marginal decline in the financial year ended June 2002 (-0.3%). (Table B13).

- Employment in accommodation establishments dropped marginally in 1998, 1999 and 2000 (by an average of 0.3% pa) and then by 3.5% in 2001. In the year ended June 2002, the decline was 0.9%. About 11,000 persons are employed, including 5,000 in Tropical North Queensland (Table B14). Caution is required when comparing these figures with the total number of people employed in hospitality because of definitional differences; however, Table B11 shows that the total number employed in accommodation, cafés and restaurants was about 26,000 in the total Great Barrier Reef regions, with 9,400 in the Far North alone.

- Takings by accommodation establishments are about $500 million in the Great Barrier Reef regions, with about $270 million in Tropical North Queensland. The latest observation was a decline of 2.3% in the area as a whole, and also in Tropical North Queensland (Table B15).

- Average takings per guest night were about $63.50 in 2001-02 (Table B16). It was higher in the Whitsunday region ($81) followed by Tropical North Queensland ($61), Northern ($52), Fitzroy ($48), Mackay ($43) and Wide Bay-Burnett ($40). Average takings per guest night were highest in island resorts ($93). Average takings fell in all areas in 2001-02 except Mackay.

In summary, these short-term indicators suggest that the industry is temporarily not growing, though all projections suggest that growth will be resumed. Sluggish economic conditions coupled with the impact of September 11 would be mainly to blame for the current (or recent) stagnation in the industry.

Reef-interested tourists

There appears to be no direct evidence available to show the proportion of visitors to the coastal regions of Queensland who are interested in the Great Barrier Reef as such, other than what can be extracted from direct questions to surveyed visitors. Reference has been made to three investigations attempting to build a statistical picture from the bottom up – before the availability of regional tourism satellite accounts. None of them contains individual regional estimates. Interviews with industry representatives confirmed that interest in the Reef is a central feature in Tropical North Queensland but less so in the other regions, where other activities such as bareboating in the Whitsundays take over, though pontoons and other direct reef-based activities are also important.

Pearce, Green and Moscardo (1997) have performed the most useful analysis we have come across, subjecting the Bureau of Tourism Research surveys of intrastate, interstate and international visitors to Queensland in 1994-95 to principal components analysis. Respondents are identified as belonging (or tending to belong, as the analysis uses inter-correlations to establish the principal components) to one of five categories which can be roughly allocated to one of three geographical groups: Far North Queensland (and to a lesser extent neighbouring regions), Gold and Sunshine Coasts, and dispersed (Table B17):

- *Among intrastate visitors*, only one fairly minor group had an interest in the Reef: 'Queensland natural environment with reef interest' (14%). Just over half (51%) belonged to 'active boating, beach fishing' or 'fixed site, low activity beach holiday', both associated with holidaying on the Gold and Sunshine Coasts. One quarter was only interested in visiting friends and relatives and a further 11% was attracted by 'warm weather, sightseeing, touring'. The last groups are geographically dispersed rather than being focused on either southern beaches or northern reefs.

- *Interstate visitors* were also very focused on Queensland friends and relatives (33%), and on the Gold and Sunshine Coasts, with a full 48%

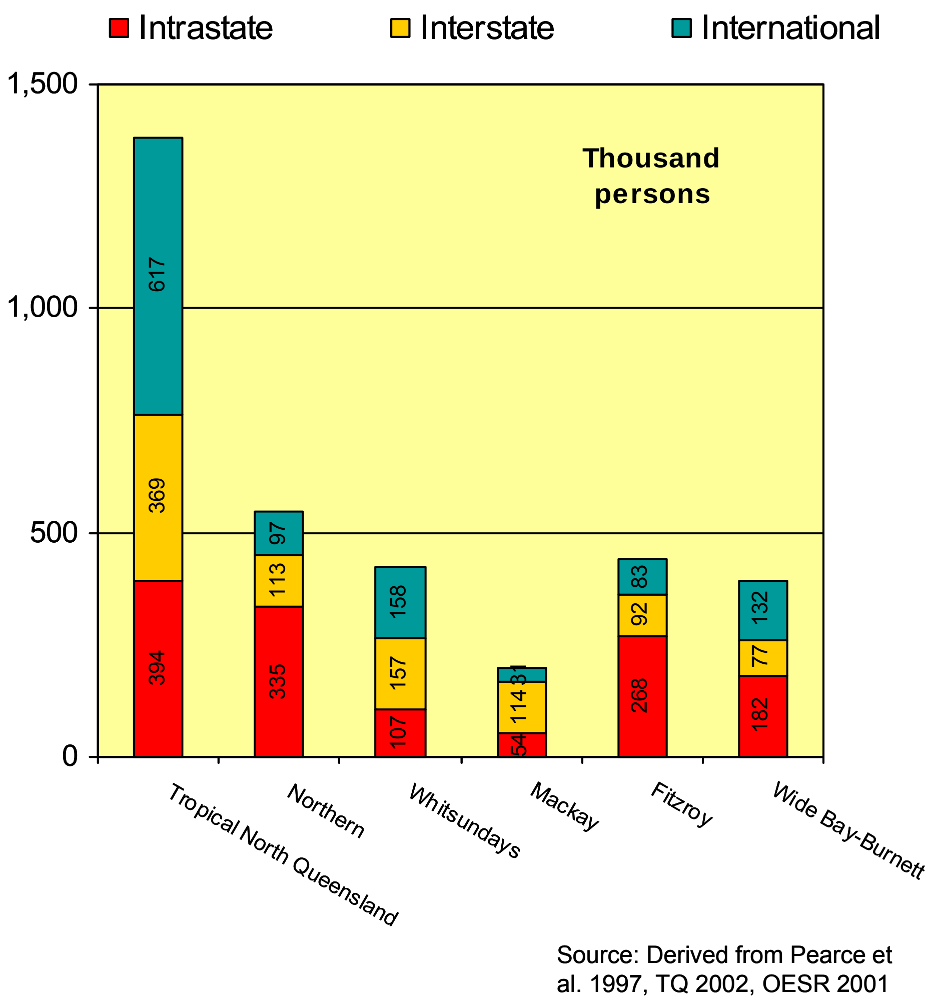


Figure 43: Estimated number of reef-interested visitors, 1999. The emphasis is on 'estimate', based on categories derived from principal components analysis of 1994-95 visitor statistics for Queensland (Pearce et al. 1997). This analysis was valuable in identifying groups who prefer the type of holiday offered on the Gold and Sunshine Coasts, and groups not interested in reef or national parks. The allocation of the groups to fit the known total visitor patterns in 1999 was also partly subjective.

falling into the categories of 'developed facilities, beaches, nightlife', 'beaches, warm weather, fishing/boating', and 'family-oriented theme parks and beaches'. This leaves just 19% focused on the 'Queensland natural environment with reef interest.'

- Even among *international visitors*, 21% were found to be more interested in visiting Queensland friends than in any specific attractions, while 30% wanted 'developed facilities, weather, beaches' (on the Gold Coast). This left just under half the total number of international visitors to Queensland with an orientation to the Reef: a group of 26% identified as 'Queensland reef', 16% being 'highly active, do everything' including the Reef, and 8% in a 'Queensland environment and reef' group.

These groups don't translate readily into distributions of reef-based and other tourists, although the 14% of intrastate, 19% of interstate and 49% of overseas visitors to Queensland falling into groups indicating interest in the Great Barrier Reef do seem to provide a fairly firm basis. There are unexplained weaknesses: we know that 550,000 inbound, 1.3 million interstate and 1.8 million Queensland-based tourists visit Brisbane, to which none of the principal components relate, but we don't know how many also visit elsewhere and therefore get into the regional statistics as well. Despite such problems we believe that it is possible to derive a measure of 'reef-interested' visitors from the base provided by Pearce et al. (1997) and using updated statistics of visitor numbers, length of stay, expenditure and gross regional product.

The first statistical task was to compile Tourism Queensland data on the number of intrastate, interstate and inbound visitors (TQ 2002). This provided a matrix for allocating the five categories from Pearce et al. (1997) to achieve a balance both with the percentage distribution of the five categories (rows) and the known regional distribution of gross numbers of visitors (columns – gross numbers because if a tourist visits more than one region he or she is counted more than once). The matrices relate to 1999 or 2000 for inbound visitors depending on the region, and to 2001 for visitors from Australia. While the solution is not unique, because variations to the distribution are possible, it is at least plausible. The resulting distributions can be viewed and either accepted or modified.

With these qualifications, Figure 43 provides the best estimate we can make of the absolute number of people who are interested in the Great Barrier Reef in a recent year (which in view of the current or recent stagnation in tourism would still apply at the time of writing). According to Table B18, of 5.9 million tourists visiting these regions in 1999, 3.3 million or 56% were interested in the Reef (42% of intrastate, 68% of interstate and 79% of overseas tourists visiting the Great Barrier Reef regions). The estimated proportion was highest in Tropical North Queensland (88%), followed by the Whitsundays (71%), Northern (64%), Fitzroy (56%), Mackay (39%), and Wide Bay-Burnett (21%).

The reader should note that while the visitor numbers shown are inflated by people who spend time in more than one region, statistics of average length of stay in each region compensates for this problem (see next paragraph).

The next step laid out in Table B18 was to estimate the number of visitor nights in each region that was associated with reef interest, and the total number of nights, from

TQ 2002 and other sources. This yields an estimate that 62% of total nights were spent by reef-interested visitors. The ratio varies from 90% in Tropical North Queensland and 73% in the Whitsunday region to lower percentages elsewhere as indicated in Table B18. These ratios are applied, in lieu of better knowledge, to the known total tourist expenditure and tourism GRP.

Estimated expenditure by reef-interested tourists is compared with total tourist expenditure in Figure 44. For the Great Barrier Reef as a whole, $2.4 billion of a total expenditure of $3.4 billion was attributable to reef-interested tourism in 1999 (70%). Based as it is on a survey that identified percentages of total tourists visiting Queensland who were at least partly interested in the Reef (Pearce et al. 1997), and on the new work on tourism GRP by the Office of Economic and Statistical Research (OESR 2001, OESR 2002a), it provides substantially higher estimates of *reef-interested* tourism than the *reef-based* tourism estimates made previously.

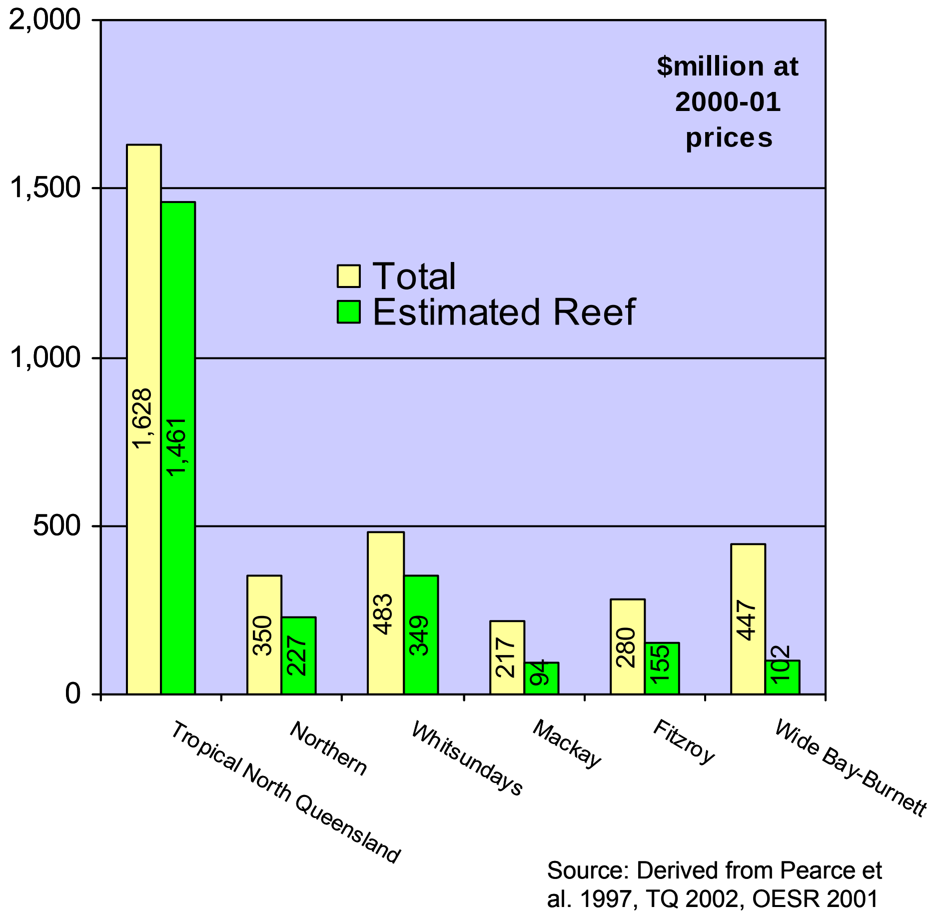


Figure 44: Estimated spending by reef-interested visitors, 1999. As explained below the previous figure, the emphasis is on 'estimate'. The allocation of the groups to fit known total visitor patterns in 1999 was partly subjective, aiming at plausible patterns for each region consistent with Pearce et al. 1997.

According to KPMG 2000, commercial tourism in the Great Barrier Reef Marine Park includes the gross value of:

- trips on vessels in the Marine Park ($156 million in 1997-98)
- mainland accommodation associated with the trip ($73 million), and
- holidays on island resorts excluding reef trips ($226 million).

This adds to $455 million. For the same year, OESR (2002a) has a total gross tourism expenditure of $3,083 million (total for six regions in Table B2 converted back to 1997-98 current dollars). The implication is that reef-based tourists (tourists who experience the Reef), including Tropical North Queensland where almost half the total tourism expenditure occurred, generated only 15% of the total tourism dollar.

The estimate excludes expenditure on air transport by tourists travelling to the region, because of difficulties in apportioning this expenditure between activities within the Marine Park and elsewhere (KPMG 2000:5). This is compatible with the work on regional tourism satellite accounts for Queensland, which makes no attempt to allocate the main component of international airfares regionally (OESR 2002a:4).

Driml (1999) arrives at a higher estimate of $640 million for 1995-96, comprised of $166 million for reef trips, $234 million for mainland accommodation and $241 million for island resorts. The actual total tourism expenditure was $2,743 million in 1995-96 values, so that her reef-based tourism estimate is 23% of the total. Innes and Gorman (2002:16-17) estimated the gross financial value of the same three components in 2000-01 to be $589 million, which is only 17% of the estimated total tourism expenditure of around $3.5 billion for that year.

The main reason for the discrepancy appears to be lack of complete coverage in the three studies quoted. The components included in the estimates would be part of the accommodation, café and restaurant industry (the hospitality industry previously identified as a tourism marker), and a minor part of transport, storage and communications. The box below shows that half the expenditure according to the satellite accounts is with other industries, notably retail and wholesale trade, and to a lesser extent services including community, recreational and cultural. Furthermore, most of the expenditure on transport, storage and communications, and some hospitality industry costs, would represent areas not covered by the previous research. Tourism GRP relates to the primary expenditure by visitors, and by definition excludes multiplier effects from flow-on caused by the primary spending.

Components of tourism GRP at factor cost, 1998-99

$million at current prices **Statistical Division**	**Accom-modation, cafès and restaurants**	**Transport, storage and communi-cations**	**All other industries**	**Total GRP at factor cost**
Tropical North Queensland	197	221	302	720
Northern	60	48	123	231
Mackay/Whitsunday	71	46	132	249
Fitzroy	48	36	108	192
Wide Bay-Burnett	53	35	148	236
Total GBR regions	429	386	813	1,628
Ratio	26.4%	23.7%	49.9%	100.0%

Source: OESR 2002a

It is possible and even probable that significant numbers of tourists attracted by the concept of the Reef do not in fact get to see it, and therefore would not appear in the activity-based estimates discussed above. That is why we distinguish between 'reef-based' and 'reef-interested' tourism. The Reef is a powerful magnet for most visitors to the area, in particular for overseas visitors to the Tropical North. If this magnet were to disappear, tourism promoters would have to de-emphasise the Reef – which could soften the blow considerably as discussed in the various scenario stories in Part 3. Most of the scenarios give the tourism industry considerable credit for resilience.

The following statement by the Association of Marine Park Tourism Operators (Thomas 2002) supports a higher estimate of reef-based tourism than that advocated in the previous studies. AMPTO is at the very heart of reef-based tourism:

> *AMPTO Ltd, formed in 1989, represents more than 200 marine tourism operations based mostly within the Great Barrier Reef Marine Park. Its members' operations include the transportation, accommodation, education and entertainment of visitors to the GBRMP. Ours is a minimal impact industry whose activities generate an estimated $1.5B per annum for the regional Queensland economy.*

Our estimate of $2.4 billion would include visitors expressing sufficient interest in the Great Barrier Reef to show in the principal components analysis by Pearce et al. (1997), but not actually getting out there. Even if they don't, however, they would still be susceptible to promotion of the Reef.

If 63% of total tourism expenditure was indeed spent by 'reef-interested' visitors to regions adjacent to the Great Barrier Reef, and with an official total tourism GRP for 1998-99 of 2.1 billion, an estimated $1.45 billion was reef-related (bottom panel of Table B18). This excludes 'flow-on' or 'multiplier' effects as local commercial establishments generate further economic activity from the visitors' primary spending.

Survey of reef-based tourism

James Cook University's Tourism Program has for several years conducted valuable research into the behaviour and preferences of visitors. Research in 2002 included a number of summary reports as part of CRC Reef Project B2.1.1: *Understanding Tourism Use of the Great Barrier Reef World Heritage Area* (Burke 2002a,b,c,d, Galletly and Hildebrandt 2002, Hildebrandt 2002a,b,c,d, Saltzer 2002a,b,c).

The project was based on a survey of passengers on reef operations in Port Douglas, Cairns, Mission Beach, Townsville and the Whitsundays in the second half of 2001. A total of 2,215 passengers completed the questionnaire, representing a response rate of 75%. People were interviewed on large and small day trip boats, island trips, overnight trips, diving trips and bareboat cruises. The methodology is described in the publications listed in the previous paragraph. Day-trippers going to a pontoon represented the largest group (54% of total responses) followed by day-trippers going to an island (24%). Dive trips, day trips on small and medium-sized boats, bareboat charters and overnight non-dive trips contributed smaller groups.

The survey explored trip planning, length of stay and expenditure, sources of information about the Reef, reasons for visiting, activities undertaken, satisfaction rates, and visitor origin. These are some of the overall results (Saltzer 2002a):

- Word-of-mouth is the most important information source. Asked to nominate three sources, 39% ticked friends or family, 28% articles in newspapers or magazines, 28% brochures and pamphlets picked up within the region and 27% books and libraries. Travel agents, other travellers (adding to the word-of-mouth factor), tour operators, brochures and pamphlets picked up outside the region, and the Internet were each ticked by between 16% and 20% of respondents. 15% had 'been before'.

- The overwhelming reason for visiting the Reef was to experience the beauty of nature (72%), followed down the line by experiencing something new and different (58%), being in a natural place (57%), and experiencing an undeveloped environment (50%). Escaping normal routine was important enough to tick for 42%, while learning about a coral reef attracted 40% and learning more about nature 39%. With the exception of 'escaping normal routine' all these main reasons would be highly correlated, and part of 'ecotourism' – indeed, one of the papers cited deals with that particular subject (Galletly and Hildebrandt 2002).

- Snorkelling and swimming were the most popular activities on this particular reef trip (65% and 50%, respectively). Other activities considered important included semi-submersible (36%) and glass-bottomed boats (33%), though arguably the sample is biased towards these because the survey was taken of boat passengers.

- Passengers were generally very satisfied with the trip. Staff attributes (friendliness and knowledge) attracted the highest ratio of very good and good ratings, followed by 'clean environment', 'overall environment', tour facilities, water quality, the fish, and the coral – in other words, a combination of tour operator attributes and natural attractions. About 80% rated the fish and the coral good or very good.

- Only 5% of respondents would not return for a visit to the Reef, while 14% didn't know. Forty-six percent would definitely return, while the remaining 35% would do so if they returned to the region.

- Sixty-one percent of respondents were international tourists, 26.5% interstate visitors and 12.5% from Queensland (approximately evenly distributed between local and other Queensland residents.

Another study explores overall satisfaction (Saltzer 2002b). Based on multiple regression analysis, she concludes that the factors with the greatest impact on visitor satisfaction are:

- Satisfaction with the fish, coral and other marine life,

- The importance attached to learning about and experiencing nature, being in an undeveloped environment, and experiencing something new and different, and

- Number of activities undertaken – the more activities, the more satisfaction. The six most common activities included in the analysis were swimming, snorkelling, marine biologist snorkel tours, scuba diving (introductory and certified), and reef talks.

The survey revealed that different groups had different preferences for coral. Two items dealt directly with coral and may be considered as 'markers' of relative tourist preferences: the percentage who ticked 'to learn about a coral reef' as a very important reason for visiting the Great Barrier Reef, and the percentage indicating that coral was very important for the overall satisfaction of the trip. The box below shows these findings for a number of different groups of tourists.

The top five items show a number of special analyses of particular groups of tourists: a relatively young category of single people and couples without children (of whom almost half feel that the coral is a very important satisfaction factor), fully independent travellers and the so-called discerning traveller, who spends a minimum of $250 per day (7% of the total sample). The group with least interest in coral was bareboat users, who were sampled exclusively in the Whitsunday region. This group also had by far the smallest international component.

Divers, whether certified or introductory, not unexpectedly had relatively high interest in the coral (the groups of day-tripping and live-abroad divers are relatively small). A larger percentage of dive tourists than other groups were international.

Among international tourists, North Americans feel that coral is particularly important, while Europeans rate it least important. Only 25% of Asian tourists thought that 'learning of coral reef' was a reason for the visit, but 44% still ticked 'coral very important for overall satisfaction'.

Coral markers in CRC Reef/JCU survey, 2001

Type of visitor	Coral very important for satisfaction	Learn of coral reef ticked as reason for visit	International visitors (overall 61%)	Source
Ecotourists	64%	77%	64%	Galletly/Hildebrandt 2002
Singles/doubles no children	48%		54%	Burke 2002d
Fully independent travellers	46%	39%	61%	Hildebrandt 2002c
Discerning travellers	41%	40%	62%	Burke 2002c
Bareboat charters	29%	14%	21%	Burke 2002a
Divers - certified	50%	45%	77%	Burke 2002b
Divers - introductory	55%	45%	77%	Burke 2002b
Divers - day trippers	46%		71%	Burke 2002b
Divers - live-aboard	48%		87%	Burke 2002b
US/Canada	67%	50%	100%	Hildebrandt 2002b
UK/Ireland	50%	46%	100%	Hildebrandt 2002b
Other Europe	36%	37%	100%	Hildebrandt 2002b
Asia	44%	25%	100%	Hildebrandt 2002b
New Zealand	41%	35%	100%	Hildebrandt 2002b

Note: 40% of total respondents ticked 'learn of coral reef'.

One category remains to be described. Ecotourists were defined as those who gave a high rating for: opportunity to experience beauty of nature, to experience an undeveloped environment, to learn more about nature, to be in a natural place and to learn about a coral reef (Galletly and Hildebrandt 2002). Naturally 'learn of coral reef' was biased upwards by this definition of ecotourists, which is as it should be.

Ecotourists defined in this way comprised 37% of the total number of respondents. This would appear to be a hard core – the 72% wanting to experience the beauty of nature are perhaps all 'ecotourists'. The 37% group compares roughly in size with the total number of backpackers, international youth travellers and young Australian travellers (totalling 31%), singles and couples with no children (39%), and the total number of divers (28%). The groups overlap, of course, as a diver can also be an ecotourist, part of a couple without children, and so forth.

Other aspects of the James Cook University Tourism Program could have been pursued. The program yields valuable information for the understanding of reef-based tourism, and it is to be hoped that it will pose some 'hard questions' to assist in the planning of a problematic future in programs to come. It is recommended in particular in view of the impending threats to the Reef that comprehensive research be undertaken, region by region, to refine and quantify the concepts of 'reef-based' and 'reef-interested' tourism.

Synthesis

The statistical basis for understanding the tourism industry along the Great Barrier Reef has improved, with two sources being particularly valuable. The first is the recent development of regional tourism satellite accounts, which subject to remaining data limitations put a true value on the industry (OESR 2001 and 2002a). With the benefit of unpublished input-output tables, the consumption of tourism product could be factored into the conventional industry classification, showing the contribution of tourism to each main industry group.

While the satellite accounts provide a recent value of tourism Gross Regional Product, it begs the question of how much tourism is attracted by the Reef itself. Attempts to measure reef-based tourism in the past have now been shown by the tourism satellite accounts to underestimate the true proportion of total tourism – furthermore no regional detail has been available. It was therefore a major quest of this study to attempt to find another measure.

This measure was provided by a principal components analysis of holiday-makers in Queensland in 1994-95. Five factors were identified for inbound, interstate and intrastate visitors, respectively (Pearce et al. 1997). These factors provided a basic distinction between tourists attracted to the Great Barrier Reef regions, tourists whose preferences pointed them towards the Gold and Sunshine Coasts, and tourists who had other objectives, such as visiting friends and relatives. The analysis allowed estimates of 'reef-interested' tourism to be made for each region, in terms of net value of production, gross regional product contribution, and employment. These estimates exceed previous attempts to measure reef-based tourism by a factor of three.

The analysis in this chapter shows that the total tourist Gross Regional Product for the five regions along the Great Barrier Reef exceeded $2 billion in 1998-99. Of this, 43% was generated in Tropical North Queensland, while the contributions of the four remaining regions varied between 12% (Fitzroy) and 16% (Mackay including the Whitsundays). However, the reef-interested proportion varied widely from an estimated 90% in Tropical North Queensland to 23% in Wide Bay-Burnett. Hence, the distribution of reef-interested tourism is even more heavily skewed towards the Far North (57%), with the Northern region and Mackay-Whitsundays accounting for 14% each, Fitzroy for 10% and Wide Bay-Burnett for only 5% of the five regions.

9. Fisheries and Other Reef-based Activities

Overview

Fisheries and other reef-based industries

The purpose of this chapter is to estimate the economic value of reef-related industries for the regional economies along the Great Barrier Reef coast, as well as reviewing issues associated with these activities. The main activities are associated with fisheries but others need to be mentioned too:

- *Commercial fisheries* in the wild including trawling, reef line fishing, inshore fish netting and crabbing; and the harvesting of corals, bêche-de-mer or sea cucumber, trochus shells, bloodworms and aquarium fishes;
- *Aquaculture*;
- *Recreational fishing* by local residents and tourists, including charter fishing;
- *Bio-discovery* (bioprospecting); and
- *Research and development activities* related to the Great Barrier Reef, which provide much or most of the essential knowledge about reef-related issues.

Relative to tourism, these reef-related industries may be small in economic terms. Quite apart from the environmental considerations, however, fisheries and related activities are important for several economic and social reasons:

- Commercial fishing activities and fishers are an important part of the socio-economic web of the coastal communities;
- Aquaculture has been identified by the Federal Government as a top growth industry for the Australian rural sector and is a potentially significant but currently small-scale industry in North Queensland;
- Recreational fishing is practised by an estimated 25% of the Queensland population at least once a year and is considered by many as an important part of the regional lifestyle;
- The potential of bio-discovery is unknown but potentially enormous. It depends on the retention of biodiversity in the Marine Park. Within the context of this study, we can only note rather than explore this potential in detail.

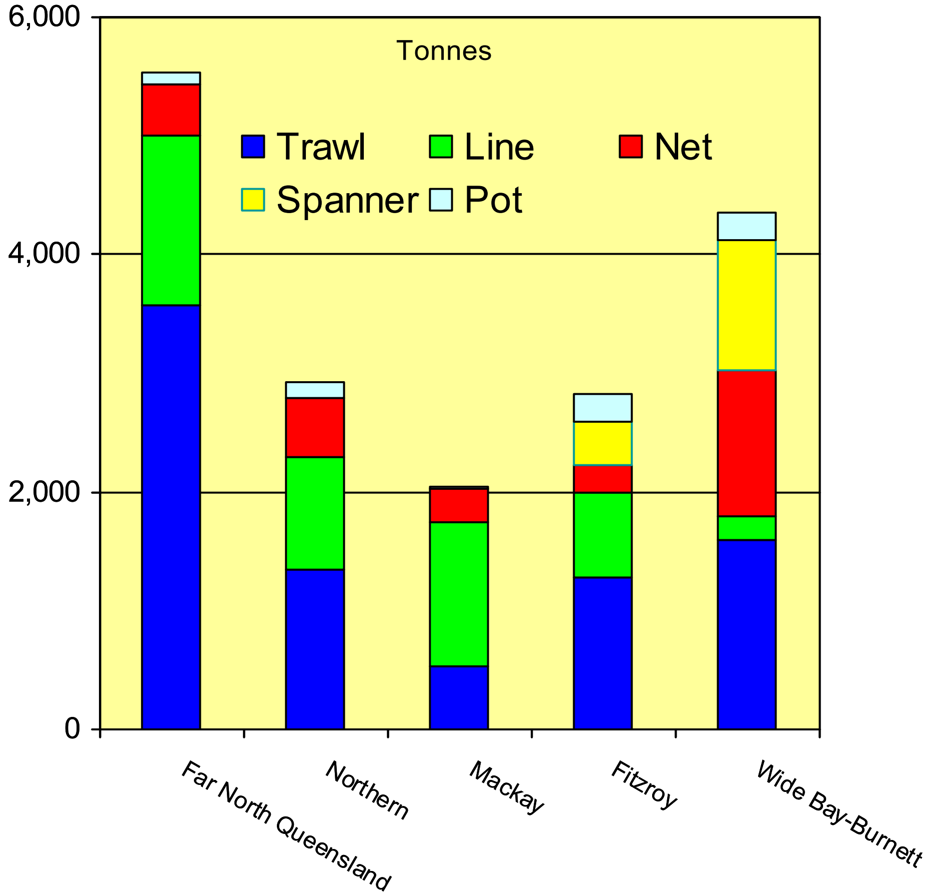
Commercial fisheries of wild stock

Main industry activities

Commercial fisheries are defined as commercial fishers operating in the wild. Queensland's fisheries were thoroughly investigated and reported on in 2002 in *Queensland's Fisheries Resources: Current condition and recent trends 1988-2000* (Williams 2002a). It investigates issues associated with commercial species, areas and activities:

- Trawled species, notably tiger, endeavour and other prawns, and scallops;
- Line-caught species, which are particularly important in the Great Barrier Reef. Coral trout, Spanish mackerel and red throat emperor are the top catches;
- Inshore species including barramundi, mud crab and various types of shark, which are all caught in significant quantities, using different fishing gear such as nets and pots.

The quantity and estimated value of catches of most species is available for 1991-97 in an investigation of direct use values for the Great Barrier Reef region (KPMG 2000). The statistics are shown in Table C1. The total tonnage fluctuated from year to year but showed a rising trend over the six years as a whole. So did the value of production, based on estimated averages for each species which were not varied over



Source: Williams et al. 2002

Figure 45: Annual commercial fisheries harvest in each GBR region classified by method. The five regions represent 73% of the total Queensland east coast harvest, Brisbane and Moreton the remaining 27%.

the period (bottom panel of Table C1).

Accepting this valuation method as the only one available, prawns are clearly confirmed as the prime species. Their estimated value in 1997 accounted for exactly half the estimated gross value of production of commercial fisheries: $68 million of a total $136 million. The other main species in 1997 were scallops ($16.8 million), coral trout ($13.5 million), crab ($9.4 million) and lobster ($8.3 million). The other identified species in Table C2 are Spanish mackerel ($4.6 million), red throat emperor ($3.8 million), shark ($1.9 million) and barramundi ($1.1 million).

A subsequent estimate for 2000 (Hall and Kenway 2002) puts the total catch in the Marine Park at $145 million, of which trawling for prawns, scallops and other species in the Great Barrier Reef lagoon, between reefs and along the coast accounted for $73 million (before restructuring of the trawling industry reported below). Coral reef fisheries had an identified value of $27 million, including coral trout ($15 million), Spanish mackerel and red throat emperor ($3.5 million each). Estuary and coastal net fishing was valued at $8 million and pot fishing for mud crab at $7 million.

Queensland's Fisheries Resources (Williams 2002a) contains a number of graphs showing catches by species at 30 locations in the Marine Park and six further south. Reading off these graphs makes it possible to review the different types of fisheries in some detail. The distribution of tonnages harvested along the east coast by method of fishing is shown in Table C2, with more detailed information in Tables C3 to C7. The main features are shown in Figure 45. The Great Barrier Reef regions accounted for 73% of the total tonnage (average 1998-2000). Table C2 also shows total tonnages for individual locations which are aggregated to regional totals in Figure 45.

Far North Queensland accounted for the largest part of commercial fisheries activities: 23% of the east coast total or 31% of the Great Barrier Reef regions. Trawling was a dominant activity. Seventy percent of the harvested tonnage was from waters between Cape York and Cape Tribulation, the remainder from between Cairns and Cardwell.

Line fishing accounted for most of the remaining harvest in the Far North. This fishing technique is most intimately associated with the Reef with 96% of the total east coast catch occurring there (further detail below). The main line fishing activity is in the Far North with Mackay Statistical Division not far behind, Northern region in third position followed by Fitzroy, and with line fishing a minor part of the total activity in Wide Bay-Burnett. Net fishing was most important in Wide Bay-Burnett, which used the most diverse techniques among the five regions. Spanner crab fishing is concentrated in South Queensland with the Town of 1770 in the Miriam Vale Shire of Wide Bay-Burnett region accounting for 30% of the Queensland total.

Further detail is shown for the main types of commercial fisheries in Appendix C. *Trawling* in Far North Queensland almost exclusively yielded prawns (Table C3). They accounted for 96% of the total trawling tonnage compared with 71% in the Northern region, 74% in Mackay, 59% in Fitzroy and 31% in Wide Bay-Burnett. Scallops, bugs and other species become relatively more important going further south. The Far North, however, remained the most important area for trawling, with 32% of the total Queensland catch in 1998-2000 compared with 11-12% in the Northern, Fitzroy and Wide Bay-Burnett regions and 5% in Mackay.

The Far North is therefore the area most influenced by the restructure of the trawling industry that took place from the beginning of 2001. Approximately 30% of the Marine Park was closed to trawling, bringing the total closed proportion to 50%. In addition, 98 trawling licences were bought back by the Queensland government through a joint $20 million Commonwealth-Queensland scheme. The Commonwealth Grants Commission notes in a review of Federal Budget measures (CGC 2001): 'Funding is intended to achieve a significant reduction in fishing effort (of around 15%) in the World Heritage Area and contribute to the protection of world heritage values. … [The scheme is a] structural adjustment to permanently remove fishers from within the Great Barrier Reef Marine Park.'

As already noted, east coast *line fisheries* are concentrated on regions along the Great Barrier Reef (96% of the total catch). Table C4 shows that the Far North accounted for 31% of the Queensland total, followed by Mackay (25%), Northern (20%), Fitzroy (15%) and Wide Bay-Burnett (4%). Coral trout accounted for 45% of the total catch in the Mackay region, 38% in the Far North and 32% in the Northern region. Spanish mackerel represented about 20% of the catch in Far North Queensland and the Northern region. Red throat emperor was most prevalent in the Northern and Mackay waters, accounting for 23% and 20%, respectively. Further south in Fitzroy and Wide Bay-Burnett, other species represented two-thirds of the total catch.

The total tonnage taken by line in coral reef areas increased from 1,885 tonnes in 1988 to 4,475 tonnes in 1998, then subsided in 1999 and especially in 2000 when the catch was 4,095 tonnes (Table C5) but jumped to 4830 tonnes in 2001. The coral trout catch more than doubled from 817 tonnes in 1988 to 1,672 tonnes in 1996. Lower catches around 1,400 tonnes in the three subsequent years have been attributed to cyclones, while increased catch in 2000 (to 1,528 tonnes) is almost certainly due to high export market demand. Table C5 also shows that red throat emperor reached a maximum of 774 tonnes in 1997 but subsided to around 630 tonnes in the three subsequent years, while Spanish mackerel catches were highest in 1999 (709 tonnes) but fell to 527 tonnes in 2000. In September 2003, the Queensland Government approved the Coral Reef Finfish Fishery Management Plan which sets a total catch level for the fishery of 3061 tonnes and includes specific catch levels for coral trout and red-throat emperor within the overall quota.

Contrary to trawling and line fishing, the main *inshore fishing* activity, coastal and estuarine net fishing, is practised mainly on the southern east coast (Table C6). The five Great Barrier Reef regions accounted for 48% of the total net fishing catch; Wide Bay-Burnett alone for 21%. Pot fishing, on the other hand, was well and truly based in the north, with Far North Queensland and the Northern region each accounting for 29% of the total east coast catch, and all five regions along the Marine Park for 93%.

Inshore commercial fishing in the Great Barrier Reef regions (from Cape York to the Town of 1770) is subject to a special table in *Queensland's Fisheries Resources* (Williams et al. 2002). It is summarised in Table C7. The total catch of these activities increased between 1996 and 2000. After averaging about 1,200 tonnes from 1989 to 1996, there was a jump to about 1,600 tonnes in 1997 and 1998, 1,725 tonnes in 1999 and 2,059 tonnes in 2000. The increase was due to rising catches of mud crab (from 290 tonnes in 1996 to 646 tonnes in 2000), shark (220 to 465 tonnes), barramundi (128 to 214 tonnes), and grey and spotted mackerel (89 to 180 tonnes).

As far as mackerel is concerned, however, there have been large fluctuations in the catch and a big increase to 145 tonnes for spotted mackerel in 2000, way above any previous catch. Increasing concern for the species by conservationists, scientists and recreational fishers caused the Queensland Government to ban net fishing of spotted mackerel from 1 May 2003.

Mark Fenton and Nadine Marshall conducted a special survey of the commercial harvest industry (Fenton and Marshall 2001b). Like the main commercial fishing activities described above, regulation of this small industry is part of commercial fisheries management in Queensland. It collects aquarium fish, bloodworms, coral, bêche-de-mer and other objects from the Great Barrier Reef area under licence. The industry is estimated to have a gross value of production of $15 million, of which by far the largest component is aquarium fish ($10 million), with trochus and sea cucumbers contributing $2.7 million, bloodworms $1.4 million and coral harvesting $400,000. Other minor activities make up the balance.

In conclusion, commercial fisheries in the Great Barrier Reef World Heritage Park increased rapidly up to the second half of the 1990s and have remained at potentially unsustainable catch and effort levels. Trawling is subject to a management plan that caps further increases in fishing effort. Far North Queensland has been a particularly important area for trawling activities, and the industry restructure in 2001 would have affected communities on the coast of that region more than regions further south. Furthermore, almost all line fishing along the east coast takes place in the regions along the Reef, and although this activity is more evenly distributed than trawling, the Far North again accounts for the greatest catch. Restrictions of commercial line fishing on the coral reefs, mainly through extensions of the Representative Areas Program discussed in Chapter 7, will therefore again primarily affect communities in the Far North region, though significant effects would also be felt in the Northern and Mackay regions.

Fisheries and tourism

A survey of restaurateurs in the Cairns region (Port Douglas to Mission Beach) showed that 65% of meals consumed were by visitors to the region and that seafood-based meals represented 45% of the total number of meals in a normal week. The seafood was overwhelmingly from local suppliers (though it was unclear whether it was always locally harvested). Some 95% of the restaurants surveyed served seafood-based meals, two-thirds actively promoted local seafood dishes on their menus and 78% felt that customers expected local seafood to be available on the menu. At the time of the survey, the market was expected to double by 2006 from an estimated $35 million, of which $23 million was from visitors to the region (Turton et al. 1993). Most of the growth in demand would come from increases in tourism.

Special analysis of origins of commercial fishers

The compact disc which accompanied Fenton and Marshall's analysis of commercial fishers (Fenton, Marshall and Edgar 2001) made it possible to reverse the view provided by their report (Fenton and Marshall 2001a), looking at the origin of fishers of the various Great Barrier Reef regions rather than the characteristics of fishers living in these regions. The CD contains a numbered grid of the Marine Park area, which was allocated among the adjacent regions. The regions were identified by extending the lines of latitude easterly from where statistical division boundaries intersect the coastline – a similar definition was used by the Productivity Commission (PC 2003:63).

While not all areas are specially identified in the tables, there is enough information to establish that the home port for the great majority of all fishers lies within the Great Barrier Reef area (Table C8). The main exceptions are the waters adjacent to the Mackay/Whitsunday region, where an identified 16.7% lived in the Mooloolaba, Brisbane or Southport town resource clusters, and the combined Fitzroy/Wide Bay-Burnett regional waters, where an identified 11% lived in Mooloolaba and Brisbane and an unknown additional number (<5%) in the Southport town resource cluster.

Perhaps the most interesting result of the analysis of home port was the analysis of the whole Great Barrier Reef (right-hand column of Table C4). It reveals Bundaberg as the leading home port for commercial fishers of the Reef (16.8% of all observations), followed by Cairns (10.6%), Townsville (9.9%), Gladstone (9.3%), Innisfail (8.3%), Mackay (6.9%) and Yeppoon (6.3%). These ports were followed, in order, by Brisbane, Bowen, Mooloolaba, Hervey Bay and Tin Can Bay (all by definition less than 5% in accordance with the rules for setting up the table in the software program).

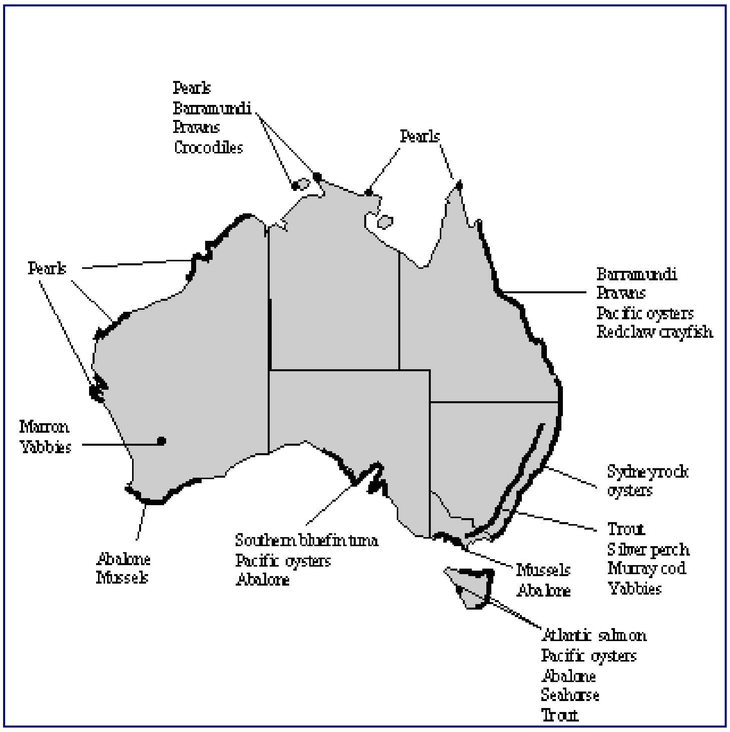
This analysis shows that home ports in the southern part of the Great Barrier Reef area are relatively important throughout the area, given that the largest catch is in the Far North followed by Wide Bay-Burnett. On the other hand, Cairns-based businesses are most likely to fish in the Gulf of Carpentaria as well as the Great Barrier Reef Marine Park, which probably explains why Cairns is the largest home port (see Chapter 7, Table 11) in terms of production value (though Bundaberg has slightly more employees) but Bundaberg has the largest share of the actual fishing on the Reef.

The socio-economic features of the fishers of the region are specified in detail in the standard tables generated from the analysis. Table C9 shows a selection relating to operators' age, gender distribution and family characteristics, years living in the home town and working in the industry, education levels, housing tenure, and business details. The standard tables contain more information relating to resource use, business purchases, domestic sales, home purchases and employees' shopping. We commend again this rich source of socio-economic analysis of the industry. As an additional feature, the CD distinguished between two different behaviour patterns among commercial fishers: 'roamers' who work a large area and 'localisers' who fish a restricted section only. Not surprisingly, the 'roamers' were more likely to come from faraway home ports than the 'localisers'.

Aquaculture

Fish and crustacean marine farming is a declared growth industry in Australia. The right-hand map shows that it is already widespread. The map was taken from the web site of the Commonwealth Department of Agriculture, Fisheries and Forestry (www.affa.gov.au).

The east coast of Queensland is identified as providing aquaculture facilities for barramundi, prawns, oysters and redclaw crayfish. This represents only a small proportion of Australia's total aquaculture capacity, but the potential is regarded as significant, including the regions adjacent to the Great Barrier Reef.



Aquaculture is considered a prime candidate for expanding Australia's rural industry potential, as most recently expressed in a joint media release by the Federal Minister for Forestry and Conservation Senator Ian Macdonald and Federal Minister for Industry, Tourism and Resources Ian Macfarlane (Macdonald and Marfarlane 2002). 'Tripling Australia's aquaculture production to $2.5 billion and creating 29,000 new jobs by 2010 are the cornerstones of the Federal Government's Aquaculture Industry Action Agenda.' Aquaculture is one of Australia's fastest growing primary industries, both in terms of production capacity and in finding new markets, and it is the economic mainstay of many communities. Aquaculture in Australia is currently worth approximately $746 million and employs around 7,000 people, mostly in regional areas, according to Senator Macdonald.

The Australian Department of Agriculture, Forestry and Fisheries points out that Australian aquaculture production, though modest in a global context, is increasing at about 13% per year with improved technology, investment interest, and the consolidation of markets for aquaculture products:

- Commonwealth, State and Territory governments are promoting Australia's clean waters image and encouraging aquaculture investment.

- The viability of aquaculture operations depends on issues such as access to suitable land and water resources, assured feed availability, assured markets and the long-term management of environmental impacts and disease.

- Conflicting resource use by environmental and recreational interests constrains the development of coastal sites. Possible alternatives for expansion involve offshore aquaculture, the use of inland saline waters and the re-use of irrigation waters.

- Technological advances in feed production, genetic improvement of culture species and improvements in husbandry practices can be anticipated to offer potential for significant increases in quality and productivity from aquaculture.

In Queensland, aquaculture between 1993-94 and 2000-01 increased its proportion to total fisheries from 10.1% to 22.7%. Total fisheries increased from a gross value of $231.1 million to $247.5 million (essentially they stagnated over this period), while the value of aquaculture rose from $23.4 million to $56.1 million (that is, without aquaculture total fisheries would have been lower in 2000-01 than seven years previously). These figures may be found in the Department of Primary Industries *Report to Farmers: Queensland Aquaculture Production Survey 2000-2001* (Logegeiger 2002).

Australia accounts for a tiny proportion of world aquaculture production (estimated at 0.6% by value) despite apparently contributing something like 60% of the global research. It has been suggested that Australia is capable of running technologically advanced operations which comply with issues of water quality, invasion of alien species, visual pollution and disease, and with the potential to achieve technical breakthroughs in areas such as low-energy reticulation systems and polyculture using algal substrates.

The Queensland Department of State Development (QDSD 2002) notes that the expansion of local aquaculture has not been as quick as in other Australian states largely because of the strict environmental restrictions which severely limit the locations at which marine aquaculture can take place. 'It is likely', it continues, 'that Queensland aquaculture will continue to be governed by some of the strictest environmental controls in the world. This will continue to restrict the pace of growth of industries such as the prawn and barramundi sector.' However, the next paragraphs indicate that while growth may be restricted, it could still be quite strong.

The existing main aquaculture species are prawns and barramundi. The industry produces about 2,500 tonnes of prawns and 500 tonnes of barramundi each year (Williams 2002a:2). According to QDSD 2002, 'expansion forecasts put the potential for the Queensland prawn industry at around $100 million (farm gate value of production) in the next five years [compared with $45 million in 1999-2000]. It is probable that this controlled expansion of the industry will take place especially in the Bowen and Mackay areas of the state and farms will be larger, internationally linked, corporate operations.'

Meanwhile, there are currently about 40 licensed aquaculture operations adjacent to the World Heritage Area. Operations include pond and tank-based aquaculture for finfish and crustaceans as well as hatcheries. Aquaculture operations adjacent to the Marine Park can be considered as users of it for the assimilation of aquaculture waste.

The outlook for the barramundi industry according to the Department of State Development is a potential of about $30 million (farm gate value of production) in the next five years (compared with $4.9 million in 1999-2000 for 527 tonnes). 'It is probable that this controlled expansion of the industry will take place especially in the tropical far north of the state. Increasingly operations will be larger, taking advantage of economies of scale and greater market penetration.'

Other species still have to prove their potential. Redclaw is a species of freshwater crayfish native to tropical Queensland and the Northern Territory. They occur predominantly in the rivers flowing into the Gulf of Carpentaria and some easterly flowing rivers of the northern Cape York Peninsula. Production is currently small and expansion forecasts of considerable growth potential have not yet convinced investors to commit to significant projects. Most industry growth is expected north of Bundaberg and in the west of Queensland.

Despite this slightly pessimistic assessment in QDSD 2002, production at licensed redclaw crayfish farms in Queensland has increased from 60.1 tonnes in 1997-98 to 86.3 tonnes in 2000-01, with the total value growing from $777,000 to $1.1 million (Logegeiger 2002). Other species may become economic propositions. In the meantime, marine prawn farming and hatcheries appear likely to provide the greatest absolute potential given the appropriate economic and environmental circumstances.

Recreational fishing

General characteristics

Since the start of the Queensland Government's RFISH program for gathering knowledge about recreational fishing activities (described in DPI 2002), three surveys of fishers have been carried out (1996, 1998 and 2001), supplemented by diary programs in 1997 and 1999 to establish the number of fish and crustaceans caught by these fishers. The information is important on socio-economic grounds as well as for its main user, the Queensland Fisheries Service, which is responsible for managing Queensland's marine and freshwater fisheries and need to know the location and frequency of recreational fishing and what species are caught and harvested.

Recreational fishing is one of the most frequent leisure activities in Queensland. In both 1996 and 1998, 33% of households had at least one member aged 15 and over who had fished, crabbed or prawned for recreation during the previous 12 months. The proportion was higher for coastal Queensland from the Sunshine Coast to the Far North (DPI 2002, Roy Morgan Research 1999).

The 2001 survey is reported to show that 24.6% of Queenslanders aged 5 years and over fished during the past year (PC 2003:357). The 1998 survey suggested that 848,000 Queensland residents aged 5 years and over (26%) went fishing for leisure that year. The proportion was down from 28% in the 1996 survey.

Recreational fishing tends to be a male activity, with 33% of males and 17.3% of females having fished during the past 12 months according to the 1998 survey. The proportion of males was roughly twice that of females through all age groups. The participation for males falls from 49% for 5-14-year olds to 19% for people aged 60 years and over. The comparable proportions for females were 33% for children and only 6% for the oldest age group. The typical recreational fisher according to DPI (2002) is either a male aged 15-49 years (of whom about 38% had fished during the past year) or a 5-14 year-old of either gender.

Sixty percent of the respondents went fishing less than once a month, 22% once a month, 10% fortnightly and 7% weekly or more often.

Saltwater fishing dominates: 69% only went saltwater fishing while 7% went freshwater fishing only, and 23% did both. Brisbane and Moreton dominated saltwater fishing with 61% of the State total fishing there, compared with 14.5% in Wide Bay-Burnett and 10% in the Far North. Most saltwater fishers did not target particular species (63%); those who did mainly targeted whiting except in Far North Queensland (15%), mud crab in all coastal areas (7.5%), barramundi and mullet in northern and central northern areas, and coral trout and mangrove jack in the north.

Thirty-one of saltwater fishers fished from the shore only, 28% from boats only, and 41% from both. One-third lived in a boat household, two-thirds didn't.

In 1997 the estimated catch by recreational fishers in the five regions along the Reef was 15.8 million fish and crustaceans (excluding prawns), of which they harvested 7 million and released 8.8 million. The total Queensland catch in that year was 46.1 million fish and crustaceans (harvest 21.7 million). The estimated catch along the Great Barrier Reef in the second survey in 1999 was 19.6 million fish and crustaceans, of which 9 million were harvested and 10.6 million released. The total estimated catch for the State in 1999 was 48.4 million (harvest 23.7 million). (Higgs 2001:16)

Fishers living in the Far North represented 20.4% of the harvest in Great Barrier Reef regions in 1997 and 19.6% in 1999. The proportions for the other four regions were: Northern 17.0% and 25.1%, Mackay 12.2% and 9.3%, Fitzroy 18.4% and 15.3%, and Wide Bay-Burnett 31.9% and 30.6%. These distributions differ from those found for commercial fisheries in the wild. Higgs (2001) presents a number of tables showing regional detail for individual species, which it would lead too far to discuss here.

The estimated 1999 harvest in the five regions along the Reef included an estimated 821,000 crabs, 205,000 mackerel, 290,000 coral trout, 131,000 red throat emperor and 112,000 barramundi, according to the detailed tables in Higgs (2001).

Is expenditure by recreational fishers relevant to this study?

Much has been written about the motivation for going fishing for recreational reasons – when people think the benefit, however measured, exceeds the cost (Blamey 2002). From our point of view, however, the economic issue is not the utility to the recreational fisher but whether his or her activity has an impact on the regional economy. These issues appear to have been confused and clarification is needed.

Total expenditure by recreational fishers in Queensland is claimed to be around $300 million per annum (Williams 2002:3). An even higher estimate is implicit in ABARE's work for the Productivity Commission's 2002 inquiry, which suggests $187 million for the Great Barrier Reef regions alone (see Table D6, which is based on PC 2003). Surveys carried out for Sunfish Inc. estimate that recreational fishers in the Mackay/Whitsunday region spent $42.6 million based on questionnaire responses relating to September 2001-January 2002 (Murphy 2002a), with an even higher figure of $69.9 million for the same period in Townsville/Thuringowa (Murphy 2002b). If similar surveys were carried out for the rest of the Great Barrier Reef, the total would exceed the ABARE estimate.

There is, however, a basic problem with all these estimates, because it is unknown where the recreational fishers live. According to the Sunfish surveys, the vast majority of the respondents are locals. People visiting the Mackay/Whitsunday region on holidays accounted for only 4.6% of respondents (Murphy 2002a:34), while the proportion for Townsville/Thuringowa was an even lower 1.4% (Murphy 2002b:34). The questionnaire asked respondents why they lived in the region, to which 13.1% of respondents in Mackay/Whitsunday claimed that fishing access was the sole reason, while 27.5% ticked lifestyle, 1.4% health reasons, and 58% ticked all three reasons. The comparable proportions for Townsville/Thuringowa were fishing access 13.7%, lifestyle 26.2%, 0.4% health and 59.7% all three reasons.

The conclusion drawn from these responses, that over 70% of recreational fishers mentioned fishing as one reason for living in the area and that by implication is why they do so, is highly debatable. Firstly recreational fishing opportunities are not confined to the surveyed areas (though the Great Barrier Reef is a drawcard), secondly the fishers would include a large number who live in a particular area for work reasons and others who are long-term residents. Thirdly, the questionnaire simply asked the respondent to tick whether he or she lived in the region for lifestyle, health, fishing access, or all [these reasons]. There was no prompt to suggest that other reasons would be relevant, or more important.

While these surveys are valuable for other reasons, they cannot be used to support a notion that fishing access has a huge impact on where people live. The justification for claiming all expenditure by local anglers and other recreational fishers as adding to the economic base of a town or region would be that 73.4% of the estimated 35% of the coastal Queensland population that fish for leisure would not live in Townsville/Thuringowa if there was no fishing access (reducing the population from 145,000 to 108,000 persons).This is clearly unrealistic.

A small minority might not be living in these areas if it weren't for the fishing (possibly a town like Cardwell has gained some population of retired people attracted by the fishing). Maybe slightly more people stay at home fishing rather than go on holidays. We don't know. In our opinion, the main impact of disappearing fishing access would be on local spending patterns, given that incomes would remain more or less unchanged, and the value of the catch would provide very limited savings since these people are recreational, not commercial, fishers. There would be less need for businesses selling fishing tackle, professional bait collectors and boat builders. The savings would presumably be channelled into other leisure activities, or used to go fishing elsewhere which would be a negative impact of local fishing access disappearing. Again this is all very speculative – we just don't know.

In any case, the visitor content of recreational fishing would be captured by the tourism satellite accounts.

The charter fishing industry

Commercial charter fishing became subject to a compulsory logbook system in 1996 for commercial fishing charter and tour guide operators. In 1998, 358 charter operators fished for 15,400 days, corresponding to 103,400 angler days (Higgs 2002).

Fenton and Marshall's third study (2001c) is about the charter fishing industry. The authors identified 257 active tourism charter licence holders in Queensland, of which 97 were outside the Great Barrier Reef town resource clusters (mainly in Brisbane and on the Gold and Sunshine Coasts). Most businesses along the Great Barrier Reef coast were in Cairns (40) and Port Douglas (15), Townsville (20), Gladstone (28) and Hervey Bay (17), with Mackay accounting for 11 and Airlie Beach in the Whitsundays region for eight.

Fishing trips are chartered for day, overnight or extended trips, with reef fishing being the most popular activity for each type (66% overall, ahead of game fishing (pelagic) with 20% and estuary fishing with about 12%). The total gross value of production for this industry was estimated at $34 million.

Catering for tourists, this amount would be part of the tourism expenditure statistics and it would be double counting to include it again. However, the socio-economic data collected for the study again provide insights that would not otherwise have been available. Even more than the commercial fisheries industry, the charter fishing industry is basically composed of small businesses, with a mean gross production value of about $230,000. Two-thirds of businesses have a turnover of less than $100,000 and the average income per owner-operator was only $28,000. These operators tend to be long-term residents of their town (average 19 years), and have spent an average of 11 years in the charter industry.

Indigenous fisheries

In contrast to the general Australian community, Indigenous cultures view the sea as extensions of their traditional land, 'with all the possibilities of identity, ownership, private use rights and management responsibilities that apply to land. Some Aboriginal people today refer to the sea as "saltwater country".' (Smyth 2002:222).

Many Indigenous communities along the Reef undertake traditional fishing, hunting and collecting, and there is increasing interest in taking up commercial fishing, especially on Cape York Peninsula.

Indigenous fisheries generally occur close to communities and in conjunction with hunting. It is regarded as low-intensity fishing with targeted species including estuary and reef fish, crabs, sharks, rays and shellfish. As far as the authors are aware, an economic assessment of the value of Indigenous fisheries has not yet been carried out.

Bio-discovery

The search for new discoveries through bioprospecting goes on, especially in the Daintree National Park and on the Great Barrier Reef, which with their rich biodiversity provide the potential for discovery (see Part 1, p 28). To take but one example, there are an estimated 350 cone shell species on the Great Barrier Reef, of which probably only 50 have been looked at in detail. The venom from species of cone shells on Queensland's reefs, and from spiders, may hold the key for the effective management of chronic pain, making drugs like morphine obsolete. The potential income from this research is huge: the worldwide market for pain therapeutics is approximately $US22 billion a year (Watson 2002).

Some major initiatives are taken by the research institutions adjacent to the Great Barrier Reef, notably the Australian Institute of Marine Science (AIMS). AIMS enters into agreements with companies wishing to develop its discoveries, in return for an agreed royalty income based on the price of the final product (Tooth 2001). Elsewhere, as another example, the major pharmaceutical and agrochemical corporation AstraZeneca's facilities at Griffith University in Brisbane can assess around 80,000 biological extracts per day, using a high-volume chemical screening process. This international company came to Queensland in 1993 to discover new drugs, and entered into a joint-venture agreement with the university (Tooth 2001).

The AIMS biodiversity group seeks to find and commercialise natural chemical products (AIMS 2002). One spin-off from this research has resulted in new methods of screening seafood toxins, which will increase consumer safety. The research is based on the ecological precept that 'bioactive metabolites are produced by organisms for a range of purposes including relief from environmental stress, chemical signalling, and aggression among species. These natural processes can inform the search for functional biomolecules directed towards specific applications. For example, new sunscreen products were discovered through basic research into the tolerance of reef corals to ultra-violet radiation.'

It is beyond the brief of this report to go into detail about the potential for discovery. It clearly provides another argument for conserving the biodiversity of the Great Barrier Reef ecosystem (see also Part 1, Chapter 3). There are, however, some issues which require resolution, in particular in relation to traditional owners. The conflicting perspectives of Indigenous people and conventional legal interpretation need to be resolved (Tooth 2001):

- Traditional owners in many cases have developed knowledge over perhaps thousands of years, knowledge which a bioprospecting company can access and gain ownership of without compensation.

- Indigenous people claim ownership to land and marine areas, including the organisms growing there. But according to intellectual property expert Brad Sherman of Griffith University, a corporation can obtain specific knowledge from an Aboriginal group and, in the absence of any specific contractual arrangements to the contrary, develop this into a commercially viable product, and owe the Aboriginal group nothing.

These issues require resolution if conflict is to be minimised and a harmonious development ensured of the potential for bio-discovery. David Epworth of the Cape York Land Council's Balkanu Aboriginal Development Corporation summed the issue up as follows, distinguishing between copyright and [other] intellectual property rights (Tooth 2001):

> *I guess the issues, critically for us, are that most of the mechanisms of protection aid people with resources over people without resources. So if we're looking at reform, we need to ensure that intellectual property protection aids those people who cannot actively protect it themselves. So we have copyright, instigation of copyright protection where it was covered broadly, it was by default protected. We need the same type of mechanisms in intellectual property. So people's rights and genetic resources and in intellectual property are protected by default, rather than have to be actively pursued in an adversarial system. Aboriginal people and small rural people, agrarian people around the world, will never be able to beat the large pharmaceutical companies or national governments.*

Research and development activities

While this study provides no specific costing of research and development related to the Great Barrier Reef fisheries and other activities, a number of institutions are important stakeholders and have a major influence on matters pertaining to the World Heritage Area. It would be surprising if these activities do not grow significantly in future with the continuing need for research and monitoring activities under climate change. The main institutions are centred on Townsville:

- Much of the organisation of *James Cook University* (which also has a campus in Cairns) is guided towards a wide range of scientific and social research into matters of the Great Barrier Reef and the main industries based there. JCU research is quoted extensively through this report. The Townsville Declaration in Chapter 5 calls for additional resources for universities and other research institutions to bridge significant persisting knowledge gaps.

- The *Australian Institute of Marine Science* (AIMS) is based at Cape Ferguson near Townsville. The AIMS web site lists the following strategic directions:

    - Deriving benefits from marine biotechnology
    - Exploring and conserving marine biodiversity
    - Measuring human impacts in coastal marine ecosystems
    - Predicting climate impacts upon marine ecosystems
    - Sustaining coral reef ecosystems.

Conservation and biodiversity projects include biodiversity surveying for regional marine planning, the status and trends of coral reefs (Sweatman et al. 2002), the global coral reef monitoring network (Wilkinson 2002), reef futures, and coral reefs and climate change. Marine technology projects include tropical aquaculture, and marine environmental biochemistry and chemical ecology. AIMS also has a strong presence in coastal management research through its coastal processes group.

- Considerable government and commercial funds are invested in the *Cooperative Research Centre for Reef Research* (known as CRC Reef). The institution provides a very important link between scientific and industry interests in the Great Barrier Reef, and initiates research into fisheries and fishing, sustainable tourism, the environmental impact of ports and shipping, and innovative engineering such as best-practice mooring and pontoon design, and an atlas of wave conditions during cyclones across the entire Great Barrier Reef .

- Apart from its many administrative and overseeing roles, the *Great Barrier Reef Marine Park Authority* (GBRMPA) initiates and undertakes significant applied research, much of it related to fisheries including the Representative Areas Program of no-take zones (RAP).

- Other institutions with a specific focus on reef ecology and physiology in general and corals in particular include the *Centre for Marine Science* at the University of Queensland, which includes the Heron Island Research Station at the southern end of the Reef among its responsibility areas. James Cook University also has significant capacity in the area of coral reef ecology, with research capacity at Orpheus Island.

Conclusion

This chapter has concentrated on the ecFonomic and social value of fisheries. Economically, commercial fishing for wild stock is a relatively small industry compared with other export-based activities such as tourism, mining, agriculture and grazing. As part of the social fabric of the regions concerned, fisheries assume an importance out of proportion to their economic value. This also applies to recreational fishing, a lifestyle activity mainly undertaken by residents of the region (the numerically minor tourism component attracted by charter fishing facilities is captured by the tourism statistics). Aquaculture is a potential growth industry depending on its ability to overcome environmental hazards.

Other reef-based activities covered in this chapter have not been or cannot be costed. Bio-discovery activities in the Marine Park (and the rainforests) are potentially large and therefore subject to great potential risk if the source of materials dwindles. Research and development activities centred on Townsville are likely to expand as long as there is a need for further learning and monitoring.

10. Base Projections

Economic growth assumptions

The industry projections in the Productivity Commission's draft report on industries in the Great Barrier Reef catchment and water quality issues (PC 2002) were made by the Australian Bureau of Agricultural and Resource Economics (ABARE). They provide a convenient starting point when comparing the implications of the four scenarios in Part 3.

Because we have evolved these scenarios from the global storylines developed for the third assessment report of the Intergovernmental Panel on Climate Change in the special report on emissions scenarios (documented in IPCC 2000), it is important to compare the growth assumptions behind these scenarios with the ABARE assumptions. Table 13 shows discrepancies to be taken into account in the future assessments in Part 3.

Table 13: Annual economic growth projections: ABARE compared with IPCC

ABARE (PC 2002)	2010			2020		
	Base	Low	High	Base	Low	High
World	3.7%	3.2%	4.2%	3.5%	3.0%	4.0%
Australia	3.5%	3.0%	4.0%	3.5%	3.0%	4.0%

IPCC 2000	Scenario			
	A1B	A2	B1	B2
World 2000-20	3.8%	2.4%	3.4%	3.0%
World 2020-50	4.0%	2.4%	3.2%	2.6%
Australia 2000-20 (assumed US rate except in A2)	2.3%	1.7%	2.5%	2.1%
Australia 2020-50 (assumed US rate except in A2)	2.1%	1.5%	1.6%	1.1%

Source: PC 2003, IPCC 2000

ABARE's projections are for 2001-10 and 2010-20. Low and high cases provide a one-percentage-point band around a base case. Australian economic growth is assumed to be a little lower than the world average in 2010 but to equal it in 2020.

The IPCC projections for the four scenarios are shown for the 20 years from 2000 to 2020, and to provide further perspective also for 2020-50, which is part of the frame of reference for this study. For the world, it is interesting that the strong economic growth-driven A1B scenario is still not up to ABARE's high forecast, but only just ahead of that organisation's base case. Of the environmentally more sensitive B1 and B2 scenarios, B1 comes in between ABARE's base and low cases, and B2 is compatible with ABARE's low projection. The worst-case scenario B2, which depicts a heterogenous world of economic blocks, has significantly lower growth than even ABARE's low case.

The main problem arises when the ABARE projections are compared with projections for developed countries in the IPCC scenarios. ABARE expects Australia to grow at approximately the world average, whereas the IPCC projections anticipate a strong reduction in the economic growth of industrialised countries over the first two decades of the 21st Century. It is debatable whether IPCC projects a more precipitate reduction in growth in developed economies than is strictly realistic, or whether ABARE is unrealistic in expecting largely unchanged economic growth for 20 years. The IPCC projections would be more compatible with a sustainable system, especially the rates projected in the environmentally more friendly scenarios, B1 and B2.

Another possible outcome is that the North American and European economies will slow down but the Australian economy will keep growing. We do not find this very plausible, and therefore stick to the assumption that Australia will grow at more or less the same rate as the United States, Canada and Europe – except in the business-driven fragmented A2 world, where Australia is assumed to be left out in the cold by an isolationist United States and an inward-looking European Community. It is assumed that this factor will cut two percentage points off the growth rate compared with the United States projection.

Industries

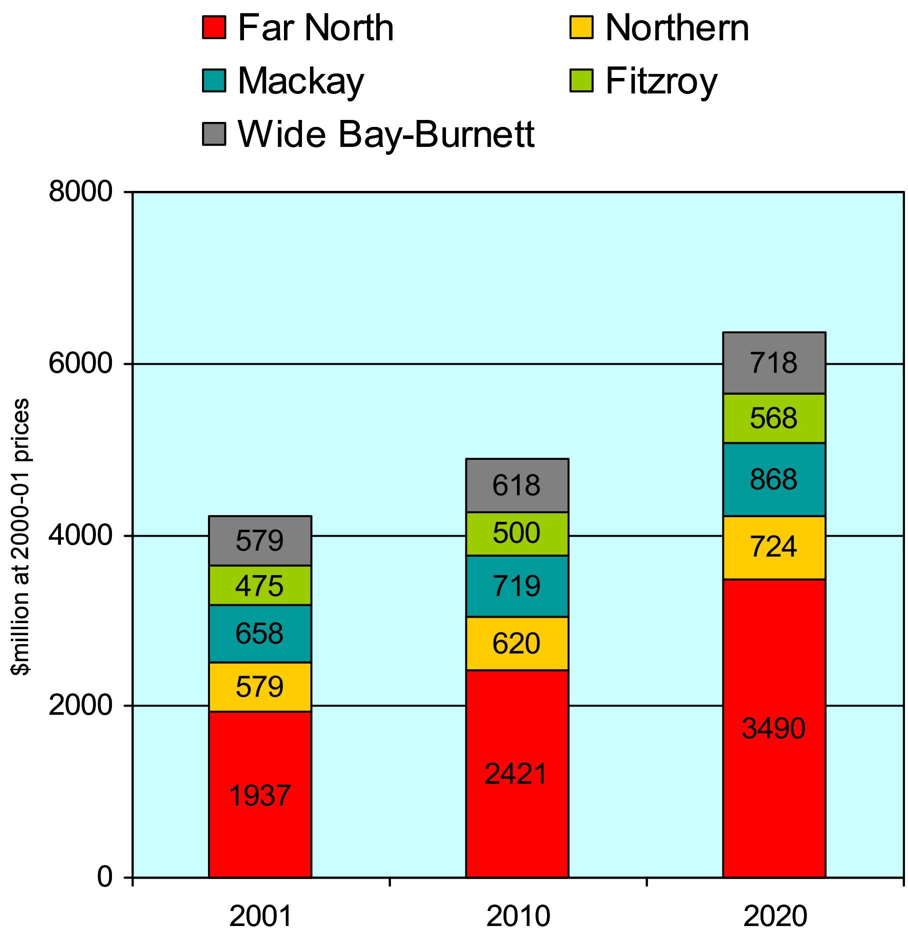
With the considerations in the previous subsection in mind, the various ABARE projections are reproduced without comment in Appendix D, again with a band of high and low assumptions surrounding the base case.

The tourism assumptions appear reasonable, if not conservative as a base case (Figure 46). Total tourism expenditure in the Great Barrier Reef region is forecast to grow from $4.2 billion in 2001 to $4.9 billion in 2010 and $6.4 billion in 2020, that is, at an average 1.6% pa during the first nine years accelerating to 2.7% pa in the second decade of the 21st Century. Apparently the projections have been revised downwards between the draft and final editions of the Productivity Commission's report, following the revisions by the Tourism Forecasting Council reported below. Domestic tourism projections in particular seem to have become quite pessimistic compared with previous forecasts.

The Tourism Forecasting Council (TFC 2002) in December 2002 revised its long-term forecasts to 2012 radically down: inbound tourist expenditure from an average 7.3% pa and accelerating through the period to 8% pa by 2012, to 4.8% pa (settling down at 5.5% pa from 2004 after the interruption in 2001 and 2002 with recovery starting during 2003). Domestic tourism has been slashed from an average of 1.9% pa projected in April, to a mere 0.3% pa from 2002 to 2012. Even that is mainly due to business travel growing at 1.1% pa, while holiday travel is expected to average only 0.1% pa and visiting friends and relatives 0.4% pa. Our current assessment is that the TFC may have over-reacted on domestic tourism while the revised projections for overseas visitors are much more realistic than the previous ones produced in April.

The origin of the inbound tourists is important. The TFC forecasts that 8.1 million visitors will arrive in 2012, compared with 4.8 million in 2002. Visits by an increasingly prosperous Asia (particularly China, India and Korea) will cause a near-doubling from that continent (other than the Middle East), from just over 2 million in 2002 to just under 4 million in 2012 (TFC 2002:2). The implied annual growth is

7.1%. The other half of visitors in 2012 would come from New Zealand and the United Kingdom (just below one million each), from the rest of Europe and the



Source: PC 2002

Figure 46: Base case ABARE projection of tourism expenditure in the GBR regions.

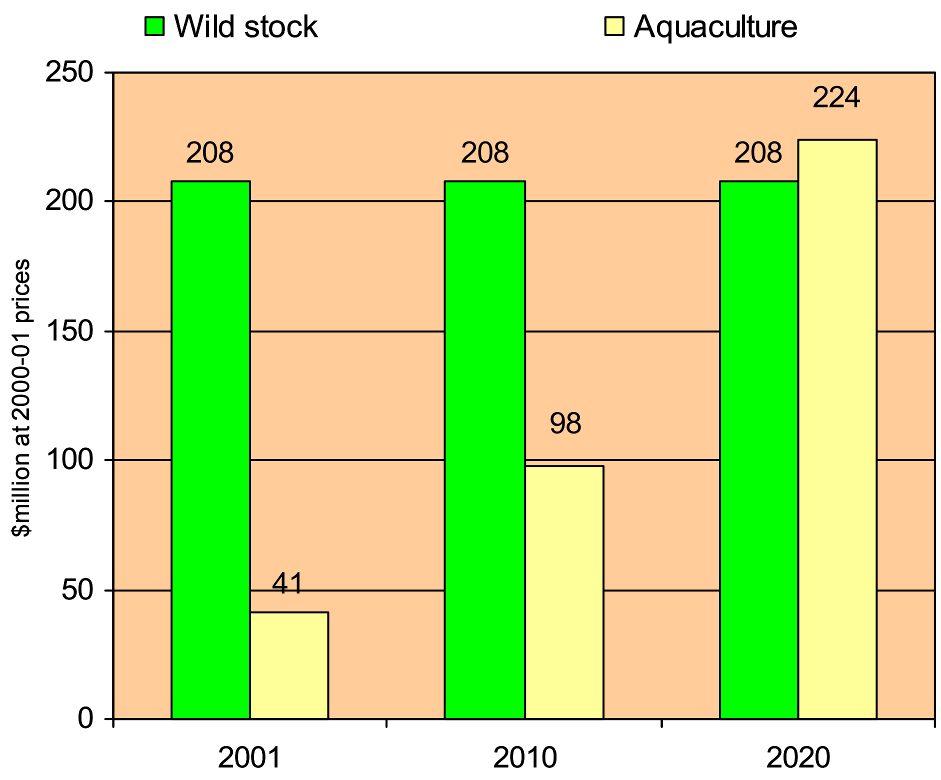
United States (800,000) and elsewhere.

All three ABARE cases assume declining commercial fisheries in the Great Barrier Reef basin (Table D5). The industry is most important in the Far North followed down the line by Fitzroy, Mackay and Northern Statistical Divisions. Because ABARE assumes that only 5% of the Wide Bay-Burnett total is part of the study area, the numbers are very small for that region, which is puzzling in view of the reputed importance of Bundaberg according to other sources (Williams 2002, Fenton and Marshall 2001a). The relevant town resource clusters according to Fenton and Marshall are Bundaberg and Hervey Bay, which are large, and Maryborough and Tin Can Bay, which are smaller.

After due consideration of the current ABARE estimates for commercial fisheries, we decided to discard them in favour of what is basically the assessment in Fenton and Marshall (2001a). The background for this was discussed in Chapter 9 under the heading of 'Another set of social indicators'. Figure 47 shows the amended projections for commercial fisheries at about twice the initial level shown in PC

(2003). The estimates were reduced by 15% to reflect increased restrictions on trawling within the Great Barrier Reef Marine Park from the beginning of 2001.

Furthermore, we have removed ABARE's recreational fishing estimates, which are erroneous because fishers are mainly local as discussed in Chapter 9. In ABARE's base case, the GVP of recreational fishing would remain constant at about $189 million through the first two decades of the 21st Century. Participation rates have been falling from 28.1% in 1996 to 24.6% in 2001 in Queensland, but are higher in the Great Barrier Reef catchment (32.5%). Participation rates are forecast to fall as the population ages: they drop off strongly at age 60, but rates are also expected to fall within particular age groups. Table D6 shows further detail about these projections.

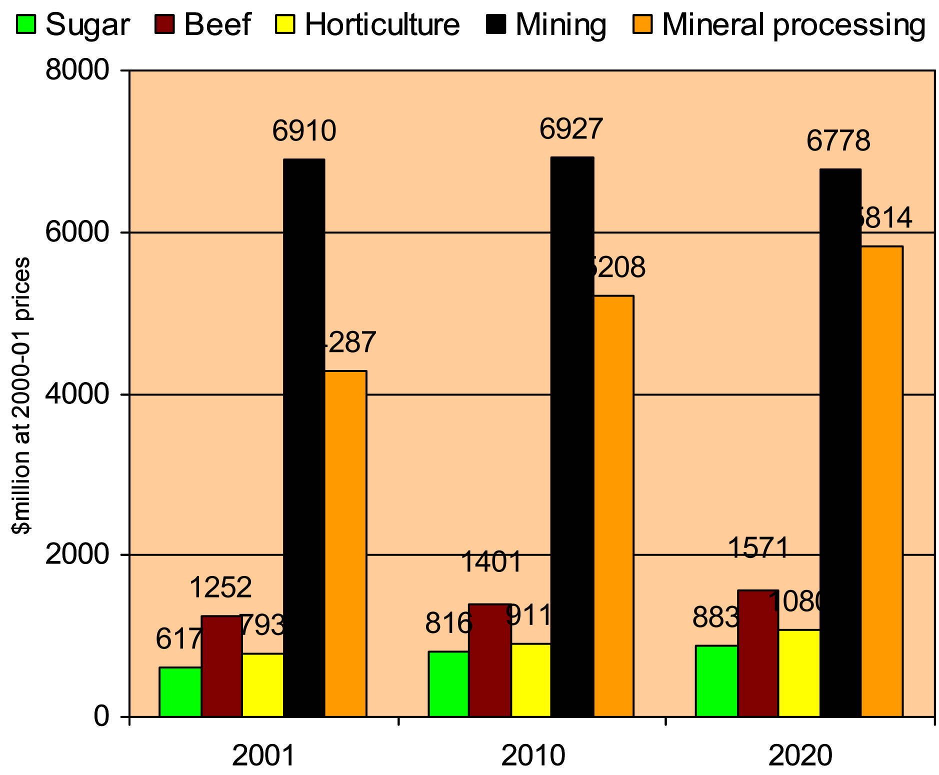


Source: Fenton & Marshall 2001a); PC 2003 (ABARE)

Figure 47: Gross value of production: fisheries of wild stock and aquaculture. The wild stock estimate was derived from Fenton and Marshall (2001a) and the base projection assumed that supplies will be available and prices unchanged. The scenarios developed in Part 3 build in the appropriate supply limitations and price trends. Aquaculture is projected by ABARE to increase strongly according to the base case; in the high case it reaches $279 million in the GBR catchment, in the low case $194 million.

The regional growth industry apart from tourism according to ABARE is aquaculture (Table D6), which is in line with the discussion in Chapter 9. The base projection of gross value in the Great Barrier Reef region is from $41 million in 2001 to $98 million in 2010 and $224 million in 2020. The region in 2001 accounted for 73% of the total value of aquaculture production in Queensland but remained small compared with the rest of Australia: 5.5% in 2001. This proportion is forecast to double by 2020 (to 11.1% according to the base projections in Table D6), even though total Australian production may almost triple from $746 million in 2001 to just over $2 billion in

2020. Employment in aquaculture is projected to increase from 423 in 2001 to 1,100 in 2010 and 2,500 in 2020, more than enough to compensate for the loss of employment in commercial fisheries.



Source: PC 2002

Figure 48: Base case ABARE projections of gross value of production of other exporting industries.

While tourism and fisheries are the main reef-dependent industries, other industries add to the economic base of the region, while their main influence relative to the Reef is through water quality. The main industries shown in Figure 48 were part of ABARE's projection brief. In terms of gross value of production, mining and mineral processing dominate, though the picture changes when industry employment is substituted: the sugar industry (cane and milling) employed 12,790 persons in 2001, mining 11,029, horticulture 10,743, the beef industry 7,469 and mineral processing 4,069.

In the regional economy employment is the important socio-economic indicator, though it is obviously important that mining and mineral processing provide most of the value added, which translates readily into gross regional product (at factor cost). The gross value added by mining in 2001 according to Table D7 was $4 billion, mainly in the Fitzroy and Mackay Statistical Divisions. Mineral processing had a gross value added of $1 billion in 2001, mainly in the Fitzroy and Northern regions (Table D8). These values exceed the value added by the beef, sugar and horticulture industries, not to mention commercial fisheries.

Details on industry projections, including regional distributions, can be found in Appendix D: Tables D2 for sugar, D3 for beef, D4 for horticulture, D7 for mining and D8 for mineral processing.

Population

The Planning and Forecasting Unit of the Department of Local Government and Planning produces population projections to 2021, which are published in the regional community reports compiled by the Office of Economic and Statistical Research (OESR 2002b). Table D21 shows details for local government areas and statistical divisions for five-year intervals from 1991 to 2021.

The current population in the five statistical divisions adjoining the Great Barrier Reef is just on 1 million. It is forecast to increase to 1.3 million by 2021, growing at an average of 1.5% per annum. The Far North is expected to show the fastest growth, from about 225,000 currently to 320,000 by 2021. Cairns, even without spills into neighbouring Johnstone Shire, is projected to grow from 120,000 currently to 188,000, starting to rival Townsville as the second-largest city in Queensland. The projections appear to be tourism-driven, with Douglas Shire showing the highest growth rate (2.5% pa between 2001 and 2021) followed by Cairns City (2.2% pa) and Cardwell Shire (1.8% pa).

Wide Bay-Burnett is forecast to have the second-highest growth rate of the five regions; 1.6% pa taking the total population from 237,000 in 2001 to 327,000 in 2021. Again, growth rates may be tourism-driven, with Miriam Vale topping the scale with 3.4% pa and Hervey Bay at 2.8% pa. A 2.8% annual projection for Burnett Shire would be at least partly attributable to Bundaberg growing across its current city area.

The remaining three regions are all forecast to show a 1.2% annual population growth rate. The Northern Statistical Division is expected to increase from 191,000 persons in 2001 to 243,000 in 2021, with the bulk of this growth in Townsville/Thuringowa (1.6% pa from 145,000 to 198,000).

The forecast for Mackay Statistical Division is an increase in the total population from 137,000 to 176,000, concentrated on Mackay City expected to grow from 76,000 to 104,000. The highest growth *rate*, however, is for the tourism-dominated Whitsunday Shire (2.1% pa).

In Fitzroy, the highest growth rate is projected for the tourism-dominated Livingstone Shire (2.6% pa, from 26,000 to 44,000 persons over the 20 years). Of the two main urban areas, Gladstone is expected to grow considerably faster than Rockhampton. Including the surrounding local government area in both cases, which may exaggerate the urban population estimate slightly, Gladstone plus Calliope Shire is expected to grow from about 42,000 to 67,000 persons, while Rockhampton including the whole of Fitzroy Shire would only manage an increase from 69,000 to 75,000.

The population of coastal areas along the Great Barrier Reef is forecast to grow from 722,000 in 2001 to 927,000 in 2021 (1.6% pa), with inland areas (and coastal areas south of the Fraser Coast) showing an increase from 248,000 to 303,000 (1% pa).

Synthesis of Part 2: Providing a basis for analysing the future

Part 2 has presented the available social, economic and environmental data as a basis for evaluating possible futures for the Great Barrier Reef World Heritage Area and the adjoining regions. It has endeavoured to introduce a broad economic, social and ecological context rather than simply presenting the statistics.

Chapter 5 set out to demonstrate the sound theoretical basis that lies beneath the contemporary emphasis on concepts that are broader than economic statistics – taking account not only of social indicators but also of broad environmental concepts to arrive at what has become popularly known as the triple bottom line. Economic theory at the time of writing is ahead of economic practice, as witnessed by the theoretical concept of 'genuine investment' (investment expenditure that also accounts for environmental degradation and natural resource use) versus its actual measurement.

The broad regional picture was presented in Chapter 7. On the economic side, Far North Queensland has shown the strongest growth in the past, based on what is by far the largest tourist sector of the five regions adjoining the Great Barrier Reef. The other largely reef-dependent industry, commercial fisheries, is small in terms of employment and economic product relative to the total regional labour force, but is disproportionately important in both social and environmental terms. So is recreational fishing, which has no measurable economic impact except for attracting tourists from other regions, which is captured by the tourism statistics. Chapter 7, in short, shows tourism as a major economic influence, especially in terms of growth prospects, even though other mainland industries such as mining, grazing and crops provide the bulk of the economic base for the regions except in Far North Queensland.

The coastal regions facing the Reef appear in conventional terms to be slightly worse off, in terms of social disadvantage, than the average Australian region. This may be more apparent than real, in view of the numerous unquantified aspects of social well-being, though it is probably correct that the main tourism locations such as Douglas Shire, Cairns and the Whitsundays are relatively well off, and that Wide Bay-Burnett is relatively disadvantaged. Another important feature, especially in the Far North, is the concentration of Indigenous people (including Torres Strait Islanders).

Chapter 7 ends with a comprehensive regional analysis of environmental issues, starting with the crucial ones associated with the Reef itself and proceeding to activities causing stress to the Marine Park. Coastal management is a crucial issue needing to be addressed in the endeavour to mitigate the impact of climate change on the Reef. Other issues include fisheries and tourism, and hazards such as potential mining activities and shipping accidents.

The statistics of tourism and extractive industries led by fisheries were the subjects of Chapters 8 and 9, and Part 2 concluded with neutral projections of major industries in Chapter 10 based on the Productivity Commission's report on regional industries and water quality in the Great Barrier Reef catchment areas (PC 2003). The last chapter provides a bridge to the third and last part of our study, which applies the technique of scenario planning – the analysis of alternative but equally plausible futures – to the problem of how to conserve as much as the present and former glory of the Great Barrier Reef for the benefit of all future generations.

PART 3 – THE FUTURE

Overview

Dramatic change will occur in the world even in the absence of climate change – volatile political, social and economic factors will breed an unpredictable and possibly turbulent future. Technological change adds another layer of unpredictability – is it sensible, for instance, to imagine that a growing world population will be adequately fed by modified crops? Will technology ensure these crops are environmentally safe and will the public accept this? What will be the technology-based economics governing the choice between developing new crude oil fields in increasingly inaccessible locations, natural gas reserves and renewable fuels? A host of other questions adds to the complexity of understanding the future.

Scenario planning is a strategic tool designed to cope with unpredictability. The aim is to devise a set of credible stories of what *might* happen – though probably not one of them *will*. One story may tell of rapid population growth, unequal rates of economic growth, and widening income gaps both internally and internationally. Another story may stress environmental and social care, international cooperation and technology transfer, and moderate population and economic growth benefiting all countries and income groups. There is no way to say whether one or other of these stories is more likely to happen – but scenario planning helps ensure that strategies for the future cover all plausible eventualities. While difficult, these strategies may be critical to determining the future of a nation or region.

Chapter 11 discusses scenario planning and the choice of a suitable starting point for this report in a particular set of worldwide scenarios. The chosen starting point was the four 21st Century 'marker scenarios' developed for the *Third Assessment Report* of the Intergovernmental Panel for Climate Change (IPCC 2000). Two of the four scenarios are labelled 'A' (economy-dominated), and two 'B' (more environmentally friendly). Within each group there is a global (A1 and B1) and regionalised (A2 and B2) version. This makes for four very different worlds.

Chapter 12 develops the four scenarios from the worldwide IPCC marker scenarios, successively developing storylines for Australia, the Great Barrier Reef, tourism and fisheries in the Great Barrier Reef Marine Park, and the impact on the regional economies adjacent to the Great Barrier Reef.

All four scenarios envisage a Reef significantly damaged by coral bleaching over the coming twenty or thirty years, but the longer-term perspective is very different. The worst-case scenario, A2, depicts a world with low economic growth, high population growth and little attempt to divert a rising long-term trend in CO_2 emissions, which would spell the end of coral dominated reefs on the Great Barrier Reef for very long periods. The future of coral reefs is also bleak under the global economic growth scenario, A1, even though there will be a trend towards renewable fuels as crude oil reserves dwindle, and this world may develop into an environmental 'B1' world in the second half of the century. The best hopes for an ultimate future for coral in Queensland is the development, as soon as possible, of more environmentally sensitive policies in the B1 or B2 worlds to minimise pollution from the mainland and other sources of damage to the Reef. Previous chapters have shown that preserving and even building reef resilience will be critical to how reefs fare under increasing sea temperatures and carbonate alkalinities, especially over the coming quarter century or so.

Part 3 concludes with a synthesis setting the stage for the formulation of policy directions required to save the Great Barrier Reef for a future Australia and world community (Part 4). These policy directions are essential if Australia's reef-related industries are to benefit from a sustainable future.

11. Development of Scenarios

Variations on scenario analysis

Scenario planning moved from the military sphere into the civil domain during the 1940s. It was subsequently developed by Herman Kahn at the Hudson Institute. *The Year 2000: A view from 1967* (Kahn and Wiener 1967) stood out in the early scenario literature. In the late 1960s the Shell oil company became a pioneer of corporate scenario planning. One scenario envisaged a steep increase in crude oil prices before the actual energy crisis occurred in 1973, which strengthened Shell's competitive position in an industry which had routinely planned for capacity increases to match 6-7% annual growth in demand, and kept doing so for years after that growth ceased (van der Heijden 1996).

Scenario planning over the past 30 years has developed to deal with an increasingly turbulent world, in which social, cultural, economic, environmental, technological and political factors interact in unpredictable ways. Scenario analysis aims to take all such factors into account, not just those which managers traditionally try to 'predict and control' using a single forecast or at the most a narrow 'optimistic' and 'pessimistic' band around a base case.

Good scenarios are based on stories about the future, usually two, three or four storylines covering a range of credible and internally consistent possible futures. **Importantly, scenarios are not predictions.** Another frequently misunderstood feature is the need for all scenario storylines to be equally plausible; one consequence of this it that scenario planners should engage personally in each of the stories, as we attempt to do in this report.

Furthermore, as all scenarios are equally credible, no probability analysis can be attached to them. This is often misunderstood by those who are professionally used to numerical estimates and projections. Simply put, given that we cannot estimate GDP or any of its components more than a short period ahead, any attempt to put probabilities upon complex alternative long-term futures is meaningless.

The essential purpose of scenario planning is to explore a range of possible futures. Policy recommendations must address the same broad range to be effective - not just, say, a middle range within a wider band. Actually, the scenarios in Chapter 11 exclude some extremes from the frame of reference such as a world GDP of $700 trillion in 2100, an 18 billion world population by 2100 (the highest United Nations projection), and radical changes to society. And no scenario in this report has a 7^{o}C rise in temperature used in a study of climate change and electricity demand quoted in a recent Australian Greenhouse Office booklet (AGO 2002b:28).

The scenarios may just consist of the stories themselves or they may be accompanied by numerical projections which are consistent with a particular storyline. Often there is some terminological confusion as to what is the scenario – the storyline, the associated numerical projections, or both? Some approaches minimise the storyline in favour of an intricate model; others are long-term extrapolations of past trends rather than scenarios in the sense developed in the literature (though they may use the term).

One possible way of identifying true scenarios is whether or not a range of narratives about possible futures was developed before quantitative implications were considered (as we do in Chapter 12). The following paragraphs touch on three Australian studies, valuable in their own right but following other approaches.

The CSIRO study, *Future Dilemmas* (Foran and Poldy 2002), presents the implications of three different net migration projections to 2050 and 2100: zero, 70,000 persons, and 0.67% of the population. It is based on a model of the physical economy, which the authors claim as a new approach, though the 1930s creator of input-output analysis, Wassily Leontief, developed physical as well as financial transaction matrices (SCB 1999:9). Some of the models used in the IPCC Special Report on Emissions Scenarios (IPCC 2000 Appendix IV) used a systems-engineering (bottom-up) rather than macroeconomic (top-down) approach, and physical quantities are also required in satellite accounting for the environment (SEEA 2002). While one of the merits of the CSIRO study is its explicit reference to exhaustible physical resources, it has been rightly criticised for ignoring the price mechanism and on a number of other economic grounds (Murphy and Wooden 2002).

The study uses two innovative CSIRO-created empirical frameworks: the *OzEcco* embodied energy model and the Australian Stocks and Flows Framework (ASSF). In *OzEcco,* all activities in the economy are expressed in energy terms (petajoules or 10^{15} joules), and all goods and services are expressed in terms of the chain of energy processes that eventually become included - *embodied* - in a final product or service (p 21). The ASSF keeps track of all physically significant stocks and flows in Australia's socioeconomic system. Stocks include everything: people, livestock, trees, buildings, vehicles, capital machinery, infrastructure, land, air, water, energy and mineral resources. Flows resulting from physical processes represent the rate of change in stocks and constitute the development of the system in more or less desirable directions (p 24).

It is not clear how ecosystems – the dimension beyond land, water and air resources as such – are treated in the framework. As discussed in Chapter 5, large ecosystems cannot really be valued although attempts have been made, even on a worldwide scale (Costanza et al 1997).

Future Dilemmas, despite its economic flaws, breaks important new ground in research into the potential for sustainable development in Australia. However, the base case for the future is derived from past trends and makes allegations about sustainability based on model simulations which need further testing (as the authors acknowledge). For instance:

- The authors find their high population scenario, which assumes net migration levels of 0.67% of the current population each year, physically feasible to 2050 when the population would reach 32 million. By 2100 (50 million people) they see risks 'with the potential for continually expanded energy use and greenhouse emissions together with a potential decoupling of the large urban agglomerations from the base of ecosystem services that support their lifestyles and functions.' But they do list the 'rewards of this scenario' ahead of the risks: continual economic growth, strong export industry growth, synergies for service clusters and competition, and the formation of world-sized cities to act as a basis for international commerce (pp 12-13).

- The number of inbound tourists is assumed to be sustainable for the whole of the base case future, resulting in 34 million international visitors in 2050 staying an average of 16 days compared with 4.2 million staying 24 days in 1998 (p 59). This is based on industry expectations of full economic recovery and growth in Asia, resulting in more Asian tourists (p 282). The number of inbound tourists in 2050 represents the equivalent of 1.5 million full-time citizens but with higher travel and consumption impacts than the average citizen (p 34).

- The settings for materials and energy transformation represent current techniques and energy sources, and all three population futures result in rising greenhouse emissions through 2050. The best case for 2050 (zero net migration) is 475 million tonnes CO_2 from the energy sector compared with 284 million tonnes in the 1990 base year (p 169). Emissions increase to 541 million tonnes and 651 million tonnes, respectively, under the two other futures. There will be improvements in the efficiency of generating and supplying electricity. Renewable energy sources provide a minor contribution currently, and an assumption is made that petroleum resources will remain relatively available and cheap (p 302).

Future Dilemmas, in addition to the base case for the three different population futures, includes some interesting 'sub-scenarios' which brings the study closer to true scenario making. One is a simulated 'Factor Four' economy, so called because it aims at increasing resource efficiency by 75% within a generation. It is a close relative of the 'Factor 10 Club', which aims at 90% and issued the Carnoules Declaration, named after a French village where the initial meeting was held in 1994. It stated, realistically or not, that 'within one generation, nations can achieve a ten-fold increase in the efficiency with which they use energy, natural resources and other materials.' (Hawken, Lovins and Lovins 1999:11). The Factor Four principle of 'doubling wealth, halving resource use' was developed by prominent German biologist and Bundestag member Ernst von Weizsäcker (Weizsäcker et al. 1997).

The *Future Dilemmas* simulation aims at halving energy and material usage by 2020. This reduces emissions from the energy sector in 2050 to below or near 1990 levels in the three population models, but the authors anticipate major stumbling blocks to prevent early implementation (the centrality of energy use to economic growth, and differential rates of technology uptake). The alternative of a 'high-tech' versus a 'low-tech' path provides some of the most riveting reading in the report, with the 'high-tech' models leading to major improvements in building technology, vehicle energy consumption and mass, and aviation fuel economies per international passenger (Foran and Poldy 2002:174-176).

Australian Federal Treasurer Peter Costello circulated an *Intergenerational Report 2002-03* as a Budget Paper (Commonwealth Treasury 2002), as required by the Government's *Charter of Budget Honesty Act 1998*. The intergenerational concept originated in the 1987 report of the World Commission on Environment and Development chaired by Norwegian Prime Minister Gro Harlem Brundtland (WCED 1987). It is intimately associated with sustainable development, which seeks to meet the needs and aspirations of the present generation without compromising the ability of future generations to meet their needs.

Based on assumptions about future population growth, the ageing of the population, productivity and total economic growth, and growth in the underlying cost of government programs, the Budget Paper produces a base case projection of fiscal requirements between 2002-03 and 2042-43. Sensitivity analysis using variables such as mortality, fertility, migration, productivity growth, labour force participation rates and health cost growth suggests that the projection is robust with the broad policy conclusions being unaffected by plausible changes in the assumptions (p 4 and pp 60-71). However, the sensitivity parameters are narrow given the long-term nature of the projections.

The *Intergenerational Report* projects spending in the following six areas: health and aged care, payments to individuals, education and training, government superannuation, defence, and (p 52) the environment:

> *Australia's environment provides natural capital, offering many essential services. Deterioration of our natural capital would be likely to affect the wellbeing of current and future generations, reduce the economic base and consequently affect intergenerational equity.*

The report acknowledges that

> *Australia currently faces a number of significant environmental problems, which may have ongoing implications for Commonwealth spending. These include land and inland water quality degradation, loss of biodiversity, air quality, climate change and pressure on coastal, marine and wetland ecosystems. … Problems also*

> *arise when biophysical processes are not well understood, leading to unintended impacts.*

However, while the value Australians place on their natural environment is likely to rise, resulting in increasing demand for environmental quality, and calls for environmental protection may increase as knowledge and understanding of ecosystems and human impacts on the environment improve,

> *… this need not translate into more Commonwealth spending on the environment. … For example, adopting voluntary, regulatory, and market-based approaches would lead to polluters meeting many costs. Also, the States have wide responsibilities for environmental matters, so often State or Local governments can intervene most appropriately. In addition, increased demand for environmental quality is likely to provide new market opportunities for the private sector, leading to more environmentally friendly production.*
>
> *Governments also could reduce future economic and budgetary costs by integrating policy approaches to economic development to minimise environmental damage. This should increasingly occur as Australia's understanding of environmental problems improves over time. Early action to prevent environmental damage, rather than later action to remedy it, is likely to reduce long-term costs.*

Arguably the horse has already bolted in areas such as the Murray-Darling Basin.

While this long-term view of policy requirements is laudable, looking forward 40 years may well result in developments which would require Commonwealth spending on the environment to increase, depending on its share of the total cost. Regardless of how the cost is shared with State and local government and the private sector, it is questionable whether the approach goes far enough towards meeting the sustainability criterion. Scenario planning in the sense of considering alternative futures, composed of a broad range of social, cultural, economic, environmental, technological and political facets, can provide further insights.

Future Makers, Future Takers (Cocks 1999) is subtitled *Life in Australia 2050*. It is written as a narrative with few numbers, and presents three alternative political manifestos to take Australia to a prosperous mid-century position ('conservative development', 'economic growth', and 'post-materialism'). Basic past trends will determine the world in 2050; for instance:

> *… it can be taken as given that the world of 2050 will still be divided into first, second and third world countries, much as it is now, and that the world will be populated by a billion or so 'rich' people and eight or nine billion 'poor' people. Driven by the communications and information industries and other knowledge-intensive industries, the world economy will be dominated by capitalist countries and will continue to globalise (that is, come to function as a single system), grow and shift towards service industries. (p 34)*

These Australian studies are valuable contributions, as already noted, and provide good ideas. But the scenario planning approach in this study requires different methodology.

The chosen approach

The *Third Assessment Report* of the Intergovernmental Panel on Climate Change (IPCC 2001a to 2001e) is based on storylines and projections described in the IPCC *Special Report on Emissions Scenarios* (IPCC 2000). Four storylines form the basis for a set of 40 numerical projections of population, GDP or GNP, energy use, CO_2 and other greenhouse gas emissions.

These projections were carried out for groups of countries such as 'Africa' or 'Former Soviet Union' and summarised into even larger world regions, including OECD (as at 1990) and Asia-Pacific (other than Australia, Japan and New Zealand, which are in the OECD group). They have also have been downscaled to individual country level, but the GDP estimates assume the same growth rates for countries within a given region (Lutz and Goujon 2002, CIESIN 2002a and 2002b). This renders the projections for Australia invalid as it is in the same 'Pacific OECD' group as Japan. The detailed quantitative models in IPCC 2000 were developed by six agencies located in Japan, the US, the Netherlands and Austria (see Appendix E), and subsequently analysed by the SRES writing team.

The four storylines form the basis of the numerical scenarios developed for this study. They represent the quadrants of a matrix divided into economic and environmental on the vertical axis and global and regional on the horizontal axis (Figure 49).

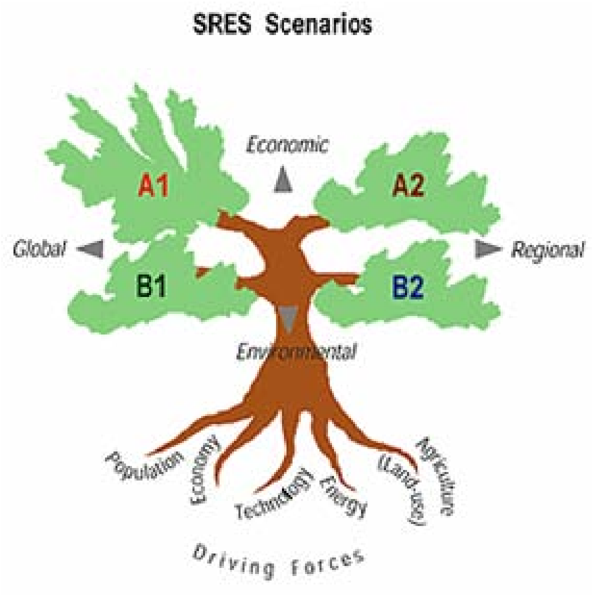


Figure 49: Schematic illustration of SRES scenarios. The four scenario 'families' are illustrated, very simplistically, as branches of a two-dimensional tree. In reality, the four scenario families share a space of a much higher dimensionality given the numerous assumptions needed to define any given scenario in a particular modelling approach. The schematic diagram illustrates that the scenarios build on the main driving forces of greenhouse gas emissions. Each scenario family is based on a common specification of some of the main driving forces. (Text quoted from IPCC 2000, Chapter 1.7.2.)

Following the development of the 40 quantitative projections, the SRES team chose one from each quadrant as a 'marker scenario' – generally the set of projections which best fitted the storyline. In the case of A1, the global economics-driven family, two variants were added: one depicting a future where fossil fuels continue to dominate (A1F1), and one in which the world 'decarbonises' (A1T). The 'A1B' marker scenario envisages a 21st Century future where neither fossil nor alternative fuels dominate.

Population is an exogenous input into the scenario building (see Figure 50). A1 and B1 are based on low projections from the International Institute for Applied Systems Analysis (IIASA), combining low fertility with low mortality and central migration assumptions – resulting in the world population rising to 8.7 billion by 2050 and then falling to 7 billion by 2100. The A2 family uses the high IIASA projection, assuming an increase to about 15 billion by 2100, while B2 assumes that the United Nations median projection 1998 will apply (IPCC 2000, Section 6.2.1).

The assumptions about economic growth – another exogenous input – are explained as follows:

> *The SRES scenarios span a wide range of future economic growth rates and resultant levels of economic output. The A1 scenario family, with a global GDP of US$520 to 550 trillion in 2100, delineates the SRES upper bound, whereas the A2 and B2 scenarios, with a range of US$230 to 250 trillion in 2100, represent its lower bound. The B1 scenario family is intermediary. Uncertainties in future GDP*

levels are governed by the rates of future productivity growth and population growth, especially those in developing countries. Different assumptions on conditions and possibilities for development 'catch-up' and for narrower per capita income gaps in particular explain the wide range in projected future economic growth rates.

Two of the SRES scenarios explicitly explore alternative pathways of the gradual closure of existing income gaps. As a reflection of uncertainty, the development

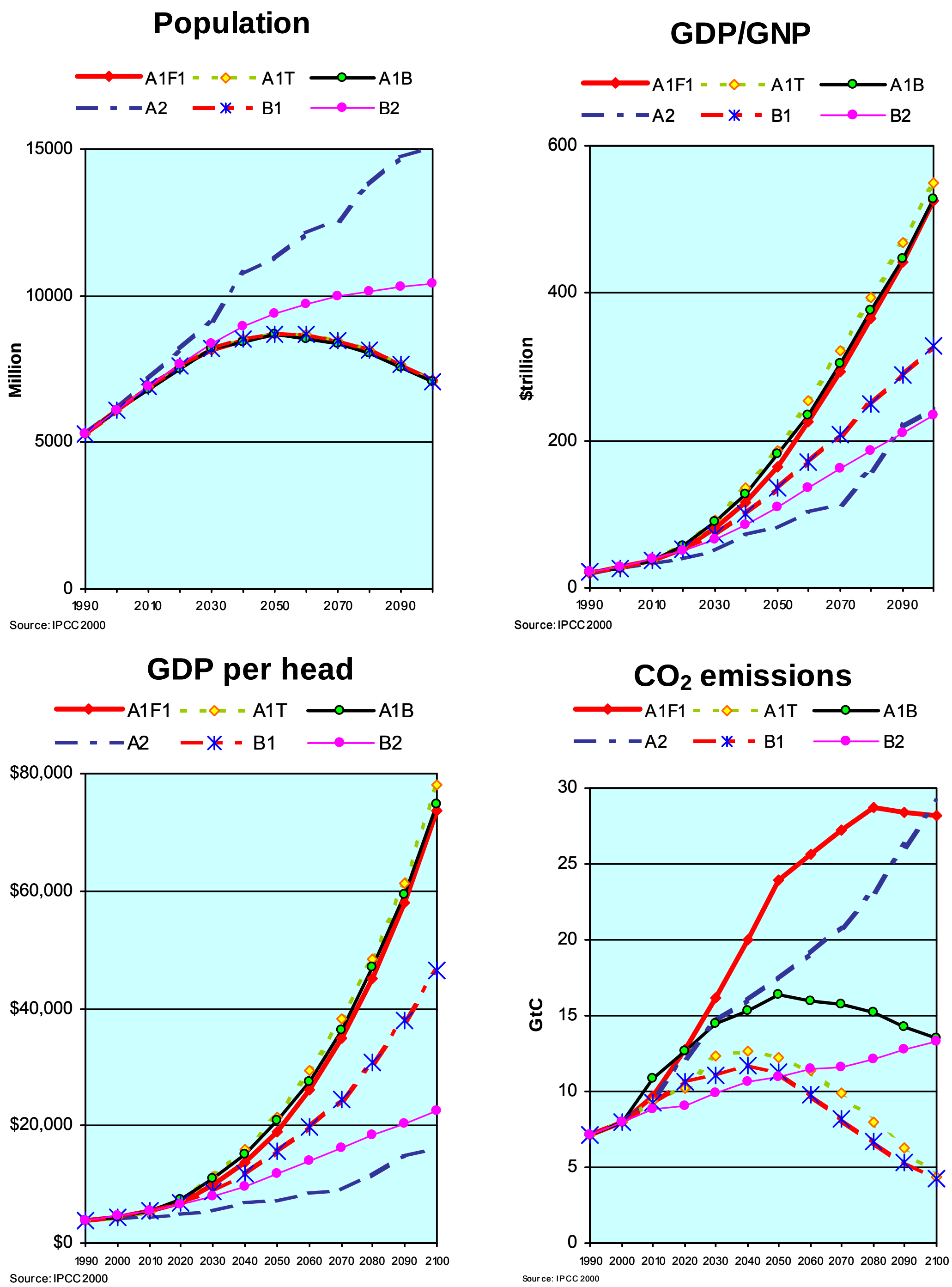


Figure 50: Six IPCC scenarios projected to 2100. The three variations of the A1 family are A1F1 (continued fossil fuel dominance), A1T (rapid transition to alternative energy sources), and A1B (balanced fuel mix). A1B is the marker scenario. The graph also depicts marker scenarios for the A2, B1 and B2 families.

> *'catch-up' diverges in terms of geographically distinct economic growth patterns across the four SRES scenario families. The scenarios of rapid development and 'catch-up' remain in dispute within the SRES writing team because they imply high productivity growth. However, it is agreed that such scenarios of high productivity growth and smaller income-per-capita disparities cannot be ruled out, even if they certainly are very challenging from the perspective of recent growth experiences in a number of regions, most notably Africa. There is also agreement that the assumptions deployed for the SRES scenarios are within the range suggested by the literature, [in which] the highest GDP growth is up to US$700 trillion by 2100 compared to US$550 trillion in the highest SRES scenario. For scenarios developed within the context of sustainability analyses, reductions in per capita income gaps also occur faster than for any of the scenarios presented here. (IPCC 2000, Section 4.4.4)*

Before finding this reference in IPCC 2000, we had ourselves been concerned with the possible lack of sustainability of the high economic growth futures (A1 family). Appendix E shows a range of findings derived from IPCC 2000 relating to the six scenarios. The levels of GDP per capita presented as attainable by 2100 appear very high: $US 76,000 (constant 1990 prices) for every man, woman and child on earth; $112,000 for OECD countries, 76,000 for Asia-Pacific other than Australia, Japan and New Zealand, and $63,000 for the rest of the world. The detailed projections show that even the poorest part of the world, Sub-Saharan Africa, would increase its GDP per head from about $630 in 1990 to $46,200 in 2100, or by an average of 4.4% per annum (total GDP growth 5.1% pa and population 0.7% pa).

While such levels of prosperity look almost incredibly high from today's perspective, economic growth, measured by GDP, is nonetheless assumed to be slowing down. World economic growth between 1950 and 1990 was 4.0% pa, with OECD countries at 3.9% and Asia-Pacific at 6.4% pa. Between 1990 and 2050, growth rates for the four marker scenarios vary between 2.3% and 3.6% pa, with OECD ranging from 1.6% to 2.0% pa, and Asia-Pacific from 3.9% to 6.2% pa. For the full 110 years from 1990 to 2100, world GDP is assumed to grow by between 2.2% and 2.9% pa, total GDP for OECD between 1.1% and 1.8% pa, and the Asia-Pacific GDP between 3.3% and 4.5% pa.

It is difficult to imagine a world in which such high production could be sustained in terms of available material and ecological resources, or indeed how consumers could avoid being thoroughly sated with goods and services. But then of course the world in 2000 was largely unimaginable to a person looking forward from the dawn of the 20th Century. However, it would be plausible to expect a transition to lower economic growth and perhaps a gradual switch to another SRES quadrant, implying a shift towards a more compartmentalised world, greater emphasis on ecological policies, or both. We cannot see how the high growth scenario in all parts of the world can be fed entirely by non-material information and other services, so this scenario will eventually become internally inconsistent because it will no longer be feasible to produce the amount of goods required – regardless of whether greenhouse gases are reduced through the replacement of petrochemical energy sources.

One reason why the A1 scenario in particular has such high growth rates is what appears to be an erroneous base comparison (Castles and Henderson 2003). The comparison of GDP levels was made in terms of exchange rates with the US dollar, which exaggerates the difference in living standards between rich and poor countries. It has long been recognised that the price of a basic consumption package is lower in poor countries – in *purchasing power parity (PPP)* terms there is less difference than when exchange rates are used. The World Bank has recognised this and in 1995 switched to using PPP rather than exchange rate derived GDP figures in international comparisons. Failing to do so means that poor countries have to grow much faster to catch up with living standards in rich countries, which is basic to the A1 scenario family.

Castles and Henderson, in their critique, focus strongly on the seemingly unrealistic growth needed for sub-Saharan Africa – the same point that caught our attention as reported above. The implied growth rates for Asian and Latin American countries appear more plausible, though these too are boosted by the use of consumption valuations derived from exchange rates rather than purchasing power parity. Our choice of a combined A1 and B1 scenario (making the transition around the middle of the 21st Century), which we made before reading the critique, is vindicated by the Castles-Henderson critique of the IPCC scenario makers.

There is another, transitional, problem with the IPCC storylines, especially the high-growth A1 family. We need to consider the situation at discrete points (2010, 2020 and 2050), when the huge structural changes envisaged over the whole of the 21st Century will not have been played out. For example, the economic growth of developing countries often benefits the richest tenth or third of the population with little or no 'trickle-down effect' to the poor majority. Indeed, when drastic change was implemented during the Asian economic crisis in 1997-98 with allegedly heavy-handed assistance of international agencies like the International Monetary Fund, the poor got worse off and were not the first to benefit as the crisis was being overcome (Stiglitz 2002). So inequality may widen in the short to medium term with continued economic growth, unless countered by national policy measures. China, Taiwan, Korea and Japan exemplify countries where the problem has been dealt with effectively, whereas this is not currently the case in Indonesia and several Latin American countries.

The final and essential output from the IPCC work is the anthropogenic emissions, dominated by carbon dioxide (of which the vast majority is generated by fossil fuel). The projections vary widely with the increase being greatest up to 2080 in the fossil fuel variant of the economic growth A1 family, A1F1. By 2100, emissions under A2, the scenario of slowest growth, are projected to overtake emissions under A1F1 (as shown by the lower right quadrant of Figure 50).

Both the storylines and the quantitative futures are extensively documented with references to the relevant literature. Each storyline in IPCC 2000 is inspired by or at least compared with other scenario studies with similar features. The IPCC scenarios are the logical choice to make for the worldwide assumptions, and given that all four describe equally credible futures none of the main storylines should be left out. They provide the world perspective for each scenario developed in the next sections, supplemented by narratives in the current study to cover the following:

- In some cases where the IPCC storylines mentioned general technological development or postulated the substitution of alternative fuels for petrochemicals, it was deemed appropriate to be a little more specific to illustrate such developments. This was done carefully to avoid distorting the IPCC story and had the added advantage of making us work at and accept ('own') the storylines rather than blindly reproducing the IPCC story.

- Three workshops conducted in Port Douglas, Townsville and Brisbane in August and October 2002 provided much of the material for describing Australian and Queensland futures to 2020 (Appendix F). Individual participants also provided valuable insights and references which might not otherwise have been brought to bear in the study (including some facets for the general worldwide storylines which we added). The focus of the Australian stories is 2020, though we then use 2020 as a vantage point for a further outlook to 2050.

- The estimated impacts of climate change on the Great Barrier Reef were then added in narrative and numerical form, based on the scientific evidence.

- The storylines finally served their ultimate purpose of putting reef-based industries, and the coastal regions, into context. These became, in effect, part of the scenario stories and enabled numerical estimates to be made.

The scenarios in the next four sections contain all the elements listed above and are presented under the following headings:

- Full speed ahead as far as possible (A1B to 2050 - global economic drivers; then B1. To simplify the presentation, this scenario pattern will also be referred to as A1)

- Heterogeneous regionalisation (A2 - regional economic drivers)

- Global policy reform (B1 - global environmental drivers)

- Regional sustainability (B2 - regional environmental drivers; converging into B1 from 2050).

We note that the United Nations Environment Program (UNEP) in its third global environment outlook of past and future 30-year perspectives ('GEO 3') developed four scenario stories which are similar in many ways to the four IPCC quadrants of scenario families (UNEP 2002). A summary is given in the box below. They would have provided an alternative global starting point to the IPCC stories if the latter had not been available.

Common features of the four scenarios

Though the scenarios developed from the IPCC storylines are very different, they have some important similarities:

- All IPCC scenarios predict continued increases in CO_2 emissions for many years, and warming will consequently continue. It will take a long time for policy changes to work through the system, especially because the world will still be suffering from the environmental debt taken out by the present and previous generations. It is really only after 2020 that significant differences in CO_2 emissions start to develop between the four scenarios. By 2050, however, they are expected to be of major importance, and by 2100 Figure 50 shows that the worst-case scenario (A2) has almost six times the CO_2 emissions as the best case (B1).

- The scientific evidence related to coral bleaching of the Great Barrier Reef also makes it difficult to differentiate much up to about 2020, and again it is necessary to take a longer view, as we did in Part 1, to provide the perspective for devising mitigating policies.

- It therefore becomes an urgent priority to develop policies that protect the Reef as much as possible during the next two decades when even in the best-case scenario it will be increasingly impacted by unrelenting global warming. Scenarios B1 and B2, which envisage the development of environmentally sensitive and sustainable societies, offer the best hope in this respect.

- The urgent challenge at any level of government in Australia is to adopt the appropriate policies, including control of runoff and pollution from agricultural and industrial activities on the coast and in the hinterland, adequate control of tourism and fisheries in the multi-purpose Marine Park, and funding to allow the accelerated accumulation of knowledge of the complex ecosystems that comprise the Great Barrier Reef from north to south, from coast and lagoon to outer shelf, and beyond to the complex interaction with other oceanic systems.

UNEP GEO 3: A parallel set of scenarios to 2032

Markets first

Most of the world adopts the values and expectations prevailing in today's industrialised countries. The wealth of nations and the optimal play of market forces dominate social and political agendas. Trust is placed in further globalisation and liberalisation to enhance corporate wealth, create new enterprises and livelihoods, and so help people and communities to afford to insure against — or pay to fix — social and environmental problems. Ethical investors, together with citizen and consumer groups, try to exercise growing corrective influence but are undermined by economic imperatives. The powers of state officials, planners and lawmakers to regulate society, economy and the environment continue to be overwhelmed by expanding demands. – *Outcome*: Significant increases in greenhouse gases over next 30 years. Even with a decrease in the percentage of the population facing hunger, the total number affected changes relatively little and even increases in some regions as populations grow.

Policy first

Decisive initiatives are taken by governments in an attempt to reach specific social and environmental goals. A coordinated pro-environment and anti-poverty drive balances the momentum for economic development at any cost. Environmental and social costs and gains are factored into policy measures, regulatory frameworks and planning processes. All these are reinforced by fiscal levers or incentives such as carbon taxes and tax breaks. International 'soft law' treaties and binding instruments affecting environment and development are integrated into unified blueprints and their status in law is upgraded, though fresh provision is made for open consultation processes to allow for regional and local variants. – *Outcome*: The targeting of hunger reduction as a key goal, and the emphasis on more balanced development between regions, help to achieve dramatic reductions in the percentages and total numbers of people affected.

Security first

This scenario assumes a world of striking disparities where inequality and conflict prevail. Socio-economic and environmental stresses give rise to waves of protest and counteraction. As such troubles become increasingly prevalent, the more powerful and wealthy groups focus on self-protection, creating enclaves akin to the present day 'gated communities'. Such islands of advantage provide a degree of enhanced security and economic benefits for dependent communities in their immediate surroundings but they exclude the disadvantaged mass of outsiders. Welfare and regulatory services fall into disuse but market forces continue to operate outside the walls. – *Outcome*: Significant increases in greenhouse gases over next 30 years. The sharp increases in most regions suggest that this scenario will become unsustainable in terms of social acceptability.

Sustainability first

A new environment and development paradigm emerges in response to the challenge of sustainability, supported by new, more equitable values and institutions. A more visionary state of affairs prevails, where radical shifts in the way people interact with one another and with the world around them stimulate and support sustainable policy measures and accountable corporate behaviour. There is much fuller collaboration between governments, citizens and other stakeholder groups in decision-making on issues of close common concern. A consensus is reached on what needs to be done to satisfy basic needs and realise personal goals without beggaring others or spoiling the outlook for posterity. – *Outcome*: Rapid levelling off of emissions and a decline by the middle of the 2020s. As under *Policy First,* the targeting of hunger reduction and the emphasis on balanced development between regions, help to achieve dramatic reductions.

Some other environmental implications

Biodiversity will continue under threat if there is no strenuous policy action to curb human activity. Continued urban and infrastructure expansion, plus the increased impacts of climate change, severely deplete biodiversity in most regions in all scenarios. Pressures will also increase on coastal ecosystems in most regions and scenarios. Similarly, the demands for food and the ability to meet them in the different scenarios reflect a combination of shifts in supply and demand, influenced by social, economic and environmental policies. The scenarios carry important implications for the provision of basic human needs. Growing populations and increased economic activity, particularly in agriculture, will lead to increased demand for fresh water in most scenarios. ***(UNEP 2002 Chapter 2)***

12. The Scenarios

General

As we explained in the overview at the beginning of Part 3, the four scenarios in this chapter were developed from the four main storylines of IPPC (2000), and successively present a world view, an Australian view, a Great Barrier Reef view and industry views of the future (especially the first two decades of the 21st Century). Underlying numerical projections of gross national product, population, greenhouse gas emissions and other matters are shown in Appendix E. Some information on sea temperature trends is shown as part of each storyline.

The IPCC storylines are complemented by material from other research and input from the three scenario planning workshops conducted as part of the study. Participants commented on international matters as well as on local and Australia-wide issues, and some of the resulting narratives were inserted into the IPCC story where it seemed appropriate. This was particularly the case with the environmentally orientated scenarios, which were closer to the heart of participants than the economics-driven futures.

A1: Full speed ahead as far as possible

The world

This scenario is dominated by an American or European entrepreneurial, progress-oriented perspective in which technology, especially communication technology, plays a central role. Market-oriented solutions encourage high consumption of both tangible and intangible commodities, advanced technology, and intensive mobility and communication.

Regional differences in income and wealth during the first several years of the 21st Century tend to widen, but fast economic growth in Asia and Latin America then leads to increasing convergence among regions and substantial reduction in regional differences in per capita income. Internal reductions in income inequality take longer to achieve in some countries. There is strong capacity building and enhanced cultural and social interaction. This is expected to continue largely unabated up to 2050, although unforeseen traumatic political or natural events in any scenario may intervene at any time in an unpredictable world, and disrupt the path of the system at least temporarily. That such stochastic shocks will occur is perhaps the only future certainty, or as a member of the Townsville scenario planning workshop put it, '*Accidents will occur which will be unpredictable but which will change the future*'.

The stochastic shock of September 11 gripped the developed world's concerns and changed the way we think of international security and defence issues, especially since it appeared to be part of a pattern. Traumatic issues such as the wave of terrorism and escalating regional conflicts in the first several years of the century focused public opinion on large short-term security issues. It may have seemed facile from a turn-of-the-century angle, but in the A1 family of scenarios rapid economic growth through the period of international conflict was instrumental in bringing about relatively peaceful conditions in the 2010s, further improving as rising general education levels assisted in reducing national income inequalities in practically all nations from 2020.

Economic development is generally rapid and successful. The primary dynamics are:

- Strong commitment to market-based solutions
- High savings and commitment to education at the household level

- High rates of investment and innovation in education, technology, and institutions at the national and international levels

- International mobility of people, ideas and technology.

The transition to economic convergence results from advances in transport and communications technology shifts in national policies on immigration and education, and international cooperation in the development of national and international institutions that enhance productivity growth and technology diffusion.

The global population grows to 8.7 billion by 2050 and declines thereafter. The average age increases, with the needs of retired people being met mainly through their accumulated savings in private pension systems. Global average income per capita reaches about US$21,000 by 2050, contributing to a great improvement in the overall health and social conditions of the majority of people, though some problems of social exclusion remain, similar to those encountered in wealthy countries in the 20th and early 21st Century. With the rapid increase in income, dietary patterns shift initially towards growing consumption of meat and dairy products, but decreases subsequently with increasing emphasis on the health of an ageing society. High incomes also translate into high car ownership, sprawling suburbia and dense transport networks, nationally and internationally.

Energy and mineral resources are abundant because of rapid technical progress, which both reduces the resources needed to produce a given level of output and increases the economically recoverable reserves. Final energy intensity (energy use per unit of GDP) decreases at an average annual rate of 1.3%. Environmental amenities are valued and rapid technological progress 'frees' natural resources currently devoted to provision of human needs for other purposes. The concept of environmental quality changes from the emphasis on 'nature conservation' that was dominant in the 1980s to active 'management' of natural resources and ecosystem services. This minimises the decline in ecological resilience although pressure continues on the spaces set aside for wild-life conservation. Biodiversity continues to decline due to greater pressures on ever smaller reserves and increasingly rapid shifts in the climate envelope of most species (with the optimal setting often moving beyond the reserve system). It becomes even more difficult in many places to manage these dwindling resources as the pressure on the environment increases from climate change and high consumption levels.

The scenario envisages a gradual transformation over the 21st Century from a world dominated by petrochemical energy towards renewable energy sources and nuclear energy. The petrochemical industry is planning from early in the century for its participation in the transition to greater reliance on natural gas, renewable energy and nuclear power development as it foresees dwindling crude oil resources between 2020 and 2050, and beyond. Having been on the drawing board for decades, but largely discouraged, technologies for effective hybrid and fuel-cell cars are by 2020 a central research and development concern of the automotive industry.

The world can look back from 2020 on two decades of rapid economic growth, where the introduction of new and more efficient technologies including communications, biotechnology and nanotechnology has continued unabated. Biotechnology has been dominated by the push towards genetically modified organisms, which was under intense scrutiny at the turn of the century although GM technology tended to be regarded as inevitable (King 2001 and a comprehensive economic and technical analysis in Shoemaker 2001, both on behalf of the United States Department of Agriculture).

As an internationally recognised Danish authority, Professor Birger Lindberg Møller, predicted 20 years ago, ‘gene splicing’ has made major contributions in four essential fields:

improved yields, improved product quality, improved stress tolerance of plants, and reduction of the environmental impact associated with the production of agricultural products. In all these areas the initial two decades of the 21st Century have witnessed progress far ahead of the 1970s Green Revolution (Møller 2000).

Genetically modified organisms continue to provide a growing proportion of the food requirements for the rapidly developing world in Asia, Latin America and, to an increasing extent, Africa. The design and implementation of stress tolerance varieties become increasingly important as the climate continues to change. These pressures bring further power to multinational corporations benefiting from having controlled the genetic engineering industries from the outset (Møller 2001).

One area of new technology, the development of alternative energy, is initially retarded. The main reason for this is that projections of oil and gas reserves were closer to the mark than many analysts expected around the turn of the century. The World Petroleum Assessment 2000 by the US Geological Survey (USGS 2000, Ahlbrandt 2002) was originally thought by many analysts to be excessive (Bentley 2002, Campbell 2002, Laherrère 2002 – see Figure 51). By 2020, however, it appears that costly unconventional oil and gas supplies such as deepwater resources 500 metres or more below sea level will have to be commissioned, which finally provides a powerful incentive for the development of renewable fuels.

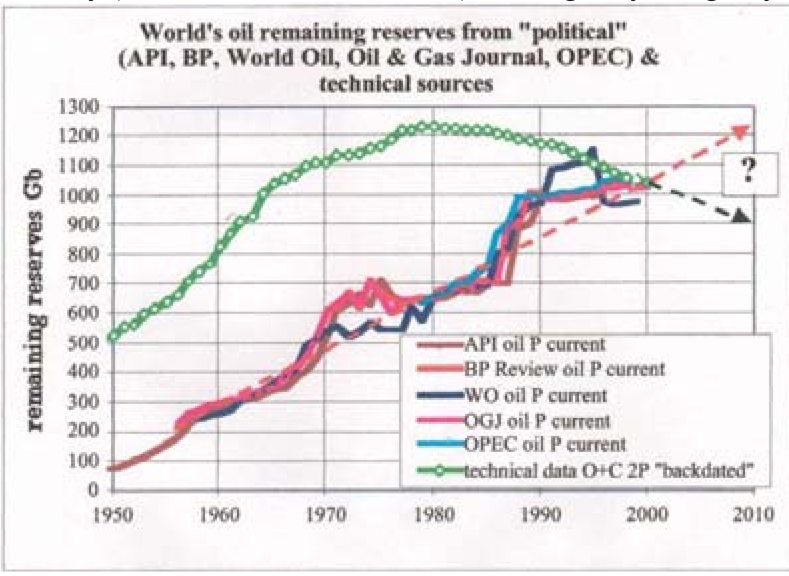


Figure 51: The world's remaining 'political' oil reserves, as reported, have been rising steadily from 100 Gb in 1950 to 1000 Gb in 2000, which has misled some analysts into proposing that they can continue to do so. By contrast, the 'technical' data show a decline since 1980, with a peak around 1200 Gb. (Quoted from Laherrère 2002:3)

About one-quarter of world energy supplies is biomass and other renewable energy by 2050 (IPCC 2000). Though its share is decreasing, the use of coal continues to grow until the 2050s, with ample resources and vast markets to supply, including the growing mega-economies of India and China. However, the cleanest fossil fuel, gas, is the dominant energy source by mid-century (Appendix E).

As we enter the second half of the century, a second shift occurs – towards greater urgency to achieve sustainability. During the 2040s, the majority of politicians and business leaders finally become convinced that the world's ecosystems are gravely threatened and tax and incentive systems are reinforced to protect these systems. The world, in effect, shifts from the A1 global economic growth quadrant to the B1 quadrant of global environmental policy change.

This world scenario is consistent with the 'balanced fuel mix' variant of the IPCC A1 family up to 2050, but growth will then slow down as a 'B1' scenario emerges. Carbon dioxide emissions will increase from 7 gigatons carbon (GtC) in 1990 and 8 GtC in 2000 to 11 GtC in 2020 and 16 GtC in 2050 (Appendix E). Continued unabated growth in the balanced fuel mix variant of A1, had it been feasible through the second half of the 21st Century, would then have caused a decline to 13½ GtC by 2100. In the present worldwide scenario, the transition to global environmental policies may see a further decline towards the 2000 level (8 GtC).

As a footnote to the A1 storyline, the following point from the Townsville scenario planning workshop serves as a reminder that the projected worldwide prosperity did not build up overnight. It was inspired by a PhD student in the group:

> *While prospects worldwide are good in terms of economic development of most countries over the century as a whole, developing countries by 2020 have not yet attained sufficient prosperity to change their priorities significantly. Over the first two decades of the century, the issue of reef degradation was just too big or too remote for countries to do anything about or make sacrifices for. Their governments had other priorities and basics such as food and shelter remain the top requirements for the vast majority of the people.*

Australia

Economic growth remains the dominant component of the 'triple bottom line' of social, economic and environmental accounting in 2020, despite statutory obligations to consider all three elements. Despite the emphasis on economic growth, the rate has fallen to an average of only 2.3% pa since 2000; considerably lower than even the low projections provided by ABARE when the Productivity Commission conducted its review of the Great Barrier Reef catchment and water quality back in 2002 (PC 2003).

Despite the very visible activities of environmental activists, the majority of the population remains indifferent to matters such as coral bleaching and the loss of the Wet Tropics – another consequence of global warming (Ostendorf, Hilbert and Hopkins 2001, Hilbert and Ostendorf 2001). People are generally unwilling to sacrifice current lifestyle for the benefit of future generations. They drive their cars as much as ever in cities and country areas alike despite the scientifically indisputable connection between CO_2 emissions and climate change. The oil industry has used its lobbying power to help minimise taxes and levies on gasoline and other petroleum products. Government funding for city transport systems favours roads over rail and other public transport.

The emphasis on economic growth and support of a global trade system to encourage worldwide market development provides a strong impetus for economically powerful groups, notably the multinational corporations which form an increasingly influential lobby group in Australia as they do elsewhere. Australian governments continue to adopt new environmental policies reactively rather than proactively. Although there has been a rise in support for stronger environmental policies in the community, this has had limited influence on mainstream political decision-making.

Australia's GDP growth has exceeded the average rate for Pacific OECD countries, which is dominated by Japan. Australia has experienced similar growth rates to the United States and Canada.

While climate change has made the world face a common problem, it is considered difficult to tackle politically and influence internationally, and is regarded as too long-term to be a major concern in Australia's current planning framework.

Progress on environmental issues was slow in Australia over the first two decades. Examples include:

- Approval to Stages 2 and 3 of the shale oil Gladstone Stuart Project despite strong campaigns by all major environmental NGOs.

- Pollution regulation relating to houses and other building, and to packaging and general waste, progressed slowly, as did any move towards resource efficiency such as more energy-efficient building design and redesigns of vehicles and aircraft fuel systems.

- Despite the public inquiries early in the century (PC 2003, Baker 2003), regulation of erosion, nutrient loss and consequent pollution along the coast adjacent to the Great Barrier Reef didn't start to become efficient until the second decade of the century, both in the hinterland basins such as the Fitzroy and Burdekin and in sugar cane country.

- Stimulated by the worldwide economic growth, worldwide demand for meat grew rapidly up to 2020 and beyond. Queensland meat exports were maximised within the constraint of having to cope with major periodic drought conditions. Generally, however, rising export meat prices helped rehabilitate properties to maintain productivity, which again helped mitigate erosion problems from the Burdekin, Fitzroy and other catchments.

- What increasing numbers of people regard as an unsustainable rampant lifestyle in Australia and other western countries was fuelled by the world economic growth and retention of materialistic consumption patterns.

In summary, the *threshold* where political will and community attitudes start to force change through effective environmental management in Australia was only just being reached in 2020. Looking forward from that vantage point, however, changes are about to happen, boosted by the need to replace a failing crude oil supply with other energy sources over the coming decades and generally to conserve energy. While it will take two or three decades more for the growth orientation of politicians and industry leaders to give way to advocacy for a sustainable environmental, social and economic system, the knowledge base has been strongly augmented, not least by the physical data and scenario studies developed since the 1990s by organisations such as the CSIRO (Foran and Poldy 2002, and Dunlop et al. 2002 who developed three 50-100 year scenarios for agricultural land and water use in Australia) and the Productivity Commission (PC 2003).

In the economics area, satellite accounts for the environment were pioneered in Australia early in the 21st Century but then included only 'measurable' variables providing fairly trivial adjustments to conventional national accounts (ABS 2002b). A system of environmental losses and gains was subsequently constructed based on comprehensive physical data and the application of estimated non-market values. As in all attempts to measure total economic value (market and non-market), the valuations are minimum estimates. There is growing agreement from 2020 that as natural capital and ecosystem services become scarcer and more stressed, the need to preserve them for our own life support makes them even more valuable.

In a booming world dominated by trade, entrenched economic concepts persisted into the 2010s. Soon after 2020, however, it becomes mandatory for economic advice to government to include comprehensive assessments of the environmental cost of exporting or producing in terms of depleting water supply, increasing salinity and other degradation. The availability of comprehensive satellite environment accounts helps sell this to all concerned.

The Great Barrier Reef

In this world of rapid economic growth, the Marine Park is subjected to increasing pressure, but this is also a world that values its environmental assets – though the emphasis as we have seen has switched from conservation to resource management. The Great Barrier Reef Marine Park Authority remains a strong manager in 2020, continuing to balance conservation and use (Sweatman et al. 2002:180). Stakeholder cooperation has also continued with successive grants to cooperative research organisations like CRC Reef enabling these institutions to remain influential in focusing the common interest of stakeholders. Philanthropic activity to save the iconic Great Barrier Reef has grown steadily, with an increasing number of corporations and individuals contributing funds towards research and towards dissemination of public knowledge and understanding.

The Representative Areas Program (RAP) has progressed, though in 2020 pressure is rapidly increasing to wind back the 30% protected as no-take-areas in 2003. Strong coastal community support for policies that underpin the 'full speed ahead' doctrine drives a political inertia that fails to take the best scientific opinion seriously. Scientific opinion continues to take a back seat to political expediency. Extensive sugar cane cultivation along the coast has caused continued runoff problems. So has the intensified horticultural activity on the Atherton Tableland, around Bowen, and in the Burnett catchment area – it is often forgotten, for instance, that the Burnett discharges close to significant seagrass beds and dugong habitats at the southernmost extremity of the Great Barrier Reef.

As noted above, cattle production has also grown strongly to meet world demand trends, causing added runoff especially from the Fitzroy River catchment – despite significant efforts to control it from around 2013. Again, these developments were strongly underpinned by an electorate that valued exports and personal wealth over improved coastal environments. The added impact of the 'shifting baseline syndrome' (Pauly 1995; Jackson et al. 2001) led to continued questioning of whether 'the science is really right'. These authors noted that humans have continually shifted their notion of natural beauty so that much of the modern countryside (though vastly changed over the past 2000 years) are now considered wilderness by many local inhabitants. In the Australian context, they noted that current declines in dugong populations are compared to numbers that were already remnant compared to pre-colonial Australia. Looking back from 2020 reveals that this syndrome played a significant role in shaping people's perspectives on the changes going on around them.

Loss of vegetation within catchments plus the periodic stocking between droughts of coastal areas with cattle to cater for high demands for beef internationally caused rapid deterioration of coastal areas. Rapid warming of coastal waters plus increased pesticide and herbicide use, due to the increased arrival rate of warm-climate exotics in agricultural settings, led to loss of mangrove, coral and seagrass systems along the Queensland coast (Duke et al. 2000). By 2020, 50% of inshore coral reefs have been lost adjacent to developed catchments. By 2050, extensive coastal development and the effects of runoff will bring these systems down to 25% of the inshore area occupied in 1990.

Two successive shocks have triggered a modicum of political and social attitude changes: When two oil tankers ran aground west of the Reef in successive years (2010 and 2011) and the spills exacerbated the weakening of coastal ecosystems that are already under stress from rising sea temperatures and other factors, the main initial political effect was to deepen the feeling that protecting the Reef was becoming a lost cause – but the subsequent reaction was more positive and constructive; here was a world heritage area for which Australia was responsible and which had to be saved for future generations.

Reduction in coral cover will bring levels to less than 50% of 1990 levels by 2025 (Part 1, Table 10). This is due to the 1°C increase in sea temperature (over 1990) that has increased dramatically the frequency and severity of bleaching events. Events that are several times more stressful than 1998 and 2002 are now very common (see Part 1 and Done et al. 2003). The loss of inshore reefs was hastened due to a combination of increased bleaching, coastal development and degradation – despite the best efforts of the management authorities. Crown-of-thorns starfish outbreaks are more frequent and wide spread, probably driven by a combination of reduced predation and eutrophication of inshore waters of the Great Barrier Reef. Few are disputing the reasons for the decline of coral reefs within the Great Barrier Reef Marine Park by 2025, which leads to last ditch attempts to slow the pace of climate impacts by regulating coastal practices. These changes have little effect and are discarded in desperation by 2035. By 2040, Great Barrier Reef benthic habitats are unrecognisable relative to those of the 1990s (when only 0.6°C of warming had occurred). It is a timely reminder that roughly three times the warming that occurred from 1880 to 2000 will occur by 2040.

Tourism

The reef-based tourism industry, while coping with the changes brought on by coral bleaching, has valiantly lobbied against the increasing pollution from runoff caused primarily by grazing and cropping, and in some instances by urban development.

Table 14: Influences on base tourism projection: A1 scenario

	2001-20	2020-50
Condition of GBR, end of period (scale 0 (worst) to 10)	**4**	**1**
ABARE base world projection (average 2001-10 and 2010-20)	3.6%	
ABARE base Australian projection (average 2001-10 and 2010-20)	3.5%	
Projected world economic growth, this scenario	3.8%	4.0%
Economic growth, United States, this scenario	2.3%	2.1%
Australian economic growth, this scenario	2.3%	2.1%
Asia economic growth, this scenario	7.8%	5.6%
Scale from -5 (worst) through 0 (neutral) to +5 (best)		
Reef-based tourism - policy (weak bad, strict good)	3	
Stakeholder cooperation (weak bad, strong good)	2	
Australian economic growth factor	-2	
Asian tourism factor	5	
GBR competition with other reef areas: international tourists	2	
GBR competition with other reef areas: domestic tourists	2	
GBR competition with other coastal tourism: international tourists	0	
GBR competition with other coastal tourism: domestic tourists	-2	
GBR competition with other domestic tourist attractions	-2	
GBR competition with other international tourist attractions	-2	
Tourism industry success in introducing alternative product	3	

Source: ABARE: see PC 2002; IPCC projections in SRES background tables (IPCC 2000)

Operators have struggled to attract tourists who come specifically for the Reef experience, notably dive, snorkel and pontoon tourists. However, the rising economic prosperity over the past twenty years – which is expected to continue – is enabling rising numbers of Asian visitors to travel to tropical coastal Queensland. These tend to be tour group participants rather than independent travellers. The tourism industry promotes 'Caribbean-style' resort visits and cruises rather than depending directly on the natural values of the Reef, and has implemented alternative attractions such as virtual reef experiences and reef theme parks which show coral growing in controlled settings. The real Caribbean experience, however, continues to attract most of the tourists from Europe and North America, with numbers of these barely growing in the Great Barrier Reef area as the reef itself loses its drawing power.

Internationally, the Australian Tourism Commission continues to promote a total Australian experience including Uluru and Kakadu, the Indigenous cultures of the Northern Territory and to an increasing extent Far North Queensland, the attractions of the tropical Queensland Coast (with little or no reference to coral), the Gold and Sunshine Coasts, the Kimberleys, Sydney, Melbourne and other major cities, and Tasmania with its temperate English climate and convenient size for the traveller. The promotion of tropical coastal Queensland by Tourism Queensland has been directed progressively to overseas markets, especially Asia which provides the main growth.

The saving grace for total tourism demand is the strongly growing Asian market, increasingly dominated by China. Due to this, the Queensland tourism market has kept growing rapidly, though increasing numbers go to the now crowded Gold and Sunshine Coasts rather than the north. The 200 kilometre city from Noosa to the Tweed (Spearritt 2002) has become a reality, indeed with a vengeance with further major resort developments extending north towards the Fraser coast and south into northern NSW.

Promotion directed towards the Asian market in the 2010s to attract people to the Great Barrier Reef region has concentrated on balmy climate, blue waters and comfortable resort facilities rather than the reef and land-based national parks. Relaxation of tax regimes leads to further growth of casino-based tourism in Far North Queensland. Despite the rapid growth of this type of tourism, competition beyond 2020 makes North Queensland's casinos less attractive as similar casino developments in other tropical locations flood the world market in response to the impact of environmental degradation.

The tourism scenario outlined above, together with projections associated with each IPCC scenario storyline, cannot be quantified into a neat predictive model. Each scenario must be assessed separately as has been attempted in Table 14 and its equivalents in the other scenarios described below. Each of these tables notes the economic growth rates associated with each scenario family and tries to assess the competitive position of the Great Barrier Reef using a subjective rating scale.

Table 14 draws attention to an additional point in relation to the ABARE projections that are used as the basis for interpreting the alternative futures. Of the four IPCC scenarios, only the one discussed in this section (A1) matches the ABARE projection of world economic growth. And even that shows a much lower growth rate for Australia than the ABARE forecast. There is no reason to expect Australian economic growth to significantly exceed that of the United States and Canada (or the European Community). Domestic tourism growth will be pushed downwards if economic growth is lower than projected.

Reef-based tourism by 2020 is expected to be adversely affected by reef deterioration rated 4 on a scale of 10 compared with the quality in the 1990s. This is close to the date when coral populations might be expected to occupy half the area that they currently occupy. By 2050, coral dominated areas of the Reef will be largely non-coral dominated as indicated by the rating of one (see discussion of environmental evidence of trends in Part 1, pp 88-90). Reefs at this point will resemble those of Florida, where large coral dominated areas are a memory of the 1950s.

This scenario benefits from a strong reef-based tourism policy enunciated by the Marine Park Authority, with good stakeholder cooperation through the cooperative effort of CRC Reef, and donations from corporations and individuals helping to increase the research effort. The Asian tourism factor is very strong and can be manipulated towards experiences which don't involve visiting the reef itself. Being well managed, the Great Barrier Reef has a competitive edge on other reef areas in the world. However, it has become more like other major tourism destinations both in Australia (especially the extended Gold and Sunshine Coasts) and overseas (popular Asian destinations such as Phuket and Bali).

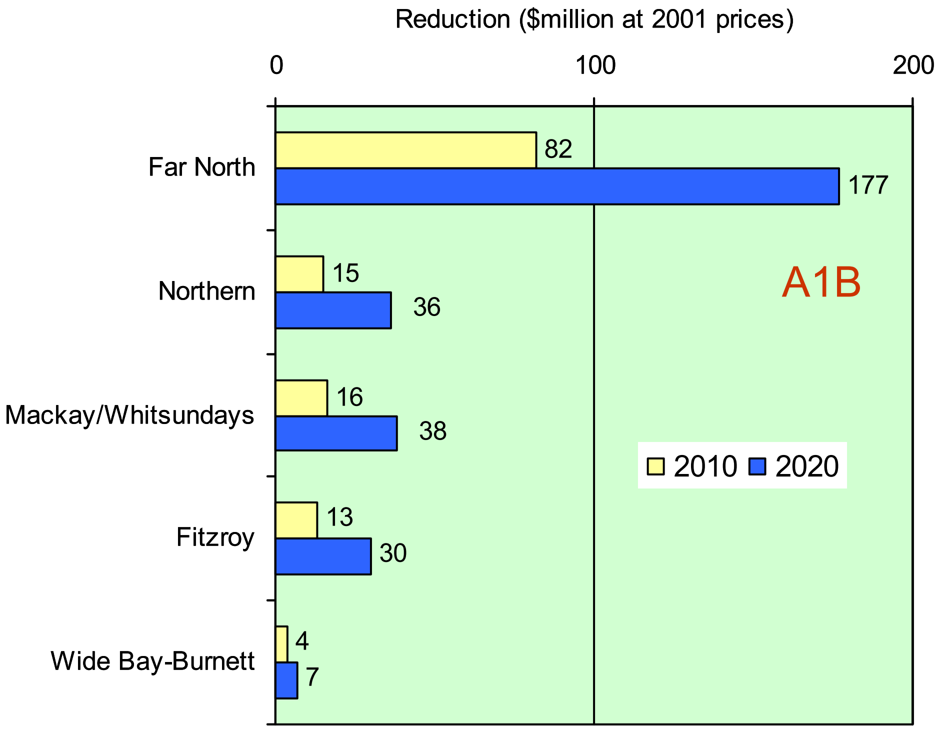


Figure 52: Reduction in tourism GRP in 2010 and 2020 according to the A1B scenario. Total for five regions: $130 million in 2010, $288 million in 2020. Reduction relative to total projected reef-interested tourism GRP (2020): 19%, relative to total projected tourism GRP: 10%. See further Appendix D, Table D22.

Full-time equivalent employment, tourism, A1B scenario

Region	Persons			Annual change	
	2001	2010	2020	2001-10	2010-20
Tropical (Far) North	16,600	16,300	17,700	-0.2%	0.8%
Northern	5,800	6,000	6,600	0.4%	1.0%
Mackay	6,100	6,300	7,000	0.4%	1.1%
Fitzroy	4,600	4,800	5,300	0.5%	1.0%
Wide Bay-Burnett	5,900	6,300	7,200	0.7%	1.3%
Total GBR regions	39,000	39,700	43,800	0.2%	1.0%

Derived from Tables D11 and D22.

These trends will extend for the following thirty years to 2050, with economic growth fuelling continued tourism from Asia in particular. The tourism industry centred on Tropical North Queensland and the Whitsundays will continue to grow, but the uniqueness of reef and rainforest experiences will have largely disappeared, apart from theme parks displaying remnant coral and rainforest in artificial "captive" conditions. The industry will develop much along the lines of the Gold Coast and similar areas around the world but will probably continue to enjoy a comparative advantage in the Asian markets.

Quantitatively, Tropical North Queensland will bear the brunt of the reduction in tourism caused by climate change and reef deterioration (Figure 52). This does not mean that a declining tourism industry is expected in any region along the Great Barrier Reef over the two initial decades of the century. Without the impact of climate change, the total tourism gross regional product is projected to increase at a constant annual rate of 2% in each of the five regions. The rate of GRP growth between 2001 and 2020 in the A1B scenario is reduced to 1.2% pa in Tropical North Queensland, to 1.5% pa in the Northern, Mackay-Whitsundays and Fitzroy regions, and to just under below 2% in Wide Bay-Burnett (calculations based on Table D22).

Full-time-equivalent tourism employment in the five regions before adjusting for the A1B scenario is projected to grow from 39,000 in 2001 to 42,000 in 2010 (0.8% pa) and then to 48,500 by 2020 (1.4% pa). The table box below Chart 52 shows that most of this growth disappears in the first decade under scenario A1 (0.2% pa) and the total growth to 2020 is approximately halved despite some improvement in the rate in the 2010s (to 1% pa). A small decline of 0.2% pa is projected for Tropical North Queensland under this scenario up to 2010, followed by an annual 0.8% increase between 2010 and 2020. Again, Wide Bay-Burnett is relatively unaffected by the fall in reef-based tourism, with the three remaining regions in an intermediate position.

Fisheries and related industries

Each scenario under this heading is discussed under the subheadings of benthic fisheries, pelagic fisheries, trawling, aquaculture and recreational fishing. The narrative concentrates on commercial activities, but one statement on recreational fishing is common to all four scenarios: *Amateur fishing is seen as a fundamental right.* The 'I fish, I vote' issue is seen as difficult to shift given that almost 25% of Queenslanders currently fish and many will continue to fish despite future declines in fish size and abundance. Clearly, however, changes in the ethics of fishing are likely under scenarios in which education of the coastal electorate on the environmental issues might lead to more of a Rex Hunt ('catch, kiss and release') ideology. There is less recognition of the fact that several studies now show that released fish don't always survive (Bohnsack 2000; Norman 2001).

Benthic fisheries

- Coral reefs lose 50% of the biodiversity associated with coral dominated areas by 2025, with the subsequent loss of fish diversity. This assumes a linear decrease which may underestimate the actual losses that may be more exponential in nature due to interactive effects of species (over and above those with coral) with each other. For example, corallivores and fish that require coral settlement cues (settlement of many species onto reefs require cues generated by living coral) decrease substantially over those that are less dependent on reef-building corals. Reef-associated fisheries undergo a similar contraction of diversity. These impacts are compounded by the continued over exploitation and habitat destruction associated with commercial fishing practices.

- Herbivorous fish increase in relative abundance due to increased areas of algae cover on coral reefs. This results in increased populations of siganids (spinefoot fishes) and scarids (parrot fishes) on inshore and mid-shelf reefs which are less palatable but are eventually accepted by the Australian fish markets as more acceptable fish species (generally more predatory) such as emperors and sweetlips (*Lethrinus*) and coral trout (*Plectropomus* spp) become extremely rare and expensive. This has happened in many places worldwide (Caribbean, Southeast Asia) and assumptions made at the turn of the century that the Australian public would not change its preferences as these changes in abundance and species composition occurred have proven untenable.

- Mangrove-associated fisheries contract as mangrove habitats are reduced by half by 2020 and by a further 30% by 2050. Mud and sand crab industries suffer, especially given that some estuaries are also being heavily affected by anthropogenic factors such as pesticide and herbicide runoff (Duke et al. 2000).

- Declining health of coastal ecosystems leads to many commercially valuable species experiencing problems in having enough nursery habitat to maintain viable commercial populations.

- There is a pronounced movement of remaining benthic fisheries in a southward direction as southern waters warm. This is quite dramatic and starts to occur as early as 2020, with northern tropical species (non-coral dependent) appearing at southern sites where stock does not have to be associated.

- By 2030, the waters of the southern end of the Great Barrier Reef reach temperatures applying to far northern tropical waters at the turn of the century. Invasion of different species leads to an uncertain future for reef fisheries. This problem becomes chronic by 2050 due to the rapid movement of warm-water Southeast Asian species into Australian waters.

- The incidence of ciguatera rises between 2010 and 2020. As discussed in Part 1 (p 46), ciguatera is a compound that is poisonous to humans and accumulates in the tissues of some reef fish. It comes from eating blue-green algae (cyanobacteria), and appears to build up as coral cover is lost. Elevated water temperatures and substrates that are now dominated by cyanobacteria lead to a change in the diets of many food fishes. This puts added pressure on the market which then requires an educational push to ensure people don't completely reject reef fish. By 2030 aquaculture varieties dominate due to loss of benthic fisheries and more cost-effective aquaculture practices.

- By 2030, the fishing industry is constrained by environmental pressures. Aquaculture expands rapidly under this scenario in the early years. Most prawns, crabs and fish that are eaten in 2030 are derived from aquaculture in coastal Queensland. Parts of the fishing industry rely on government assistance from 2020 onwards. There is an ongoing debate over whether no-catch fishing zones designated under the 2003 Representative Areas Program should be reduced in size and number. Eventually, the dire circumstances of the industry cause political pressure that either leads to a 'redesigned' Marine Park (very few no-take areas) or to the loss of a viable benthic commercial fishing industry on the Great Barrier Reef by 2030.

Pelagic fisheries

- Pelagic fisheries show a gradual decline in catch as major reductions occur in ocean productivity, and circulation patterns change. International pressure on fisheries located within Australian waters intensifies via legal and illegal channels. In 2025, a major standoff develops between Australia and its neighbours over dwindling and changing fishery resources in its coastal waters. Later in the century, wild stocks are so low that international incidents are almost non-existent and aquaculture takes over as the major supplier of seafood. Australia's major competitor for seafood derived from aquaculture is Southeast Asia. Its position within world markets is determined by its previous long-term investments in technologies such as high intensity aquaculture, genetic modification and selective breeding.

- Major changes to ocean circulation cause pelagic fish populations to shift their distributions around the globe. Warm-water species penetrate further south. This changes food webs as well as catch species. Warming of surface waters leads to shifting abundance of fish populations. Some southern ocean species experience reductions as waters warm more rapidly at poleward locations.

- The warmer conditions by 2050 promote a major increase in the risk of mass fish kills by anoxic conditions resulting from overheated stagnant waters inshore – killing large numbers at critical juvenile stages. These are localised in regions in which tidal flow and local land forms create low rates of mixing. These coincide with doldrum conditions usually occurring in strong El Niño years and are due to high metabolic activity versus low mixing rates.

- The advent of warm upwelling events shocks the system as the deep ocean continues to warm more rapidly than the surface. This leads to the activation of bacteria and a lowering of deep ocean oxygen concentrations. These events affect coral areas and although their effect on the Great Barrier Reef is minimal, there is a further general downturn of ocean productivity.

Trawling

- Trawling continues in the Marine Park. The industry adopts measures to minimise impacts but faces negative publicity as reef and associated fisheries continue to decline in quality (rise of macroalgae and unsightly blue-green algae blamed rightly or wrongly on fishing pressure). Much of the change in benthic structure is driven by climate change and fish populations change as a result of this (leading for instance to a reduced abundance of grazing fishes due to line fishery pressure which reinforces the conversion of coral dominated to algal dominated ecosystems).

- Towards 2050 the restrictions on trawling are relaxed due to demonstrable evidence that benthic habitats have been largely destroyed by the rapid shift in climate. This is also occurring as the reduced availability of some fish species mean that prices increase – creating political pressure for an increase in fishing. This is analogous to how tuna prices in Japan have increased dramatically over the past 50 years due to the increasing difficulty of obtaining tuna of the required quality for sushi.

Aquaculture

- Aquaculture is now relatively unfettered by funds or regulation as Aquaculture Regulations, specifically targeting the Great Barrier Reef, are abandoned. Aquaculture is increasingly seen as the solution to the rapidly declining fishing industry by 2015.

- There is an increase in the diseases in aquaculture stocks due to warmer conditions, large monoculture systems and overall reduced coastal water quality. This problem is chronic by 2030.

- Development of genetically modified aquaculture species is encouraged to cope with increased thermal stress and disease. Australia leads the way in the development of these technologies. Judicious investment in the high technology end of the industry in the 1990s has paid off handsomely in this respect, both in terms of domestic production and international technology exports.

- There is a constant active policy of changing stock to more tolerant varieties as climate stresses increase. A central government organisation is established to help the industry keep pace with changing conditions. This draws on the premier research and development position of the Australian industry in the area of aquaculture-related disease control.

- Warm-water aquaculture moves slowly to more southern locations. By 2030, species grown in the Far North in 1990 can be cultivated at locations 800 km further south. Northern Australian aquaculture by then has adopted species found previously in Indonesia. By 2060, large areas of coastal far northern Australia are uninhabitable for aquaculture due to temperatures rising to 33°C and above (Figure 5, Done et al. 2003).

- By 2010, the invasion of warm aquaculture species from aquaculture ponds into local watersheds has started to become a problem. Warmer than normal conditions increase the stress on local stock which assists replacement of local stock by aquaculture varieties.

- Large-scale aquaculture in fish cages becomes increasingly common globally. In Australia, many of the concerns about effluents subside due to economic and political pressures. One response is to move cage aquaculture increasingly offshore and to submarine locations as technologies are introduced to cope with extreme conditions of offshore environments.

- Inland saline aquaculture also develops, providing opportunities for rural Australia.

Summary of commercial fisheries prospects

In summary, life for fishers is a struggle under the A1 scenario. Conditions grow steadily worse towards 2010 and 2020, with a greater number of industries requiring assistance as fish stocks either dwindle or undergo major changes. The seafood market changes both in terms of variety and quality. There is more intensive competition for fewer and fewer fish. Beyond 2020, benthic fisheries can be expected to remain in decline and have issues like ciguatera to be concerned about. This will require considerable investment in medical responses, public education and marketing. Aquaculture will represent a temporary solution to the major upheaval within the commercial fishing industry. Active policies to move warm-water species into more southern areas will provide a buffer against the fact that waters will be warming by as much as 0.5°C per decade. Beyond 2030, large areas of the coastline may well be unusable for aquaculture unless ponds can be stocked with varieties that have been genetically altered to live in water temperatures beyond 34°C.

Recreational fishing

Recreational fishers are affected by the factors discussed above. They remain socially if not economically important to the coastal regions. Coastal people in the five regions still value the outdoor experience of recreational fishing – even if catch rates are largely reduced by 2025 due to the influence of changing benthic habitats. While the falling fish stock by 2020 has accelerated the falling trend in participation rates that was evident from the RFISH surveys in 1996, 1998 and 2001 (Higgs 2001, DPI 2002), a substantial 24% of the regional population has retained the hobby. Line fishing on the Reef has, however, become quite rare as costs went up and fish populations down, accelerating another trend which was noted from the RFISH surveys, towards inshore fishing.

Expenditure on fishing equipment by recreational fishers may not decline as much as their catch (in any case, this does not have any significant net impact on regional economic activity). The ABARE base projection is for unchanged real expenditure over the two initial decades of the 21st Century (Table D6). Recreational fishers in this scenario would accept smaller catches and sizes, and being largely local, would remain in the area. They may, however, take up freshwater fishing, are likely to largely abandon line fishing on the Reef in favour of inshore fishing, and general participation may fall further compared with the base projection. The changes to water flows in streams, discussed by Dunlop et al (2002) and others, must be kept in mind. Australia is a drier, hotter climate under this scenario which may have major ramifications for freshwater as well as marine-based fishing activities.

Local economies before Reef damage

The ABARE reference projections that best fit scenario A1 are a mixture of base, low and high projections (PC 2003), except for fisheries where the projections are based on estimated reduction in catch plus a price factor (Table D26). ABARE's projections are shown in Appendix D. Industries with significant export content are assumed to move according to ABARE's high projection (sugar, beef, mining and processed minerals, and inbound tourism), while the low or mean projection has been used for industries dependent on domestic demand: domestic tourism and horticulture. The base case was used for aquaculture and for recreational fishing expenditure, which is not included in the regional impact estimates because fishers appear to be mainly local people (Murphy 2002a, 2002b), or are otherwise part of the tourism statistics.

Table D9 shows that the total gross value of production of these eight industries (excluding recreational fishing) according to ABARE and supplementary sources is projected to increase from $18.3 billion in the Great Barrier Reef catchment area in 2001 to $22.1 billion in 2010 and $24.8 billion in 2020. The average annual growth rate for the first decade is 2.1%, and for the second 1.1% (Table D10). The projections in the first decade are led by aquaculture (10.2% pa) and sugar (6.2% pa), followed by minerals (4.7% pa) and inbound tourism (4.6% pa).

The top growth industries in the second decade of the ABARE projection are aquaculture (8.6% pa) and inbound tourism (4.7% pa). Domestic tourism remains flat. A continuing increase for commercial fisheries of around 1% pa is due to rising real prices, and assumes that supply remains constant before imposing specific scenario conditions such as the deterioration in benthic catches described above.

The growth rate for beef is projected to be 1.3% pa during both decades. This is based mainly on an assumption that the long-term decline in prices will continue (assumed to be 2% pa in the high ABARE case). It is likely, however, that beef prices will pick up under this rapid world growth scenario, especially in the second decade. Similarly, coal exports (the main part of the mining projections in Tables D9 and D10) also seem low at a continued trend of about 0.5% pa, in view of the assumption that India and China will grow huge economies under the A1 scenario.

ABARE also provided projections of gross value added and employment for most industries. One exception was tourism, which has to be represented by its gross regional product, which includes taxes paid less subsidies received on top of the gross value added (see OESR 2002a). Value-added estimates were also missing for aquaculture, and assumed to equal 55% of gross value of production.

Based on these additional assumptions, the base projection of gross value added in the regions adjacent to the Great Barrier Reef for main export-oriented industries is from $9 billion in 2001 to $12.1 billion in 2020 at constant 2000-01 prices (Table D11). Tourism is estimated to represent 23% of total value added in 2001, growing to 26% by 2020 (slightly less as tourism is represented by GRP rather than gross value added). In employment terms the share is higher (growing from 44% to 48% of the total for the eight industries), because tourism is labour-intensive.

The regional economic impact of a change in employment, value added or GRP can only be approximated, especially in the absence of current regional input-output tables. There is reasonable consensus that multiplier effects are in the order of 1.8 for regions the size of those along the Great Barrier Reef coast. Innes and Gorman (2002) use 1.9 (from KPMG 2000), which is in the same area considering the uncertainties surrounding flow-on values. This means that for a given change in output we may expect the total regional impact to be about 1.8 times greater. We have worked on this assumption below.

Given that the industries presented in Tables D9 to D11 represent the main economic base in terms of exports to other regions, the current estimated total employment in these industries represents slightly less than one-quarter of the total number of employed persons in the area (Table A2, showing total rather than full-time-equivalent workers). A detailed economic impact study would have identified more export-oriented companies and industries, but the ones analysed by ABARE include the main drivers of these economies.

It is assumed that the 1.8 multiplier also applies to gross value added, gross value of production and the most appropriate measure, gross regional product contributed by a given industry. Hence, a $1 million change in the activity level of a given industry is assumed to have associated net local secondary effects adding to 80% of the primary impact. This estimate could be refined given proper input-output data or a disaggregated approach, as demonstrated by Driml (1987) in her study of specific tourism activities on the Great Barrier Reef. For this study we proposed an aggregate (macroeconomic) approach which proved to be justified by the initiative of the Office of Economic and Statistical Research in producing a comprehensive set of regional tourism satellite accounts (OESR 2002a).

Impact on coastal regions

The North and Central Queensland tourism industry in Scenario A1 benefits from strict policies in relation to reef access, positive support from industry stakeholders as expressed through cooperative organisations such as CRC Reef, an even more intense research effort and a flexible tourism industry attitude in attempting to provide new attractions. The relatively well-preserved state of the Great Barrier Reef attracts tourists from areas more damaged and less well managed. We estimate that the combination of these factors limits the damage to a decline in the growth rate in the value of tourism services and tourism employment of 0.4% pa.

Strong Asian tourism and lower domestic economic growth than assumed in the ABARE projections have already been taken into account in the projection, and no further additions or deductions need to be made. The competition from other coastal tourism destinations in Australia and abroad, and from alternative tourism attractions, will cut 0.8% pa off the projected growth rate in Great Barrier Reef tourism each year between 2002 and 2020.

The sequence for estimating the impact of these assumptions on tourism was as follows (in each case deriving a base in 2001 and projections for 2010 and 2020). The first several steps were needed before applying the adjustments:

- Acceptance of ABARE's total tourism expenditure for each region (Table D9);
- Deduction of business and other visitor expenditure (Table B8) adjusted to the 2001 base year and assumed to grow by 2% pa;
- Net tourist expenditure derived by deduction;

- Estimated gross product derived for each region using ratio of GRP to total visitor expenditure in 1999, and again removing business and other components from estimates (OESR 2002a).

Having derived regional GRP projections for tourists proper, the next step was to estimate and project the proportion of 'reef-interested' GRP. This involved the following sequence:

- Accept ABARE projections of inbound and domestic tourism proportions in terms of equivalent estimated GRP;

- For each group derive regional proportion of 'reef-interested' to total tourists (Table B18), noting that there will be changes in what used to be 'reef interest' as a resilient tourist industry promotes alternatives ('converted reef-interested tourists');

- Estimate annual rates of change in domestic and inbound tourism GRP in each region, and deduct 1.2 percentage points from each estimate;

- Calculate 'reef-interested' domestic and inbound tourism GRP, and measure reduction from the unadjusted base.

Table D22 shows the key estimates from this process.

For commercial fisheries, Table D26 shows separate declines for benthic, pelagic and trawling fisheries compared with the activity in 2001, and an adjustment for prices, which are assumed to increase by 10% by 2010 and 20% by 2020, compared with 2001. The comparison base is unchanged supply but with the increase in real prices built in. The impact

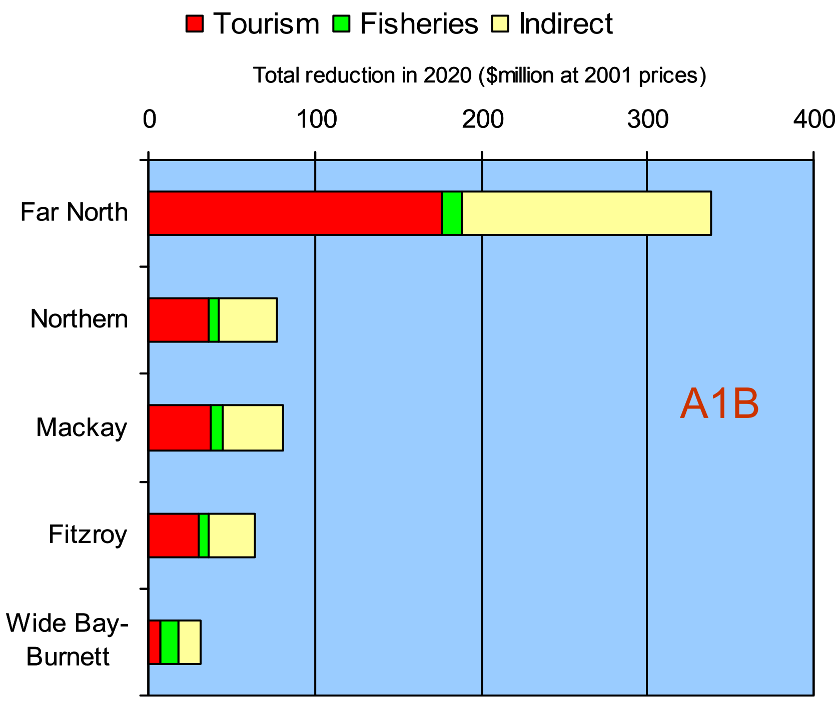


Figure 53: The reduction in Gross Regional Product is caused by reduced tourism expenditure, reduction in commercial fisheries, and indirect (multiplier) effects assumed to be 80% of the total primary reduction in each region. The total estimated reduction in 2020 is $555 million, which as in all these scenarios is concentrated on the Far North (60%). The reduction in total projected GRP in 2020 is 4.4%.

of environmental degradation is therefore the quantitative reduction of catch, amounting to an estimated 13.5% in 2010 and 42% in 2020, with benthic fisheries suffering the worst reduction (Table D26).

Aquaculture is a growth industry in ABARE's base projection, and arguably it may develop even faster in a relatively uncontrolled environment to compensate for fisheries losses. Possibly the logical step would have been to assume that the high projection applies to Scenario A1, rather than ABARE's mean projection. We did not do this.

The final step in the assessment of regional economic impact in 2010 and 2020 is to present all projections in gross regional product terms before deduction for deterioration of the Reef (Table D27, which shows detail for each region). In the absence of any Great Barrier Reef factor, the total of the five regional economies is projected to grow from a gross product of $9.3 billion in 2001 to $11.3 billion in 2010 and $12.6 billion in 2020 (more if coal and cattle prices increase more than projected). The main impact of reef deterioration is on tourism, as shown. Including multiplier effects, the estimated total impact for the year 2010 is $243 million, and for 2020 $593 million.

This may seem like a small proportion of the total gross regional product, and the analysis does remind us that other industries such as mining and the rural sector also drive these economies. Added over the 19 years, however, and assuming that the loss increases at a regular rate, the loss comes to $5.6 billion. This is massive by any account; even in discounted cash flow terms using a 5% discount factor the loss is $2.9 billion.

Furthermore, the loss is not equally distributed along the Queensland coast. Figure 53 shows that by 2020, an estimated 57% of the total loss is in Tropical North Queensland, a region accounting for 18% of the total gross regional product in 2001. Another 13% of the loss is in

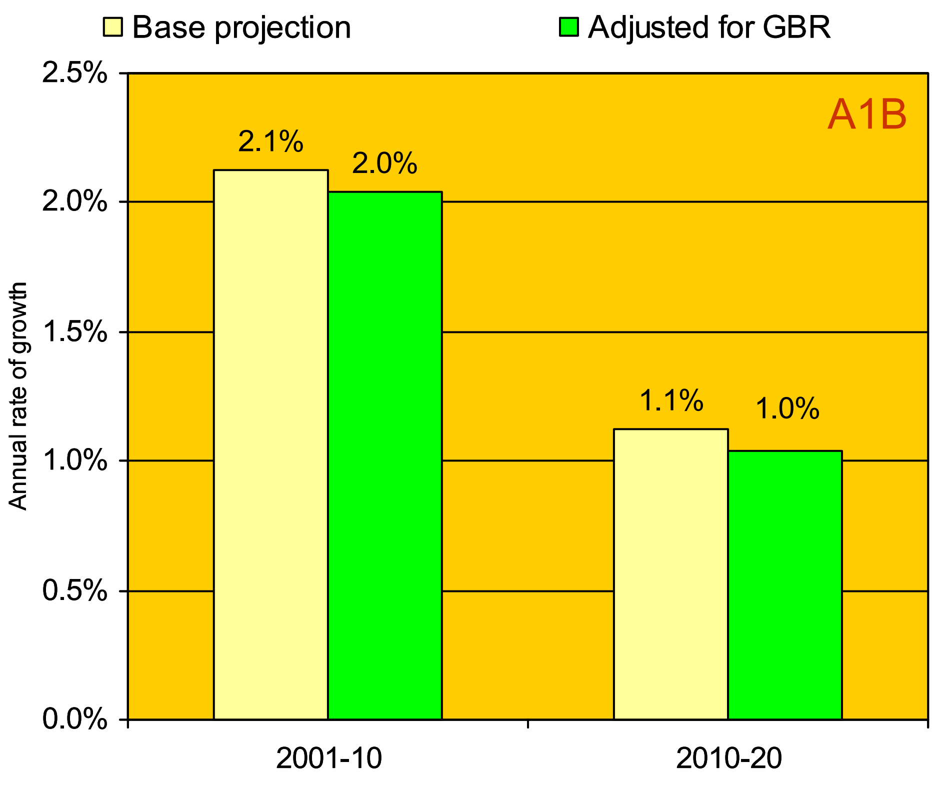


Figure 54: Growth in gross product in regions adjacent to the Great Barrier Reef: Scenario A1B before and after specific impact on Reef.

the Northern region, 14% in the Mackay region including the Whitsundays, 11% in Fitzroy and 5% in Wide Bay-Burnett.

Finally, the industries most affected by reef deterioration are relatively labour-intensive. We estimate that tourism employment will be reduced by 2,300 by 2010 and by 4,700 by 2020, and fisheries employment by about 260 in 2010 and over 1,000 in 2020 (Table D26). The total impact for 2010, including a 1.8 employment multiplier, is 4,600 persons, and for 2020, 10,300.

Numerical projections have not been made beyond 2020. Scenario A1 implies that the gross product of fisheries, and fisheries employment, will continue to deteriorate, but that this will be more than compensated for by employment growth in the aquaculture industry (increasingly favouring southern rather than northern locations). Tourism product and employment would probably continue to grow for many years to come despite the loss of reef and rainforests.

Sustainability, including the impact of relatively uncontrolled development of Cairns and other major urban areas, would become a key issue beyond 2020. But the problem could become even more critical in south-eastern Queensland with the extensions of the 200 kilometre city into NSW and north from Noosa.

Figure 54 summarises Scenario A1 in terms of total economic growth with and without reef deterioration. The impact is about one percentage point on the base projection, which leaves annual economic growth averaging 2% to 2010 and then 1%. The impact would be worse in employment terms, which may mean that the total negative multiplier effect may exceed 1.8. This is difficult to judge.

This concludes the development of scenario A1 from global to local impact. The three other scenarios will follow similar lines, although some of the local detail will be omitted from the description to avoid repetitiveness. However, the standard figures and tables included above for this scenario will be presented in each of the others.

A2: Heterogeneous regionalisation

The world

This scenario represents a differentiated world, in which the underlying theme is self-reliance and preservation of local identity. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change is more fragmented and slower than in other storylines. The A2 world is characterised by lower trade flows, relatively slow capital stock turnover, and slower technological change. It 'consolidates' into a series of economic regions. Self-reliance in terms of resources and less emphasis on economic, social and cultural interactions between regions is characteristic for this future. Economic growth is uneven and the income gap between industrialised and developing parts of the world does not narrow nearly as much as in the A1 and B1 scenario families.

The A2 world has less international cooperation than the A1 or B1 worlds. People, ideas and capital are less mobile so that technology diffuses more slowly than in the other scenarios. International disparities in productivity, and hence income per capita, are largely maintained or increased in absolute terms. With the emphasis on family and community life, fertility rates decline relatively slowly, which makes the A2 population the largest among the four scenario families (continuing growth to 15 billion persons by 2100).

Global average per capita income is low relative to other storylines (especially A1 and B1), reaching about US$7,200 per capita by 2050 and US$16,000 in 2100. Technological change is more rapid than average in some regions and slower in others, as industry adjusts to local resource endowments, culture and education levels. Regions with abundant energy and mineral resources evolve more resource-intensive economies, while those poor in resources place a high priority on minimising import dependence through technological innovation to improve resource efficiency and make use of substitute inputs. The fuel mix in different regions is determined primarily by resource availability. High-income but resource-poor regions shift toward advanced post-fossil technologies (renewable or nuclear energy sources), while low-income resource-rich regions generally rely on older fossil technologies. Final energy intensities decline at 0.5 to 0.7% per year.

Social and political structures diversify; some regions move toward stronger welfare systems and reduced income inequality, while others move toward 'leaner' government and more heterogeneous income distributions. With substantial food requirements, agricultural productivity in the A2 world is one of the main areas for innovation, research and development – and environmental concern. Initial high levels of soil erosion and water pollution are eventually eased through the local development of more sustainable high-yield agriculture. Although attention is given to potential local and regional environmental damage, it is not uniform across regions. Global environmental concerns are relatively weak, although attempts are made to bring regional and local pollution under control and to maintain environmental amenities.

One positive aspect of this scenario is a tendency towards cultural pluralism with mutual acceptance of diversity and fundamental differences. Most nations protect their threatened cultural identities. Some regions achieve relative stability while others suffer under civil disorders. Economic growth slows down as protectionist trade blocks strengthen. As societies adopt western technology without western culture, conflicts between societies rather than globalising economies may determine the geo-political future of the world.

IPCC's broad-brush storyline above, which concludes with the most threatening line in any of the IPCC scenarios, does not explain how the regionalisation will occur in a world that had previously taken a strong direction towards globalisation. A comparison of GDP growth rates 1990-2020 in the expansive scenario A1 and the regionalising scenario A2 shows the main differences to be in Africa, the Middle East, the former Soviet Union and Eastern Europe, and Latin America. It also shows US growth being marginally higher in the A2 scenario (2.5% as against 2.4% pa), while the projection for Pacific OECD countries (Australia, Japan and New Zealand) is two percentage points lower (1.6% pa, compared with 1.8% in A1).

The following would seem to fit that pattern and the subsequent Australian story:

As a sequel to the strong economic expansion in the 1990s, the first decade of the new century was a disappointment for the industrialised world led by America. Failure of economic growth to resume kindled a protectionist, beggar-thy-neighbour mood in the United States. Given that American perceptions changed profoundly in September 2001, the aftershocks of that event combined with the gloomy economic outlook to create an anti-globalisation backlash and a new isolationism, from which those regions most dependent on free trade and a globalising economy suffered most. This applied especially to Latin America, from Mexico south, with its close economic ties to the United States.

On the other side of the Atlantic, the sluggish economic conditions caused the European Union to look inwards, to restrict imports, subsidise the rural sector and discontinue plans to admit new members. Eastern Europe suffered as well as Russia – which was also fighting corruption and coping with the awesome logistics of administering an impoverished and geographically vast economy. Conflicts continued to plague the Middle East, while any emerging African renaissance was severely compromised by widespread hunger and pandemics including AIDS, and political dictatorships.

These developments postponed real expansion in Africa, Latin America, the Middle East, Eastern Europe and the former Soviet Union until the late 2010s; growth is set to accelerate in these regions during the 30 years from 2020 to 2050 (Appendix E). In the meantime, Asia, from India to China and including Southeast Asia, Vietnam and Korea, performed relatively well under the regionalised conditions but growth was significantly lower than in Scenario A1, especially during the first two decades.

Australia

Despite starting the century as America's close friend and ally, Australia was not immune to the new isolationist mood in the United States. Restrictions on our rural exports to America were tightened, not removed. The transfer of technology, which had been an important feature with a strong representation of multinational corporations in Australia, began to dry up as multinationals restructured and repatriated their research and development activities to their home country. Australia, like other countries outside North America and the European Union, was reduced to branch marketing office status, with little opportunity for independent R&D in a corporate context.

Australia was particularly disadvantaged by missing out on major corporate research into the task of feeding a growing developing population while being a major supplier of rural produce. The fruits of past research into and development of genetically modified organisms are there for all to see, but remain firmly in the hands of major multinational corporations. The development of this technology was accompanied from the second decade by breakthrough fermentation technology replacing polymers for the production of low-priced consumer goods and intermediary products, affordable worldwide while the technology was previously limited to the production of high-priced pharmaceuticals (Professor John Villadsen, Technical University of Denmark, pers. comm. 2002). Both technologies found major markets in the third world; and both were developed or at least acquired and then marketed by the multinationals.

The Australian Government and its State counterparts recognised the problem in the latter part of the first decade and acted to budget for substantial increases in the funding of higher education and government research institutions. One reason governments were able to act with relative speed was the new long-term planning orientation which was introduced by the *Intergenerational Budget* report (Commonwealth Treasury 2002). This document grew in size and sophistication from year to year and allowed governments to speed up their response to structural change.

Despite this, the relegation by the multinationals of Australia to the backwaters was a serious problem up to 2020, and affected the nation's competitive position as a 'clever country' relative to the American and European 'in-groups'. To be at least partially cut out of leading technology transfer proved serious in an increasingly technocratic world. Australia's economic growth rate has fallen below that of North America and Europe.

Australia remains a supplier of raw materials to the growing Asian market – coal, minerals, natural gas – and rural produce. There is little political and cultural exchange with a regionalised Asia which excludes Pacific Rim countries that had been part of the disbanded APEC (Asia Pacific Economic Cooperation) organisation. Furthermore, China, India and Southeast Asia look west and east to the European Community and the US for technical cooperation – not south. Japan remains in the doldrums leaving Australia in the position that its former greatest trading partner has ground to a halt.

Successive governments, with faltering economic growth, have found it difficult to allocate substantially growing funding to environmental protection, whether for rural rehabilitation in the Murray-Darling Basin or the Queensland river catchments or for preservation of Australia's heritage areas. Principles like 'polluters pay' were not given top priority until well into the 2010s. In Australia's somewhat exceptional situation as a relatively high-income and resource-rich country, fossil fuels remain the main energy resource. As sources became depleted towards 2020, there was renewed clamouring for drilling new areas - including the Great Barrier Reef Marine Park.

The Great Barrier Reef

Tourist industry pressure on the Great Barrier Reef in the A2 world is modest compared with the A1 scenario. Expectations that world tourism would grow were brought into perspective by 2010 as the US and Europe started to look inward to enjoy tourist experiences in their own continental backyards. Regional conflicts and the rise of world health problems exemplified by SARS (Severe Acute Respiratory Syndrome) and AIDS further emphasise this trend. While incomes in Asia have grown, the net effect is reduced tourism on the Great Barrier Reef. Increased rates of degradation due to climate change, exacerbated by other factors such as coastal degradation and a poorly protected Great Barrier Reef Marine Park, cause the area to lose competitiveness. 'Why go there if the coral reefs are in such poor shape?' tourists ask.

Coastal degradation increases, though world demand for sugar and meat are lower than in scenario A1, especially meat. However, action to mitigate the degradation is also less determined than in the previous scenario, due to lack of political enforcement and lower levels of prosperity. Fruit and vegetable growing on the Atherton Tableland, around Bowen and in the Burnett catchment area is as high as in Scenario A1, providing a unique range of produce for the domestic market (PC 2003:346). Continued agricultural expansion within catchments leads to further deterioration of coastal areas from sediment and nutrient flows. Rapid warming of coastal waters and increased pesticide and herbicide use lead to loss of mangrove, coral and seagrass systems along the coastal regions of Queensland. The 'diebacks' seen in the early part of the century (Duke et al. 2000) are widespread in most catchments by 2030.

Due to pressures to discover new sources of petrochemicals, resistance to drilling for oil on the Reef is waning rapidly together with the hope of leaving any part of the reef reasonably intact much beyond 2030, with key sections of the Reef already down to 30% of its former living coral cover by 2020. Two decades further down the track from 2002, prospects for the Reef look bleak. IPCC's long-term assessment of CO_2 emissions has not changed for the better but is still headed towards levels more than twice the 1990 level by 2050 and a four-fold increase on 1990 by 2100. Sea temperatures are projected to be at least 1.5^{o}C warmer by mid-century.

Shocks to this world include major oil spills on the Reef in 2013 and 2017. Ironically, these incidents happened when exploration companies were having some apparent success in lobbying for drilling licences, and were due to oil tanker traffic entering the Park – a problem never dealt with by previous governments or management agencies. Major damage was reported for almost 500 km of reef coastline and islands. Initial outrage met with a weak public response, distracted by the need to deal with increasing isolation from major international markets. While drilling of the Reef is postponed for almost 15 years, it eventually comes into play as the natural values of the Reef decline further as rising sea temperatures reduce coral survivorship and biodiversity generally.

Early in this scenario, rates of warming lag behind A1 and hence impacts by 2020 are less overall. However, the rising sea temperatures in the Great Barrier Reef Marine Park are exacerbated by increasingly elevated temperatures during El Niño events and the reversal of the Pacific Decadal Oscillation into its warm phase during the late 2010s (the downward swing of the PDO had actually retarded the warming of the Western Pacific during the first decade of the century). In 2020, the risk is mounting that reef degradation postulated by a scientist in the Townsville scenario workshop in 2002 may occur in the foreseeable future (see Appendix F). According to him, there is an accelerating trend not only in the frequency of bleaching events but also in the proportion of the reef area affected.

This develops much as he suggested with the PDO entering its warm phase and a series of events with thermal stress thresholds that were two or three times those of 1998 and 2002 (the last time the PDO was in its warm phase) cause havoc among the remaining reef sectors. Coral cover at the end of these events in 2030 leave most areas of the Reef with less than 50% of the previously abundant coral cover of 1990 (Part 1, Table 10).

Tourism

This scenario has a serious impact on tourism, mainly through a diminished international market and through adverse publicity generated by a strong development philosophy for the Reef (such as drilling for oil). Domestic tourism also suffers, since economic growth is low because of Australia's isolation from North America and Europe.

Table 15: Influences on base tourism projection: A2 scenario

	2001-20	2020-50
Condition of GBR, end of period (scale 0 (worst) to 10)	**5**	**1**
ABARE low world projection (average 2001-10 and 2010-20)	3.1%	
ABARE low Australian projection (average 2001-10 and 2010-20)	3.0%	
Projected world economic growth, this scenario	2.4%	2.4%
Economic growth, United States, this scenario	1.9%	1.9%
Australian economic growth, this scenario	1.7%	1.8%
Asia-Pacific economic growth, this scenario	4.3%	3.6%
Scale from -5 (worst) through 0 (neutral) to +5 (best)		
Reef-based tourism - policy (weak bad, strict good)	-2	
Stakeholder cooperation (weak bad, strong good)	-2	
Australian economic growth factor	-5	
Asian tourism factor	-3	
GBR competition with other reef areas: international tourists	-1	
GBR competition with other reef areas: domestic tourists	0	
GBR competition with other coastal tourism: international tourists	-2	
GBR competition with other coastal tourism: domestic tourists	-4	
GBR competition with other domestic tourist venues	-4	
GBR competition with other international tourist venues	-3	
Tourism industry success in introducing alternative product	0	

Source: ABARE: see PC 2002; IPCC projections in SRES background tables (IPCC 2000)

By 2020, the reef-based tourist industry is in damage control. Attempts to plan around the problem of the disappearing coral, attacked by the triple whammy of rising sea temperatures, coastal pollution and crown-of-thorns starfish (outbreaks of which have increased in scale and

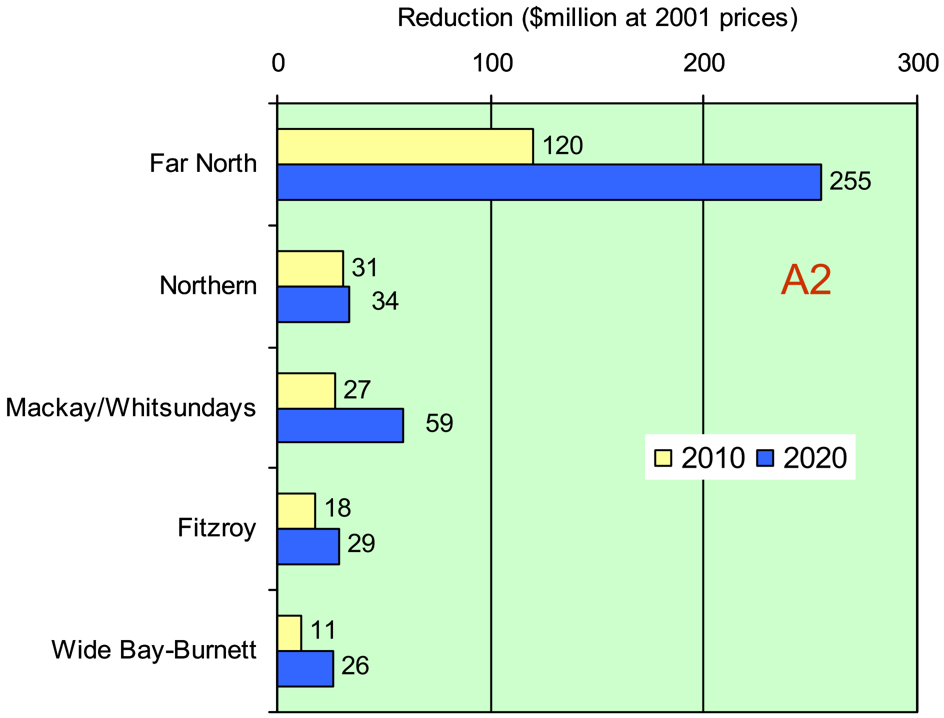


Figure 55: Reduction in tourism GRP in 2010 and 2020 according to the A2 scenario. Total for five regions: $207 million in 2010, $403 million in 2020. Reduction relative to total projected reef-interested tourism GRP (2020): 31%, relative to total projected tourism GRP: 15%. See further Appendix D, Table D23.

Full-time equivalent employment, tourism, A2 scenario

Region	Persons			Annual change	
	2001	2010	2020	2001-10	2010-20
Tropical (Far) North	16,600	13,600	12,700	-2.2%	-0.7%
Northern	5,800	4,900	5,200	-1.9%	0.6%
Mackay	6,100	5,200	5,100	-1.8%	-0.2%
Fitzroy	4,600	3,900	4,000	-1.8%	0.3%
Wide Bay-Burnett	5,900	5,200	5,300	-1.4%	0.2%
Total GBR regions	39,000	32,800	32,300	-1.9%	-0.2%

Derived from Tables D14 and D23.

frequency) have proved disappointing. Overfishing continues to be a major factor influencing the health of the Reef. Predatory fish stocks are very low – shifts similar to the Caribbean in the 1990s are seen across the Great Barrier Reef ecosystem. The real competitive advantage of the Great Barrier Reef originally was its pristine condition. This gave it an edge that has now disappeared when compared with, say, the Caribbean. Coral reefs are hardly mentioned any more as the slogan has turned to attract tourists via one more focused on 'sun, sand and sea' (Dixon et al. 2001). The shorter distance travelled for a holiday also becomes significant, especially in a slower world market, as there is no real competitive advantage remaining from the previously 'pristine' Great Barrier Reef by 2050.

The huge Caribbean market (10 times the Great Barrier Reef in terms of tourist numbers at the turn of the century) now enjoys an increasingly dominant share of the North American and European tourism markets due to its ability to provide a diverse offering of attractions and cultural settings. This is a reversal of trends up to about 2008 in which the more rapidly declining natural values of Caribbean reefs had led to the movement to Queensland of tourists seeking unblemished reefs.

By 2020, most if not all factors are negative for reef-based tourism in this scenario (Table 15). Policies and stakeholder consensus are breaking down, the inbound tourism factor is not strongly positive as in scenario A1, and the industry is losing in the competition with tourism attractions in other locations. The combination of factors causes the tourism industry to lose much of its ability to adapt to change – its resilience.

The estimated reduction in tourism gross regional product under the A2 scenario relative to the case of no reef deterioration is $207 million in 2010 and $403 million in 2020, 60% and 40% worse, respectively, than under A1. Furthermore, the basic tourism industry projections, before applying the Great Barrier Reef factor, are significantly lower under A2, with domestic tourism actually going backwards (Table D23). The brunt of the reduction is once again borne by Tropical North Queensland – an estimated 58% in 2010 rising to 63% in 2020 (Figure 55).

Regional tourism employment projections are shown in the table below Figure 55. The reduction is particularly severe in the first decade (from 39,000 to 32,800 or an annual decline of 1.9%). The decline in the second decade is less severe, from 32,800 to 32,300 persons. As in A1, Tropical North Queensland suffers the greatest reductions in rates of change, reflecting the high proportion of tourists interested in the Reef.

Fisheries and related industries

Benthic fisheries

Up to 2025, impacts within scenario A2 are caused by similar rates of warming to A1. Later, rates of warming associated with this scenario pick up and head on a higher track than the other three scenarios (indicated by the steadily increasing CO_2 emissions trend in Figure 50). As in A1, coral reefs lose 50% of their associated biodiversity by 2030. As in all scenarios, this leads to reduced fish diversity on reef systems – previously popular predatory species are rarer and harder to obtain. This has measurable impacts on reef-associated fisheries by 2010. There is an increasingly heavy leaning in market offerings towards less palatable herbivores, which were not eaten in any significant quantity by Australians in the previous century.

The main variation from A1, however, is that prices will be lower due to sluggish markets – leading to earlier economic anguish for the fishing industry. The total catch falls by 30% between 2000 and 2020, and more losses are expected. The importance of coastal electorates is reflected in a political seesaw between governments that fails to solve the real issues. Both sides of the debate succumb to demands of the main reef-based fisheries interests, who demand and obtain more freedom to fish.

Similar changes occur in the composition of fish communities (as compared to A1) but at a slightly slower rate up to 2050. The slower rate of change leads to a delay of about 10 years in the advent of the effects seen under the growth-driven A1 scenario.

There is a steady rise in the incidence of ciguatera towards 2020. Marketing resources are needed to ensure people aren't scared off eating reef fish. Special detection kits allow the market to identify ciguatera in reef fish, and the problem is reduced some time later. Some species are unaffected. Others are phased out of the market.

Fisheries management of the reef area has been dogged by decreasing water quality and severe loss of stock. There has been increasing conflict between government and fisheries interests with the latter trying to maximise the catch in a deteriorating environment. The Representative Areas Program in 2003 designated 30% of the total Marine Park as no-take areas – this amount is under constant attack from industry groups who struggle with dwindling populations of more and more traditional reef fish stocks.

Movement of benthic fishes occurs at a slower rate than in A1. Waters of the southern end of the Great Barrier Reef reach Cape York temperatures only by 2065. This still causes some issues to develop over the southward movement of warm water exotics from Papua New Guinea and Southeast Asia.

Pelagic fisheries

The challenges faced by pelagic fishes are similar to those faced under all scenarios except that the rate of change is slower by approximately 20 years. Changes in sea temperature lead to reduced productivity and changes in circulation. The lacklustre world economy translates into lower demand for seafood – this leads to reduced international pressure on Australia's fisheries. Less international disputes eventuate.

There is some risk of warm anoxic upwelling events, but it is lower than in the A1 scenario for the first half of the century because of the slower pace of climate change.

Trawling

Trawling continues in the Great Barrier Reef Marine Park and adopts technologies to minimise impacts, as in A1. The industry still faces somewhat unjust negative publicity for the decline in quality of reef systems – rising quantities of macroalgae and unsightly blue-green algae are blamed on fishing pressure though they are mainly the result of rising temperatures. While the link between reef degradation and over-exploitation is indisputable scientifically, climate change is also a major driver of the changes that are occurring.

The debate over whether trawling should continue within the Marine Park continues until 2010. Slower growth for Australia's export earnings drives the argument for sustaining the practice, which grows slightly as greater areas of the Reef are opened up during the 2020s.

Aquaculture

The aquaculture industry is relatively unfettered by funds or regulation after the abandonment of the Great Barrier Reef Aquaculture Regulations, but grows slightly more slowly than in A1, as the demand for quality seafood is constrained by the sluggish Australian economy and lower economic growth overseas. Projected growth is still in the order of 8.5% per annum between 2001 and 2020 (Table D13).

The industry adopts genetically modified organisms and high technology. Disease within aquaculture operations becomes more frequent and problematic as sea temperatures increase. The problem does not reach chronic levels until 2050. The same approach is adopted as under A1 in which active molecular manipulation of stock is used to keep pace with the progressive pace of climate change.

Warm-water aquaculture moves slowly to more southern locations. By 2050, species grown near Cape York in 1990 can be cultivated at locations 800 km further south. By this time, northern Australian aquaculture has adopted species found previously in Indonesia. By 2080, large areas of coastal far northern Australia are unsuitable for aquaculture due to temperatures rising to 33^{o}C and above (Figure 5, Done et al. 2003).

Invasion of warm aquaculture species from aquaculture ponds into local watersheds starts to become problematic from 2020 onwards.

Summary of commercial fisheries prospects

In summary, the commercial fishing industry along the Great Barrier Reef is similarly affected physically as in scenario A1. The decline in incomes and employment, however, is a matter of greater concern for several reasons:

- World markets develop more slowly than in the A1 scenario because economic growth is lower, including the neighbouring Asian markets. The domestic market also grows more slowly and Australia is squeezed out of the lucrative American and European markets.

- Fisheries management is troubled by decreasing water quality and severe loss of stock. The total wild stock catch fell by 30% between 2000 and 2020, and more losses are expected to follow. Aquaculture as in A1 is providing a stopgap at least up to 2020, but problems are expected to occur in subsequent years due to further warming and disease.

- The less buoyant local tourism industry along the Great Barrier Reef is unable to absorb unemployed fishers who want to stay in the area, which has often been their home environment for their whole life. This leads to increased bankruptcy, unemployment and divorce rates and general social upheaval in the coastal regions along the Reef. Many other fishers leave the area for opportunities elsewhere.

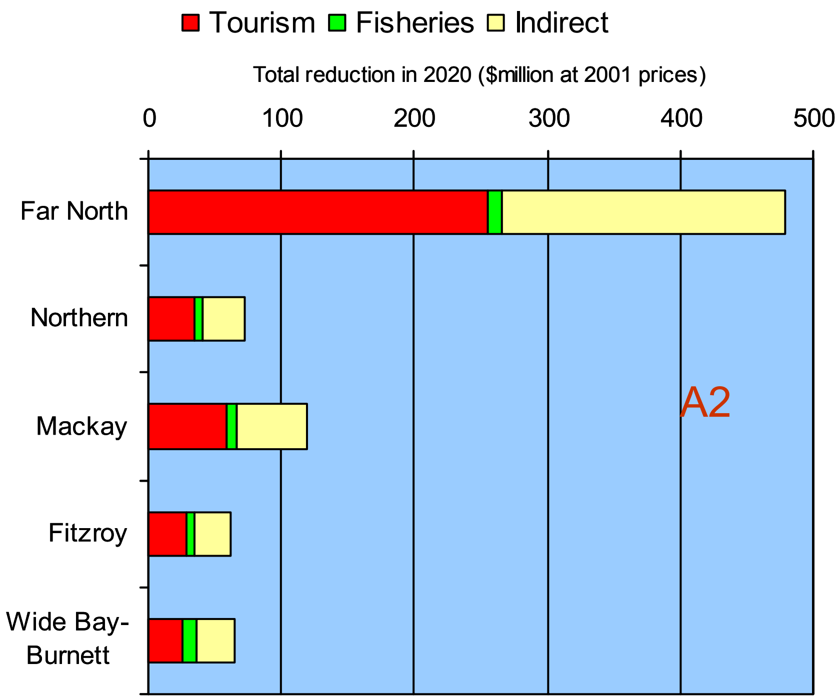


Figure 56: In the worst-case scenario A2, the total estimated reduction in gross regional product in 2020 increases to $798 million, with 60% of the decline in Far North Queensland. The reduction is equivalent to 9.5% of the total GRP for 2020.

Recreational fishing

As discussed in A1 above, recreational fishing remains a socially important activity in coastal Australia despite falling fish stocks and environmental quality, mainly because recreational fishers enjoy the outdoor component of the activity in addition to fishing. Nevertheless, participation rates have fallen by 2020, especially among younger people. Many recreational fishers have also looked for alternative locations, including freshwater fishing, in preference to the increasing reliance on inshore fishing as the transformation of the Reef from coral to macroalgae progresses and increasingly prevents line fishing there.

Expenditure by recreational fishers again is not expected to decline as much as their catch, even though fewer new people take up the hobby as sizes and catches decline.

Local economies before Reef damage

This is the worst-case scenario. It is relatively uncaring in relation to the environment and not very successful economically. Because of its strong reliance on export markets in a relatively depressed world economy, in which Australia is further disadvantaged by its exclusion from the major North American and European blocs and by slow-moving Asian export markets, the regions adjacent to the Great Barrier Reef are expected to show economic decline in the first decade followed by virtual stagnation in the second. While the rest of Australia is expected to show modest economic growth, these regions will become relatively depressed up to 2020 according to scenario A2, even *before* taking the impact of a degrading Reef into account.

The combined gross value of production for the five regions for the eight 'driving industries' is projected to decline from $18.3 billion in 2001 to $16.8 billion in 2010 to $16.5 billion by 2020 (Table D12). This is mainly based on ABARE's low projections adjusted to show twice the difference from the mean projections, in recognition of the fact that world economic growth is significantly below the low ABARE projection (as shown in Table 15).

The industries causing the shrinkage are those producing the traditional mineral and rural products in the regions: coal, nickel, copper, zinc, beef and sugar. Even the 'low-low' projection sees rising international tourism before the reef factor is taken into account, with inbound tourism growing by about 2.5% pa through the first two decades; however, the projection for domestic tourism by is negative: minus 1.0% pa to 2010 and then -0.5% pa (Table D13). The one strong growth industry is aquaculture as related above.

Total employment in the eight industries defined as driving regional economic growth is projected to decline from 88,900 in 2001 to 79,900 in 2010 and 77,100 in 2020, before considering the impact of a degrading Reef (Table D14).

Impact on coastal regions

The weak domestic economic growth and lower rate of Asian tourism were factored into the main projections in Table D12. This leaves the assumptions shown in Table 15 concerning tourism policies relative to the Great Barrier Reef, stakeholder cooperation and the industry's ability to supply alternative tourism product. All three factors are expected to be weaker than in the A1 scenario, exacerbated by the background of lower general economic growth both locally and nationally. Furthermore, the Far North and the Whitsundays in particular are expected to lose out in the competition with other destinations. These factors are all related and are estimated to cut a full 2% annual growth off the projections.

The methodology for estimating tourism is the same as for scenario A1. The results are summarised in Table D23. In the absence of any damage to the Reef, the gross regional product (GRP) associated with reef-interested domestic tourism is expected to decline by about 0.8% pa over the first two decades of the century, while the corresponding measure for inbound tourism could rise by over 3% pa on average (faster in the first decade).

Gross regional product associated with 'reef-interested' (and 'converted reef-interested') domestic tourism is estimated to decline significantly after taking climate change into account, and this is not matched by growth in the corresponding measure for inbound tourism. The total 'reef-interested' GRP (including those who would have been 'reef-interested' in the past and have been persuaded to visit) is expected to decline very slightly from $1.06 billion in 2001 to $1.03 billion in both 2010 and 2020 (Table D23). The total estimated impact on the tourism GRP is $207 million in 2010 and $403 million in 2020.

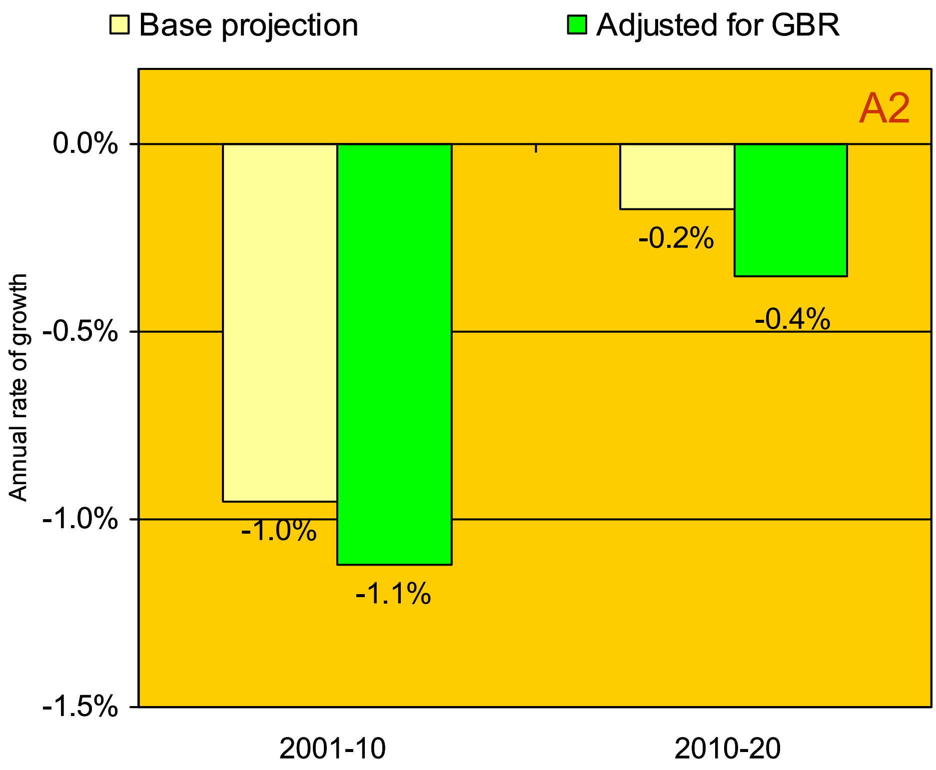


Figure 57: Economic growth turns negative in the Great Barrier Reef regions before applying specific Great Barrier Reef assumptions under Scenario A2.

The projections for commercial fisheries show little decline over the first decade but the gross product then plummets from $114 million in 2010 to $80 million in 2020 (Table D26).

Table D28 shows the regional impact under scenario A2. The total estimated loss associated with the Reef, including regional multiplier effects, is $384 million in 2010 and $798 million in 2020. The total loss over the 19 years to 2020 is $8 billion, or if discounted at 5% pa, $4.25 billion. This is the highest loss of any of the four scenarios, far ahead of the total $5.6 billion loss under A1.

In employment terms, including a multiplier effect of 1.8, this scenario implies that there will be about fewer 6,200 tourism jobs in 2010 and 6,700 fewer tourism jobs in 2020. Fisheries employment is projected to be 200 worse off in 2010 and 1,150 worse off in 2020 than before taking climate change and reef degradation into account. Including multiplier effects, this implies job losses of 11,500 in 2010 and 14,100 in 2020. Coupled with already high national unemployment rates in a sluggish economy, and with these regions being particularly hard hit, this will add to a situation of social hardship. The total employed workforce without the reef factor would have fallen by 50,000 or more from the 408,000 persons recorded in the 2001 Census, and 14,000 extra persons represent close to another 30%.

The Far North again suffers most from the reduction in economic activity, and accounts for 57% of the loss due to reef deterioration in 2010 and 60% in 2020 (Figure 56). Total prospects are summarised in Figure 57, which shows that the impact of the A2 scenario on gross regional product change is to cut a growing number of percentage points off the rate of change. This deterioration would continue beyond 2020.

B1: Global Policy Reform

The world

The global population peaks in mid-century at about 8.7 billion people as in the A1 family, but with rapid change in economic structures towards a service and information economy, 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. Economic considerations take no precedence over the other parts of the triple bottom line – on the contrary, the trend is towards reinforcement of the ecological component.

This is a world with high levels of economic activity (a global GDP of around US$330 trillion by 2100) and deliberate progress towards international and national income equality. Average global income per capita is US$13,000 in 2050, one-third lower than in A1. A higher proportion of this income is spent on services rather than on material goods, and on quality rather than quantity, because there is less emphasis on material goods and resource prices are increased by environmental taxation.

The central elements of the B1 future are a high level of environmental and social consciousness combined with a globally coherent approach to a more sustainable development. Heightened environmental consciousness is brought about by clear evidence that impacts of natural resource use, such as deforestation, soil depletion, overfishing and global and regional pollution, pose a serious threat to the continuation of human life on Earth. Governments, businesses, the media and the public pay increased attention to the environmental and social aspects of development. Technological change plays an important role.

Economic development in B1 is balanced, and efforts to achieve equitable income distribution are effective. As in A1, the B1 storyline describes a fast-changing and convergent world, but the priorities differ. Whereas the A1 world invests its gains from increased productivity and know-how primarily in further economic growth, the B1 world invests a large part of its gains in improved efficiency of resource use ('dematerialisation', and generally minimising the amount of embodied energy), equity, social institutions and environmental protection.

Politically, the world has been ‘greening’ at least since the late 1990s. Some commentators predicted as early as 2002 that a European country might have a Green majority government in the foreseeable future. That distinction went to Belgium in 2014, and other members of the expanded European Community followed (Slovenia, Finland, Poland and Germany). Parties with strong environmental agendas form the largest faction in the European Parliament of 2020. Political party platforms in the majority of countries where long-established parties retain power incorporate strong environmental policies to ensure sustainable development.

The years 2005-10 were a period of great change in ideas and perceptions, which most analysts linked to a popular realisation that the climate was changing and we were responsible. The genesis of this development was the growth in the environmental movement over the previous half-century. Scientific evidence of global warming had been mounting at least since 1980. But it is during this period that the threshold is reached in most people's perceptions, from which the dramatic development ensues during the second decade, enabling a strengthened carbon tax system and stringent pollution control to be implemented.

Large-scale assistance to developing countries to foster environmentally sound developments began in the late 20th Century. It continues to be channelled through the World Bank and the United Nations Environment Program and is increasingly backed by individual government initiatives led by the United States. One key objective is to enable rapidly growing economies to leapfrog a heavily energy-intensive phase using outdated equipment powered by petrochemicals; however, global use of coal, oil and gas is still on the increase in 2020 (Appendix E).

With the emphasis on development of low CO_2 emission forms of energy and taxation systems favouring environmentally friendly products and services, the world is retaining its resources and heritage values to a greater extent than in the A1 scenario family. This has occurred with some sacrifice in conventional GDP terms, but with a more enlightened lifestyle that copes. Industrial design, for instance, is increasingly directed towards cutting waste (including packaging) and intensifying recycling. The concept of 'natural capitalism' and that vast reductions can be made in the use of energy and materials – indeed that you can make money by being green – has become a major influence (Hawken, Lovins and Lovins 1999; von Weizsäcker, Lovins and Lovins 1997).

This development is reinforced by the realisation that crude oil supplies are running out faster than expected and the search must be intensified for alternative fuels and associated technologies designed to use them. The B1 storyline sees a relatively smooth transition to alternative energy systems as conventional oil and gas resources decline. There is extensive use of conventional and unconventional gas as the cleanest fossil resource during the transition, but the major push is towards post-fossil technologies, driven in large part by environmental concerns.

Massive programs are in place as early as 2002 for alternative energy including biomass, geothermal energy, hydrogen and fuel cells, solar energy, wind energy and hydropower (US Department of Energy 2002). Oil majors led by Shell have been developing alternative energy scenarios for decades (NRC Handelsblad 1995, Laherrère 2001), and have been carrying out major research and development work accordingly. BP has also been a driver in this development in areas like hydrogen fuel cells (Knott 2002a) and the conversion of methane gas to clean liquid fuels and chemicals (Knott 2002b).

Shell's two published scenarios to 2020 (Shell 2002) illustrated the corporation's thinking at the turn of the century:

- 'The world of *Business Class* is not run *by* business; but it is run *like* a business with a focus on efficiency and individual freedom of choice' (p 29). The attractiveness of oil is declining, the 'great game of gas' is on, and 'by 2020 ultimately recoverable gas reserves are much larger than estimated at the turn of the century.' (p 44) 'Shortly after 2020, gas overtakes oil as the dominant primary energy source as fuel cells diffuse widely in stationary and transport applications'. (p. 50)

- A 'new regionalism' is the main feature of *Prism.* National politics address local aspirations and culture to build a domestic consensus on how to engage with globalisation. In each country a rich and wide political discourse wells up from the heartland about what to protect, what to accept, and where to open up. And in addressing its culture and history, each country has to define its own community, the essence of what it means to belong (p 66). When oil prices rise to unprecedented levels in 2006 (and even though they fall again by 2010), most governments respond by establishing national energy policies designed to provide secure, stable and clean energy (p 78). Strongly supported by governments, and led by wind power, renewables achieve commercial viability in some markets by 2010 and grow rapidly through to 2020 (p 81).

Admittedly these excerpts were from a 'public summary', but it was very interesting that Shell, the corporate pioneer of scenario planning, took 'the art of strategic conservation' (van der Heijden 1996) into the public arena in this manner. Even more strikingly, neither scenario saw a great long-term future for oil, and the public was told so.

Nuclear energy was back on the drawing board from the first decade of the 21st Century as the public accepted that 'safe' nuclear technologies had virtually eliminated the risk of another Harrisburg or Chernobyl incident. Australian nuclear consultant Dr Neil McDonald predicted in 2002 that nuclear energy would play a more significant role than past projections suggested. He said that the high quality of initial construction and of plant maintenance, together with a proven safety record, enabled longer licensing extensions to be granted, initially from 40 to 60 years for the 25 US plants existing at the time. These extensions were vital for nuclear power to remain competitive (Dr Robert Smith, former Deputy Director of ANSTO, the Australian Nuclear Science and Technology Organisation, pers. comm.).

Nevertheless, the nuclear industry needed to demonstrate competitiveness with alternatives and overcome negative public perceptions on safety, waste management and security. Social concerns continued over the potential release of radioactivity in routine or accidental conditions, radioactive waste management and disposal, and proliferation of weapons of mass destruction. The OECD's Nuclear Energy Agency associated these perceptions with *catastrophic potential* in a comprehensive report on how to achieve better societal understanding of nuclear power (NEA 2002a:57):

> *People are more concerned about fatalities and injuries that are grouped in time and space, such as aeroplane crashes, than about fatalities and injuries that are scattered or random in time and space, such as automobile accidents. This is a matter of importance for nuclear energy, since nuclear accidents may involve, as has been demonstrated by Chernobyl, a significant number of casualties at once. Also, the shadow of nuclear weapon impacts remains in public minds when hazards from civil nuclear energy applications are referred to, irrespective of the absence of link between the two types of risks.*

Governments in all industrialised countries had action plans in place from about 2010 to expedite the transition to greater reliance on renewable energy, spurred on by the twin motives of replacing declining oil reserves and the need to mitigate the greenhouse effect. Innovative technologies initially concentrating on fuel efficiency but increasingly on renewable energy proliferated with Europe in the forefront. The increasing R&D activity and the increasing need for implementation has transformed renewable energy technologies across the board into a large and powerful growth sector, with businesses cashing in on the opportunities worldwide.

A strong welfare net has developed to prevent social exclusion on the basis of poverty. However, counter-currents did develop and not all people conformed to the social and environmental intentions of the mainstream in this scenario family. Massive income redistribution and high taxation levels adversely affected the economic efficiency and functioning of world markets – an inevitable trade-off if environmental and social considerations are to be given their due weight in this scenario.

Particular effort is devoted to increases in resource efficiency to achieve the goals stated above. Incentive systems, combined with advances in international institutions, permit the rapid diffusion of cleaner technology. To this end, R&D is also enhanced, together with education and the capacity building for clean and equitable development. Organisational measures are adopted to reduce material wastage by maximising reuse and recycling. The combination of technical and organisational change yields high levels of material and energy saving, as well as reductions in pollution. Labour productivity improves as a by-product of these efforts.

Given the high environmental consciousness and institutional effectiveness in the B1 storyline, environmental quality is high, as most potentially negative environmental aspects of rapid development are anticipated and effectively dealt with locally, nationally and internationally. For example, trans-boundary air pollution (acid rain) is basically eliminated in the long term. Land use is managed more carefully to counteract the impacts of activities potentially damaging to the environment. Cities by 2020 are becoming more compact and designed for public and non-motor transport, with suburban developments tightly controlled. Strong incentives for low-input, low-impact agriculture, along with maintenance of large areas of wilderness, contribute to high food prices with much lower levels of meat consumption than those in A1.

These proactive local and regional environmental measures and policies also lead to relatively low greenhouse gas emissions, even in the absence of explicit interventions to mitigate climate change. Such interventions were excluded because the terms of reference for the IPCC scenario work (IPCC 2000) stipulated that no scenario would explicitly assume implementation of the United Nations Framework Convention for Climate Change (UNFCCC) or the emissions targets of the Kyoto Protocol.

Australia

The shift from the global market-based growth philosophy that existed beyond the turn of the century, to the ecologically more sustainable regime which is in place in 2020, did not come cheap. Taxation levels have risen in Australia to fund necessary increases in education, R&D, environmental management and land care, structural unemployment, a stronger welfare safety net, and increased overseas aid to assist the transition worldwide. A full six years elapsed after 2011, when the political climate first enabled the new environmental focus to become top priority, for the new legislation to be put in place. This was a massive structural change where compensation measures had to be negotiated with industries disadvantaged in the process.

Backed by a series of specific government regulations, there is a strong upward trend in awareness among manufacturers of the need to produce environmentally friendly products and reduce waste including packaging, and to interact with consumer interests.

One significant guiding philosophy adopted by Australian producers and consumers during the two decades to 2020 was the principle of embodied energy. It has become an important selling point for producers and consumer groups query those who don't promote it. The Australian Greenhouse Office (AGO 2002a) defined the principle in the context of construction as follows: 'Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the acquisition of natural resources to product delivery. This includes the mining and manufacturing of materials and equipment, the transport of the materials and the administrative functions.' However, embodied energy can be applied to any product or service. As discussed in previous sections, CSIRO pioneered the measurement of embodied energy in Australia (Foran and Poldy 2002), which is closely related to the 'Factor Four' initiative (von Weizsäcker et al. 1997).

The principle also guides the development of new construction standards aimed at the self-contained building, which manages its own waste and water treatment and minimises energy use through its lifecycle. This is important in tropical Queensland with its specific pollution problems along the Great Barrier Reef lagoon and by 2020 has been successfully introduced through changes in State and local government regulations and subsidies.

Although conventional GDP remains important because market-driven economic theory remains influential, economic modelling and national accounting practices are no longer accepted unless supplementary analysis specifies the environmental cost of using non-renewable resources and defines any diminished heritage and other non-use values.

In Australia, a carbon tax was introduced in 2006 with the primary purpose of limiting use of petrochemicals by consumers rather than producers. The tax rate differentiates between products according to their CO_2 emissions. Farmers, tourism operators, commercial fishers and others whose business depends on the internal combustion engine were initially exempted for the time being but were later given incentives to adopt new technologies as they became viable. Heavy investment in metropolitan public transport systems by 2020 is finally having an impact on the use of cars to get to work.

Looking ahead from 2020, most of the hurdles for a long-term environmentally driven policy have been overcome. As a successful member of the community of nations, Australia is expecting to take an active role in securing that the hard-won transition from a global economically driven outlook, to a philosophy where the environment and social considerations have assumed their proper place on the triple bottom line, will have the robustness to persist over the long haul.

The Great Barrier Reef

The recognition of the value of sustainable tourism, as opposed to extractive industries such as commercial fishing, leads to a healthy tourist economy along the Queensland coast. This realisation leads in turn to higher value being placed on sustaining natural values and reef resilience. Recognition of the important role of secondary factors such as water quality and fishing pressure on the ability of the Reef to recover and sustain changes like climate change lead to an expanded number of no-take areas. As stated elsewhere, climate change by 2025 is similar under all scenarios due to the long-residence time of greenhouse gases like carbon dioxide. Reefs under the B1 (and B2 below) scenarios have higher coral cover and species diversity due to the relatively reduced pressures being placed on reefs by secondary factors like water quality, pollution and fishing. Careful scientific modelling, and experiments like those of Professor Terry Hughes of James Cook University, reveals that reefs will also return sooner (within 50-100 years as the climate stabilises). This provides additional arguments for greater levels of protection of the Great Barrier Reef.

Despite greater levels of care with coral reefs along the Australian coastline, reefs associated with the Great Barrier Reef lose 20% of their biodiversity by 2030 and coral cover is down to 50% of 1990 levels by 2035 (Part 1, Table 10). Reef management of secondary factors such as sedimentation and nutrient flows reduce impacts and improve recovery. While reefs are degraded they do retain populations of fish that are reminiscent of the composition and abundance present on reefs in the 1990s. Coral cover (due to its lower abundance) is geographically more dispersed, which is starting to create problems for strongly coral-associated organisms. There are more herbivorous fish, less predators and coral-associated fishes. Stronger protective measures for habitats have started to pay off. The Great Barrier Reef continues to have some of the most coral dominated and beautiful reefs in the world.

The recognition of the role of the Great Barrier Reef to sustainable economic growth of industries like tourism leads to strong moves to protect more of the Reef under 'no-take' zones. Increasing evidence from overseas examples (as well as solidly supported models) and the signs of major deterioration led to the expansion of the area protected in no-take zones in 2003 (30% was achieved at that date). In 2020, almost 50% of the Great Barrier Reef Marine Park was included in no-take zones during a redefinition of the Representative Areas Program in 2010 (Protected Areas Program). Though its main function remained the protection of each biological region in the Marine Park there was a growing awareness of the need to further protect reef resilience as the massive scale of climate change driven impacts were truly understood.

Commercial and recreational fishing are effectively managed through strict localised regulations of catches and bans on activities such as trawling. Water quality has improved as coastal runoff was brought under better control. The 5 km 'no-development' zone along the Queensland coast provides a measurable reduction in sediment and nutrient flows. Despite the increasingly frequent coral bleaching events, catches of reef fish have fallen by less than 20% due to the balancing influence of better protected fish stocks. The closure of half the Marine Park to commercial fishing has prevented an otherwise catastrophic decline in fish stocks and created 'spill-over' effects on fish stocks in fished areas similar to that reported by studies in the early part of the century (e.g. Russ and Alcala 1998a,b). The Protected Areas Program has helped prevent a significant part of the loss of species and biodiversity that would have occurred without closures. Fisheries interests have cooperated in the ongoing Program to achieve a high level of protection and have exerted some influence on the selection of no-take areas.

Shipping within the Great Barrier Reef is tightly controlled, with any transport of oil or other dangerous cargo being restricted to vessels with appropriate precautionary measures (e.g. double hulls, modified routes, strict registrations and protocols). This has massively reduced the spectre of catastrophic oil spills in the Great Barrier Reef Marine Park. The campaign to 'drill the Reef' is dead as the value to Australia of sustainable activities like ecotourism is weighed up against the costs and benefits of having an oil industry. The growth of alternative fuels such as hydrogen and biofuels is reducing the pressure for new oil-based energy sources.

The loss of inshore reefs has been halted and even reversed in some regions as tight restrictions on coastal development and agricultural runoff come into effect. Communities like Douglas Shire that used to lead the nation and indeed the world in sustainable practices are now commonplace along the coast of Queensland. The implementation of source-to-sink monitoring (started in Douglas Shire in 2004) plays a huge role in drawing in the participation of stakeholders to solve the problems facing coastal environments early in the millennium. As resource-extractive industries have come under pressure from anthropogenic stress, low impact industries like ecotourism have grown in stature and size.

There was a growing understanding from early in the century that big environmental problems require big and comprehensive solutions, and that 'band-aid' solutions may be worse than no solution. Degradation of ecosystems, notably the Great Barrier Reef, is tackled systematically with the cooperation of all stakeholders and all levels of government. This leads to rational responses to increasing climate stresses on the Reef – with the direct benefit that the public actively participates in appreciating how climate change can have such seemingly remote yet devastating effects on Australian rainforest and coral reef ecosystems. An appreciation follows of the need to make changes to help ecosystems survive current stresses and to change greenhouse gas emission levels and technologies to allow these ecosystems to recover their former glory in 50-100 years' time.

Tourism

The reef-based tourism industry has been able to adapt to the changes forced upon it by the continued degradation caused by global warming and the resulting coral bleaching. Several offshore reefs in 2020 remain attractive to visitors, which enhances the ability of operators based along the Great Barrier Reef to compete with competitors operating in foreign coral reef areas that are not so well managed and more damaged. Strict restrictions on visits to particular areas are accepted by the industry in the long-term interest of minimising damage and eventually restoring the reef as far as possible to its previous condition. In the total picture, dive and snorkel tourism and pontoon operations are most threatened by coral bleaching, and even these manage to survive by concentrating on reefs still reasonably intact and not declared out of bounds by regulation. While this is only a temporary respite, it has given the industry time to adapt its strategies in a difficult situation.

The fact that the Great Barrier Reef by the 2020s still has the largest coral population in the world is obviously not lost on the Australian tourist industry, backed by Federal and State tourism organisations. Its global advertising campaigns invite the international traveller to witness the 'best coral reefs in the world'; some promotion even uses tongue-in-cheek slogans such as 'the only place to see an endangered ecosystem'. The Great Barrier Reef has become more competitive with other reef areas, as indicated by Table 16. The tourism industry has also demonstrated a high degree of resilience and imagination in introducing an alternative product.

Retaining a powerful local presence as a generator of income, the tourism industry is able to exert significant pressure on coastal management practices. It has led the move to persuade the State government to impose progressively stricter environmental standards for discharge of pesticide and fertilisers from cropping areas. The 5 km 'no-development' zone along the Queensland coast is enshrined in law and is accepted as wise management by the majority of Queenslanders and other Australians. The tourism industry is also very much part of the local push to deal with issues such as better waste management generally, the specific introduction of energy-efficient building standards stipulating maximum treatment of waste on site, and the prohibition of construction close to the coast.

Table 16: Influences on base tourism projection: B1 scenario

	2001-20	2020-50
Condition of GBR, end of period (scale 0 (worst) to 10)	**5**	**3**
ABARE low world projection (average 2001-10 and 2010-20)	3.1%	
ABARE low Australian projection (average 2001-10 and 2010-20)	3.0%	
Projected world economic growth, this scenario	3.4%	3.2%
Economic growth, United States, this scenario	2.5%	1.6%
Australian economic growth, this scenario	2.5%	1.6%
Asia-Pacific economic growth, this scenario	6.0%	5.1%
Scale from -5 (worst) through 0 (neutral) to +5 (best)		
Reef-based tourism - policy (weak bad, strict good)	4	
Stakeholder cooperation (weak bad, strong good)	4	
Australian economic growth factor	-1	
Asian tourism factor	2	
GBR competition with other reef areas: international tourists	3	
GBR competition with other reef areas: domestic tourists	3	
GBR competition with other coastal tourism: international tourists	0	
GBR competition with other coastal tourism: domestic tourists	0	
GBR competition with other domestic tourist attractions	0	
GBR competition with other international tourist attractions	0	
Tourism industry success in introducing alternative product	4	

Source: ABARE: see PC 2002; IPCC projections in SRES background tables (IPCC 2000)

The local tourism industry has proven its competitiveness with its counterparts in other countries. Benefiting from strong growth spearheaded by an increasingly affluent Asian tourist market, it has managed to de-emphasise the reef experience in an environment largely declared off-limits by the Marine Park Authority (though some areas remain accessible into the 2020s). It has switched from promotion of being on the Reef itself to visiting the Great Barrier Reef theme parks outside Cairns and in the Whitsunday Shire, where 'real' coral reefs can be seen, and digital technology creates virtual experiences. Dive tourists are still attracted to reefs that remain reasonably intact and open to visitors. Fish populations, due to the much tighter control on commercial fishing, are healthier when compared to the 'A' family of scenarios. As noted above, there is even some promotion – likely to assume further prominence after 2020 as coral bleaching events intensify – that there is still time to see rare and endangered species in the wild in Australia, like the remaining intact coral.

The impact in terms of loss of productive value and gross regional product is much reduced compared with the A1 scenario, not to mention the worst-case A2 world. By 2020 the estimated loss compared with a world of no reef degradation is 4% of the total tourism GRP,

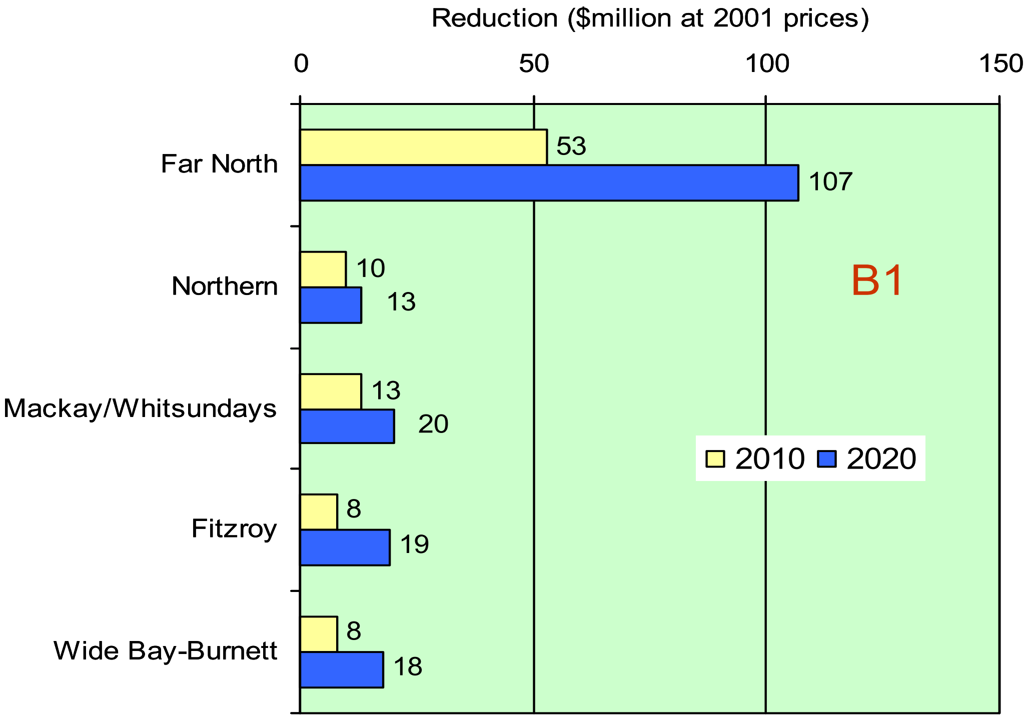


Figure 58: Reduction in tourism GRP in 2010 and 2020 according to the B1 scenario. Total for five regions: $92 million in 2010, $177 million in 2020. Reduction relative to total projected reef-interested tourism GRP (2020): 12%, relative to total projected tourism GRP: 6%. See further Appendix D, Table D29.

Full-time equivalent employment, tourism, B1 scenario

Region	Persons			Annual change	
	2001	2010	2020	2001-10	2010-20
Tropical (Far) North	16,600	15,400	17,300	-0.8%	1.2%
Northern	5,800	5,500	6,400	-0.6%	1.5%
Mackay	6,100	5,700	6,500	-0.8%	1.3%
Fitzroy	4,600	4,400	4,900	-0.5%	1.1%
Wide Bay-Burnett	5,900	5,600	6,300	-0.6%	1.2%
Total GBR regions	39,000	36,600	41,400	-0.7%	1.2%

Derived from Tables D17 and D24.

and 8% of what was defined as 'reef-interested' tourism in Chapter 8. Tropical North Queensland, however, continues to bear the brunt of the impact, though as described above the industry has succeeded in attracting people for whom the Reef would have been a major drawcard in earlier years, by promoting remaining reef experiences to a few and the availability of alternative reef-related experiences to the mass tourism market. Figure 58 shows that the Far North by 2020 would be losing $107 million in gross regional product terms, or 60% of the total loss for the regions along the Great Barrier Reef.

Tourism employment declined in the first decade but recovered in the second, providing jobs for more persons in 2020 than was the case in 2001. The rate of decline to 2010 was marginally higher in the Tropical North and in Mackay region, including the Whitsundays. Recovery rates between 2010 and 2020 were reasonably similar in all regions, given the rounding of the underlying figures.

Fisheries and related industries

In 2020, with 50% of the Great Barrier Reef Marine Park forming part of the Protected Areas Program, commercial and recreational fishing is being effectively managed through strict localised regulations of catches and bans on activities such as trawling. Water quality has improved as coastal runoff was brought under better control. Despite the increasingly frequent coral bleaching events, benthic and pelagic fish catches have fallen fairly modestly since 2000 (see assumptions in Table D26 suggesting about 12%). The Protected Areas Program (which introduced further no-take green zones into the GBRMP – now at 50% of the Park area) has helped prevent a significant part of the loss of species and biodiversity that would have occurred without controls. This program has also improved the resilience of reefs after coral bleaching. Fisheries interests have cooperated in the ongoing Program and have influenced the selection of no-take areas. The benefits of these policies – increased increased fishing success outside the no-take areas via 'spill-over' effects – are now widely appreciated by the commercial and recreational fishing industries.

Social hardship from the loss of catch has been minimal, as fishers have been absorbed into a growing tourism industry or have become involved in a growing but environmentally well-regulated coastal aquaculture industry.

Benthic fisheries

- As stated in the general description of the state of the Great Barrier Reef, coral reefs lose 20% of the associated biodiversity by 2030 and coral cover is down to about half of what it was in the 1990s by 2035.

- Changes occurring in the fish communities inhabiting the Great Barrier Reef include increased numbers of herbivores and declining numbers of fish associated with the coral. However, the larger no-take zones and better coastal management practices have led to healthier and more sustainable reef fish populations. Loss of coral cover does eventually lead to the loss of some species (coral obligates). This is complete by 2050, when coral cover is roughly 10% on sites that used to have coral cover of 50-70%.

- Mangrove-associated fisheries expand due to reformed coastal policies, and the increase and distribution of mangrove habitats under sea level rise. Control of coastal pollution and increasing water quality leads to improved conditions for mud crabs. The mud and sand crab industries are doing relatively well, especially in the estuaries that are not too heavily affected by anthropogenic factors. By 2020, there are noticeable gains in crab industry profits. This continues to grow until 2060 when conditions become too warm for some species. As with fish communities, there is an invasion of warm-water species from Papua

New Guinea and Southeast Asia, and the incidence of disease increases as in the other scenarios.

- There is a gradual rise in the incidence of ciguatera towards 2030. The rate is slowed by better coastal management of the Great Barrier Reef area which sees coral cover being more abundant and more persistent. Similar attention is paid as in the A1 scenario to ensure the market for fish does not decline drastically. However, the appreciation (and increased protection) of the ecological value of reef fish as functional groups within the ecosystem, coupled with the ciguatera negative, shifts the demand from fresh reef fish to pelagic fisheries (which suffer the smallest decline of all wild stock fisheries according to Table D26) and aquaculture.

- Improvements in coastal habitats and ecosystems like seagrasses and mangroves mean healthier fisheries stocks. Buoyed by the successful Protected Areas Program, the resulting fish harvests are not too dissimilar to those of the 1990s, up to 2025. Fishing continues, especially given that aquaculture is still highly regulated and small scale compared to Southeast Asia. Concerns about coastal runoff still dominate the industry's development. Beyond 2025, the effects of changing benthic habitats lead to changes in community composition (more herbivores and less palatable reef species). By 2060, the Reef has a substantially different benthic structure and fish fauna.

- As in other scenarios, fisheries move southwards as the waters warm and northerly species from PNG and Southeast Asia invade the northern waters.

- Challenges are faced by wild fisheries as aquaculture expands. This expansion is moderate in a world growing at a rate intermediate between the high-growth A1 scenario and the sluggish and disjointed world of the A2 scenario.

Pelagic fisheries

- Continued warming sees similar ecological phenomena as in the other scenarios. Warm-water species gradually move polewards. Pelagic fishes undergo community change and require increasingly complex technologies to track and catch. The rate at which these ecological changes occur is similar up to 2040 but increasingly slower than A1/A2 thereafter.

- Some risk of warm anoxic upwelling events exists. The slightly slower pace of climate change means that this risk is lower in the first half of the century.

- Infringement of Australia's Exclusive Economic Zone (EEZ) grows more intense as fishery resources become shorter in supply globally (by 2050). Several international incidents result in stand-offs over the ownership of international fisheries. These intensify as the second half of the century unfolds.

Trawling

- Trawling became quite strongly regulated from early 2001: as described in Chapter 9 the restructure that year resulted in closure of half the Marine Park to trawling. Half the remaining area was closed by 2010 due to concerns about climate change and improving or protecting reef resilience and connectivity. Educational programs like the 'Blue Highway' in 2001 found their mark as the resurgent environmental awareness in the community led to major changes in legislation regarding coastal practices and the way trawling was conducted. The true significance and threats of climate change were identified and appreciated by the wider marine management authorities.

- Although new techniques were devised to capture prawns in the wild using non-damaging fishing gear, which does not damage the benthos and is very selective of the target species, by 2020 trawling has been phased out in the entire Marine Park (Table D26). Public pressure grows as the benefits of a healthy environment to a larger tourist industry swamp those of a relatively small commercial fishing industry.

Aquaculture

- Aquaculture is highly regulated and despite seemingly impressive growth rates from a low initial level does not develop its full regional potential until after 2020 when major breakthroughs in recirculation systems, polyculture and vegetable foods make low environmental impact aquaculture possible. Australia continued through the initial decades of the 21st Century to be the leading country conducting research into high technology aquaculture. Due to the problems that require resolving, Australia in 2020 remains a very small producer of bulk seafood from aquaculture.

- Up to 2020, less environmentally scrupulous aquaculture suppliers in the international arena support the major portion of the Australian seafood consumption. Seafood continues to grow as a major import up to 2020.

- By 2020, however, Australia finds itself with a competitive advantage due to its investment in high-technology aquaculture, and its decades of research into the environmental issues associated with aquaculture. Its citizens and companies own much of the technology associated with intensive low-impact aquaculture. Whereas many foreign suppliers have started to suffer declines in production due to coastal degradation and disease, Australia's industry is set to grow rapidly from 2020 from this competitive position. As in Scenario A1 but 15 years later, inland saline aquaculture also grows and provides further opportunities for rural Australia.

- The relatively modest expansion of bulk seafood production from aquaculture up to 2020 is partly offset by a budding 'boutique' non-food aquaculture industry that focuses on biochemical products and pharmaceuticals from sponges, and ornamental pearls from species like the black-lipped pearl. These continue to grow and introduce new products based on bioprospecting, and become large sectors of ecologically sustainable economic growth by 2040.

- Genetically modified stock is encouraged but highly regulated. Growth really only takes off in this area when systems become completely recirculation-based (a requirement to avoid genetic pollution of local fish stocks and ecosystems) after 2020.

Summary of commercial fisheries prospects

In summary, scenario B1 depicts a combined wild fisheries and aquaculture industry which goes through a relatively successful restructuring process, including the phasing out of trawling by 2020 and the eventual replacement of the main trawling products with product provided by a highly environmentally conscious Australian aquaculture industry. Benthic and especially pelagic fisheries suffer relatively little damage during the first 20 years, though their long-term future remains clouded by further impacts of climate change.

Recreational fishing

Recreational fishing continues to be a major component of the leisure pastime of Australians in the coastal strip. The greater care within this scenario for coastal environments means that the recreational fishing experience continues to be attractive to Australians. Fish stocks don't decline as fast and hence the great outdoors experience combines with catch rates that remain satisfactory well into this century. Regulation of catch size and quantity continues with tighter restrictions due to the need to preserve grazers and key predator species. Recreational fishers are increasingly concerned with the health of their respective ecosystems and local environmental resources and become strong allies of environmental groups and agencies aimed at reducing pressure on the Reef from land-based runoff and commercial fishing.

Local economies before Reef damage

In a world economy growing at intermediate rates between the market-driven A1 and the compartmentalised A2, most export industries are projected using ABARE's mean estimates. The exceptions are horticulture and domestic tourism, which are assumed to be influenced by the lower rate of economic growth in Australia according to the IPCC scenario, and with the comparative advantages of the horticulture industry circumscribed by environmental restrictions.

The total gross product of the eight driving export industries in the five regions along the Great Barrier Reef is assumed to increase from $18.3 billion in 2001 to $20.1 billion in 2010 and 22.4 billion in 2020. This is equivalent to a constant growth rate of 1.1% pa (Tables D15 and D16). The top growth industries are aquaculture (10.2% pa in the first period followed by 8.6% pa from 2010 to 2020), and inbound tourism (4.1% pa, then 6% pa). Domestic tourism even before taking reef degradation into account is projected to decline by 0.5% pa to 2010 and then 0.2% pa to 2020. As in the other scenarios these projections were based on the Tourism Forecasting Council's forecast dated December 2002 (TFC 2002), and adopted by ABARE for its projections for PC (2003). The Council's previous forecasts had erred on the optimistic side and the severe reductions made in December could be an over-reaction to events such as September 11 and the ANSETT collapse. However, these are the reference forecasts we adopted in Chapter 10.

The corresponding employment projections show a small fall from 88,900 persons in 2001 to 87,800 in 2010 followed by a rise to 94,700 in 2020 (Table D17).

Impact on coastal regions

The tourism industry is in a relatively strong position with effective reef-based visitor policies, good stakeholder cooperation and success in introducing alternatives to reef visits. It enjoys a reasonable degree of success in its competition with other destinations in Australia and abroad and scores high marks for resilience and inventiveness (as discussed in relation to Table 16 in the tourism section of this scenario). We estimate that it may lose 0.2% annual growth in association with the first set of factors, and 0.6% to the competition, compared with the base projections. This scenario is considerably more benign in terms of losses to tourism than A1 and A2. The estimated loss for 2010 is $92 million and for 2020, $177 million (Table D24).

With the phasing out of trawling and despite better maintained benthic and pelagic catches, the total impact on fisheries is heavier than in the A1 and A2 scenarios. The total gross regional wild fisheries product is projected to be 18% down on the 2001 base year by 2010, and 38% lower in 2020, after taking a real price rise of 5% in 2010 and 15% in 2020 into account, relative to 2001 (details in Table D26).

The main aquaculture growth in this scenario may be delayed until after 2020 by the need to ensure environmentally safe technology. Even ABARE's low projection may be too high, though it is assumed to apply with 'boutique' enterprises being established in addition to some mainstream establishments. Table D29, which shows total impact on the regional economies, contains an adjustment for reduced aquaculture activities compared with the ABARE projection. While this shows up as an additional 'cost', the real reason is ecological prudence, and Northern and Central Queensland stands to reap the benefits when it introduces environmentally safe aquaculture operations in the years beyond 2020.

The total reef-related impact, including multiplier effects, is estimated at $211 million in 2010 and $450 million in 2020. The total estimated loss over 19 years is $4.5 billion, which is more than $1 billion better than A1. Discounted at 5%, the loss over 19 years without any residual value to account for the future after 2020 is $2.4 billion at 2001 prices.

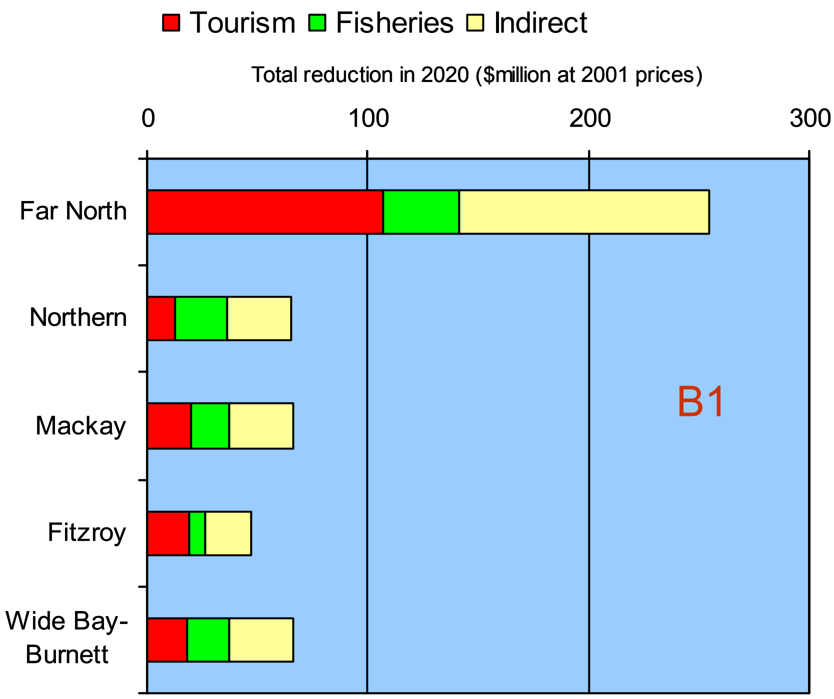


Figure 59: The reduction in Gross Regional Product in 2020 is $450 million, of which 52% is in Far North Queensland. The fisheries estimates include a delay beyond 2020 in aquaculture development compared with ABARE's low projection, driven by environmental caution. The reduction in total projected GRP in 2020 is 3.9%.

The reef factor is estimated to cause a total loss in employment of 4,000 by 2010 (1,400 from tourism, 600 from fisheries, 200 from the adjusted projection for aquaculture, and 1,800 from flow-on to other regional industries). The total loss is projected to increase to 10,600 by 2020, (tourism 3,600, fisheries 1,300, aquaculture 1,000 and local flow-on effects 4,700).

As in all scenarios other than A2, tourism employment will grow, providing an alternative employment opportunity for unemployed commercial fishers.

Figure 59 shows the regional distribution of the total estimated loss in 2020 of $450 million, with Far North Queensland accounting for 52% (numbers in Table D29).

Figure 60 summarises the projected regional economic growth before and after allowing for deterioration of the Great Barrier Reef. As in all scenarios, the adjustment to life in a lower economic growth regime will prove a challenge to government, business and consumers alike, and scenario B1 will remove some 0.1% annual growth each year on top of the already reduced economic expansion.

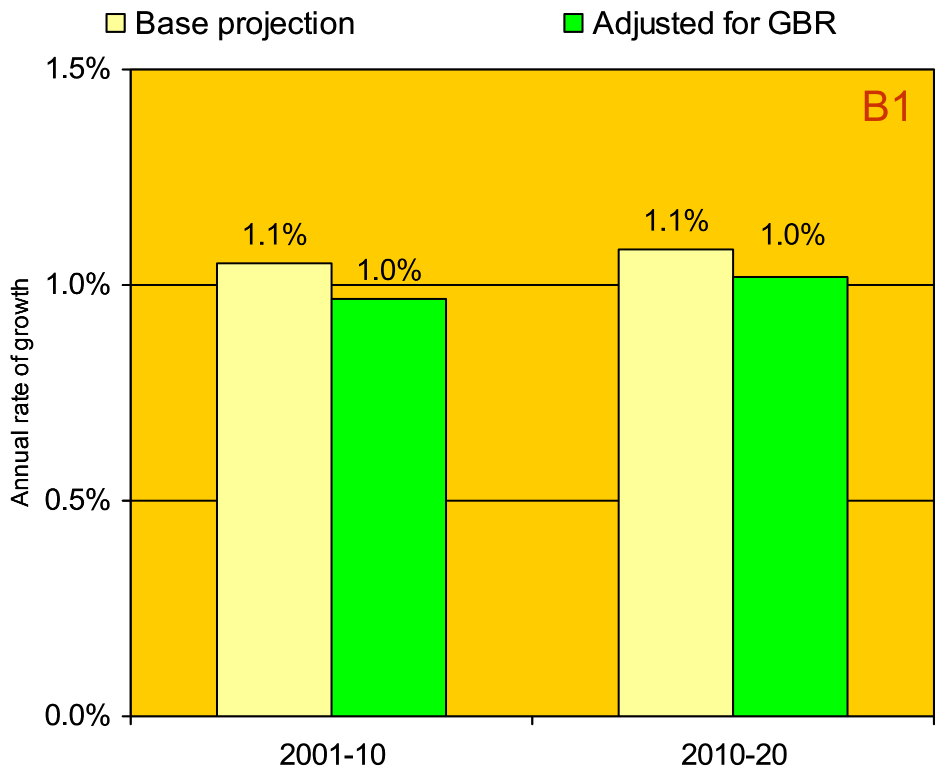


Figure 60: Economic growth along the Great Barrier Reef under Scenario B1 is less than under the economics-driven A1 scenario but the reduction in growth caused by a deteriorating Reef is similar up to 2020 (the difference would probably widen in B1's favour in longer-term projections).

B2: Regional sustainability

The world

The B2 world is one of increased concern for environmental and social sustainability compared with the A2 storyline – with the emphasis on local rather than global solutions for sustainable use of the environment. Increasingly, government policies and business strategies at the national and local levels are influenced by environmentally aware citizens, with a trend toward local self-reliance and stronger communities. International institutions decline in importance, with a shift toward local and regional decision-making structures and institutions. Human welfare, equality, and environmental protection all have high priority, and they are addressed through community-based social solutions in addition to technical solutions, although implementation rates vary across regions.

In this world, population growth is moderate but in its pure form continues through the 21st Century. We consider a convergence from 2050 into the B1 scenario to be more plausible for the story of the Great Barrier Reef – basically meaning less rapid global warming rates than in the original B2 scenario. Economic development proceeds at intermediate rates, and technological change is less rapid and more diverse than in the A1 and B1 storylines. The scenario is oriented towards environmental protection and social equity but focuses on local and regional levels.

Like the other scenario families, B2 includes futures that can be seen as positive or negative. While the B2 storyline is basically neutral, similar scenarios have imagined a positive world with emphasis on decentralised governments and strong interpersonal relationships. On the other hand, we could see deterioration where values are only shared within small competing groups, which results in a decentralised world of tribes, clans, families, networks, and even gangs. For the purpose of this study we assume that some tendency to this may exist in a regionalised world but that it is not dominant, and will be increasingly subjugated by global policies in the second half of the century. On the positive side, this storyline appears to be consistent with current world institutional frameworks and with current technology dynamics. On the negative side is the relatively slow rate of development in general, but particularly in the currently developing parts of the world.

Education and welfare programs are pursued widely, which reduces mortality and, to a lesser extent, fertility. The population would reach about 10 billion people by 2100 in the pure B2 model (Table E3) but would turn downwards from about 2065 in a world converging to B1, reaching 8-8.5 billion by the end of the century. Income per capita grows at an intermediate rate to reach about US$12,000 by 2050. By 2100 the global economy might expand to reach some US$235 trillion in the pure B2 model, but a level closer to the B1 projection of $328 billion in the hybrid scenario we have assumed (perhaps $280 billion). International income differences decrease, although not as rapidly in the first half of the century as in storylines of higher global convergence. Local inequity is reduced considerably through the development of stronger community-support networks.

Generally, high educational levels promote both development and environmental protection. Indeed, environmental protection is one of the few truly international common priorities that remain in B2. However, strategies to address global environmental challenges are not top priority in the first half of the century and therefore less successful than local and regional environmental response strategies. The governments have difficulty designing and implementing agreements that combine global environmental protection, even when this could be associated with mutual economic benefits – the increasing constraints that this causes explains the transition to a B1 world in the second half of the 21st Century.

The B2 storyline presents a particularly favourable climate for community initiative and social innovation, especially in view of the high educational levels that develop. Technological frontiers are pushed less than they are in A1 and B1, and innovations are also regionally more heterogeneous. Globally, investment in energy R&D continues its current declining trend, and mechanisms for international diffusion of technology and know-how initially remain weaker than in scenarios A1 and B1 (but higher than in A2). Some regions with rapid economic development and limited natural resources place particular emphasis on technology development and bilateral cooperation. Technical change is therefore uneven. The energy intensity of GDP declines at about 1% per year, in line with the average historical experience since 1800.

Land-use management becomes better integrated at the local level in the B2 world – one great advantage of the initial B2 world scenario is that local community input remains strong even after the scenario adopts more global policies from 2050. Urban and transport infrastructure is a particular focus of community innovation, and contributes to a low level of car dependence and less urban sprawl. An emphasis on food self-reliance contributes to a shift in dietary patterns towards local products, with relatively low meat consumption in countries with high population densities.

Energy systems differ from region to region, depending on the availability of natural resources. The need to use energy and other resources more efficiently spurs the development of less carbon-intensive technology in some regions. Environment policy cooperation at the regional level leads to success in the management of some trans-boundary environmental problems, such as acidification caused by sulphur dioxide (SO_2), especially to sustain regional self-reliance in agricultural production. Regional cooperation also results in lower emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs), which reduce the incidence of elevated tropospheric ozone levels. Although globally the energy system remains predominantly hydrocarbon-based to 2100, a gradual transition occurs away from the current share of fossil resources in world energy supply, with a corresponding reduction in carbon intensity.

Some points from the scenario planning workshops provide further ambience to the world view:

- There is general consensus from about 2010 that humankind is responsible for environmental degradation generally and climate change in particular – a full decade after the hundreds of scientists involved in IPCC's *Third Assessment Report* agreed this was so (IPCC 2001a). One trigger for the change in human perceptions was the extreme weather conditions in the late 20th and early 21st Centuries; devastating storms and record floods in Europe, and persistent drought in Australia, were increasingly thought to be linked to climate change (see Karoly et al. 2003 on Australia's 2002 drought, which persisted into 2003 after the authors had finished their paper).

- The ascendancy of environmental thinking has also helped secure that genetically engineered products not yet commercially introduced are safe beyond any reasonable doubt before being released (an example of globally adopted protection despite the regionalisation of the B2 world). In some industries and regions, consumers reject genetically modified organisms (including aquaculture-bred fish in North Australia). Safeguards relate to the minimal risk of 'rogue' modified organisms spreading, to the rights of individual farmers whose crops have been accidentally contaminated with GM organisms, and to general safeguards of small farmers in developing countries against coercion from either multinational companies or local cartels, clans or landlords (Møller 2001).

- Similar safeguards are put in place as other breakthroughs of environmental significance occur, including fermentation technology (see p 203), though this is proving less controversial than gene splicing.

Australia

The B2 storyline is unique among the IPCC scenarios in specifically identifying local community groups as drivers of new engines forcing a local outlook on the larger picture. The Australian version of the B2 world might be dubbed the Douglas scenario. Unique among Australian local government areas, most of the Far Northern Douglas Shire is taken up by two national parks, though sugar cane around Mossman Central Mill extends right up to the Daintree River. Port Douglas is a major tourism centre focused on reef and rainforest, and the Shire is more dependent on the tourism industry than any other part of the tropical Queensland coast (Figure 42 and Table B10). It is, according to its comprehensive draft strategy (which is actively supported by the Douglas Shire Council), the only area in Australia where two World Heritage Areas meet, the Wet Tropics and the Great Barrier Reef (DSWG 2001:34). The Port Douglas scenario planning workshop made frequent references to the power of local campaigns successively influencing local, State and Federal politicians.

By 2020, this influence has grown and spread. The following stories were inspired by the Port Douglas and Brisbane workshops (the first one backs up the statement in the previous paragraph):

- Above all, there is a strong sense of local community empowerment. Successful lobbying by community action groups first at local government and subsequently at higher government levels has been going on since the 1980s, with the Internet providing a new and efficient vehicle for communication and persuasion from the late 1990s. All political parties have much stronger environmental politics today than at the turn of the 21st Century and are forced to adopt longer-term perspectives.

- The stronger representation of women in government has also meant an enhanced sense of social and environmental justice. By 2020, a new generation has come to prominence. A 38-year old female prime minister takes charge in 2015 in the Republic of Australia, supported by an increasingly strong environment support base. Young people's ideas permeate the debate, with more senior citizens in a generally ageing population adding their assent.

- Water quality and availability (rather than crude oil) is recognised as the most important issue facing Australia, and this view has been instrumental in framing wide-ranging legislation to counter further land degradation and enforce large reafforestation schemes.

- As in other countries and as advocated in Australia from the turn of the century (for example in Crowley 2000), a cautious approach continues to be taken to technologies such as genetic modification.

- The ever-increasing emphasis on environmental issues in primary and secondary schools over the past 30 years or more, reinforced by the efforts of tourism centres, has had a profound impact on both child and parental understanding of the problems confronting the country. There is now a much keener sense of responsibility in Australia for preserving ecosystems for future generations.

The emphasis on community values is reflected in a report reviewing UNESCO's role in the 21st Century (UNESCO 2000). Of a list of ten possible trends, the positive aspects implied in items 8, 9 and 10 feed readily into the B2 story:

- Enhancing the role of women, and fresh prospects for gender equality

- New cross-cultural encounters: cultural pluralism, diversity and creativity

- The growing influence of science and technology and the new ethical challenges.

These trends are sufficiently strong to reach the short-list alongside some huge perceived threats to the 21st Century world: reinforced trends towards poverty, inequality and exclusion, new threats to peace, security and human rights, increasingly acute problems arising from population growth, and the key issue in the context of this report: rapid degradation of the world's environment (item 5 on UNESCO's list).

The Great Barrier Reef

The community-based self-reliance of the B2 world leads to a rapid expansion of coastal centres that are built on the principle of 'walking proudly but leaving few footprints on the earth'. Economic reality dictates that reef-based businesses develop but with tight environmental regulations. These regulations are adopted and extended by the citizenship of these coastal centres who strive for National Green Accreditation (NGA) status. The latter is used by a selective tourist market who value 'enjoying nature while leaving few footprints'. Ecotourism expands, as does the number of reefs protected from resource extraction. The impact of climate change on coral reefs continues to develop as in the other three scenarios but as in B1, the decline of coral-dominated reefs is slowed due to the massive reduction in the influence of secondary factors such as fishing and water quality pressures.

Due to the increasing pressures of climate change and the growing recognition of the long-term value of the Great Barrier Reef Marine Park, 75% of the Park is non-extractive by 2020.

The importance of tourism income to local communities (and a now well-supported and undeniable scientific case for protecting reef systems under the pressure of climate change) leads to strong pressure to expand the no-take areas gained under RAP 2003 (30% was protected at that point). Changes outside the no-take areas are also now extensive compared to 2002. Trawling has been reduced to zero within its boundaries. Recreational fishing has been transformed into something akin to the catch, kiss and release ethic of a long-retired fishing hero from 2000-2010, Rex Hunt. As in B1, water quality has improved as coastal runoff is brought under control.

As in B1, shipping in the vicinity of the Great Barrier Reef is tightly controlled. Public concern over the risks to one of Australia's largest sustainable industrial settings (the Great Barrier Reef) demands very tight regulations on shipping oil or any other noxious cargo. Re-routing of certain classes of ships increases import costs but the public sees it as worth paying for. Another threat, from potential exploration and mining, was eliminated when legislation was passed to prohibit these activities not only within the World Heritage Area, but in adjacent areas extending eastwards to the limit of Australia's Exclusive Economic Zone.

The presence of a large and increasingly empowered, well-educated Indigenous population in tropical coastal Queensland makes possible the agreement, in 2017, that gives all Aboriginal people between Cape York and Fraser Island joint custody of the Marine Park. This is proving to work after complex negotiations with the multitude of Aboriginal coastal nations.

Strong administrative and research backup continues from GBRMPA, AIMS and academic specialists. The cooperative research originally bringing the main scientific, administrative and industry stakeholders together in CRC Reef was made permanent in 2006 with significantly increased funding after the initial seven-year trial period.

Warming rates associated with this scenario are little better than the others up to 2025. Strong action to reduce greenhouse gas emissions has led to a slightly smaller increase in sea temperatures – waters on the Great Barrier Reef are 0.7^{o}C warmer in 2025 than in 1990, which leads to increased incidence of intense bleaching events. Coral reefs lose 20% of their associated biodiversity by 2030 and coral cover declines to 50% of 1990 levels by 2040 (Section 1, Table 10). Strong local action combines with State and Federal initiatives to improve reef resilience and recovery processes are maximal after bleaching events. This leads to better recovery from the nearly annual bleaching events in the first two decades. As in all other scenarios, coral cover eventually plummets to near zero around 2060 as thermal stress increases. As in B1, there is a better prognosis for recovery in the longer term. Recovery after bleaching events is more rapid which leads to more coral remaining for longer.

Tourism

As in scenario B1, the reef-based tourism industry in B2 has been able to adapt to the degradation of the Great Barrier Reef – and the Reef is benefiting more from being cared for by local communities, both Indigenous and non-Indigenous, in a situation of continued global warming. The extensive (75%) area protected by no-take areas within the Park is seen almost universally as wise planning and stewardship of a valuable income resource for Australia. Much that was written in B1 applies here as well, including the acceptance by stakeholders of the need to restrict access but also the edge that a healthy Reef gives to business operators to compete for the international tourist dollar over and above that of less cared-for coral reef regions worldwide. The competition is taken up vigorously in the overseas promotion by the Australian Tourism Commission and Tourism Queensland. Ecotourism is big in this promotion, both because Asian mass market tourism is not as prevalent as in the A1 growth scenario, and because the Asian tourist market begins to promote greater travel independence.

Table 17: Influences on base tourism projection: B2 scenario

	2001-20	2020-50
Condition of GBR, end of period (scale 0 (worst) to 10)	**5**	**3**
ABARE low world projection (average 2001-10 and 2010-20)	3.1%	
ABARE low Australian projection (average 2001-10 and 2010-20)	3.0%	
Projected world economic growth, this scenario	3.0%	2.6%
Economic growth, United States and Canada, this scenario	2.1%	1.1%
Australian economic growth, this scenario	2.1%	1.1%
Asia-Pacific economic growth, this scenario	6.9%	4.0%
Scale from -5 (worst) through 0 (neutral) to +5 (best)		
Reef-based tourism - policy (weak bad, strict good)	5	
Stakeholder cooperation (weak bad, strong good)	5	
Australian economic growth factor	-2	
Asian tourism factor	3	
GBR competition with other reef areas: international tourists	2	
GBR competition with other reef areas: domestic tourists	2	
GBR competition with other coastal tourism: international tourists	0	
GBR competition with other coastal tourism: domestic tourists	0	
GBR competition with other domestic tourist attractions	0	
GBR competition with other international tourist attractions	0	
Tourism industry success in introducing alternative product	4	

Source: ABARE: see PC 2002; IPCC projections in SRES background tables (IPCC 2000)

The local tourism industry is also able to exert significant pressure on coastal management, as in B1. In fact, with the even more active support from local communities, the industry is highly successful in this respect. At the same time, the application of high building standards and the principle of embodied energy leads to a sea change in local community attitudes on the mainland, so the tourism industry is to a large extent preaching to the converted.

In a nutshell, tourism has become a more intimate experience, one for the fully independent traveller rather than large tour groups. The number of tourists may be slightly lower as a result, but the new eco-traveller is willing to pay for quality, so that higher average expenditure more than compensates for the reduced numbers. The world has grown sufficiently affluent to be able to afford this. Higher education in China, coupled with the 'Learn English the Aussie Way' movement – a real program in 2002 – which captured the imagination of 400 million Chinese in 2002-03, has given them the confidence to travel alone or in small groups of family and friends. Similar developments have encouraged fully independent travellers from India, Indochina, Southeast Asia and Korea – even the Japanese who were the quintessential group travellers in the old century are now into the intimate experience of small group or individual tourism.

Figure 61 suggests that the impact of reef degradation on tourism up to 2020 is the mildest of the four scenarios, though the brunt of the impact remains in the Far North. Employment is expected to reduce up to 2010 and then increase, much along the lines of the B1 scenario.

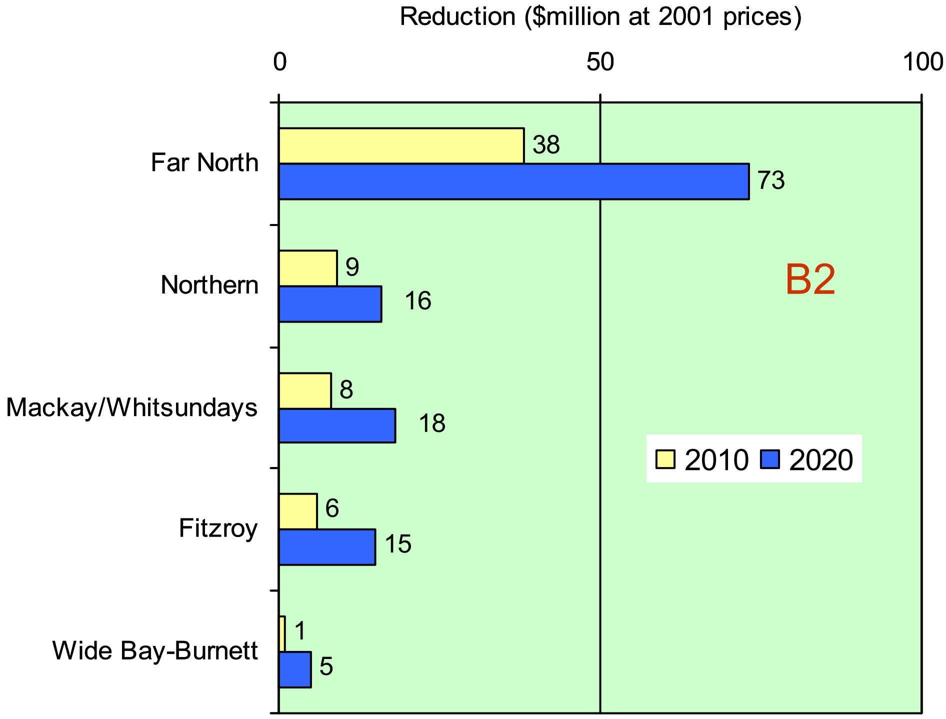


Figure 61: Reduction in tourism GRP in 2010 and 2020 according to the B2 scenario. Total for five regions: $62 million in 2010, $127 million in 2020. Reduction relative to total projected reef-interested tourism GRP (2020): 8%, relative to total projected tourism GRP: 4%. See further Appendix D, Table D30.

Full-time equivalent employment, tourism, B2 scenario

Region	Persons			Annual change	
	2001	2010	2020	2001-10	2010-20
Tropical (Far) North	16,600	15,600	17,700	-0.7%	1.3%
Northern	5,800	5,500	6,400	-0.6%	1.5%
Mackay	6,100	5,800	6,500	-0.6%	1.1%
Fitzroy	4,600	4,400	5,000	-0.5%	1.3%
Wide Bay-Burnett	5,900	5,700	6,500	-0.4%	1.3%
Total GBR regions	39,000	37,000	42,100	-0.6%	1.3%

Derived from Tables D20 and D25.

Fisheries and related activities

Benthic fisheries

Changes in fish communities are similar to those seen in the B1 scenario. The sustainable focus on best practice in the coastal zone leads to slower rates of change, which means that the effects of later dramatic changes to coral cover are delayed.

As in B1, greater environmental awareness in the community drives reform of catchment management practices and organic agriculture. This leads to better conditions for mangrove systems which are also benefiting from sea-level rise driven by climate change. Mud crab and related estuarine fisheries improve and prosper. In the longer term, they continue to do well (unlike A1 and A2) as temperatures never exceed 33^{o}C for much of the later part of the century. This is consistent with the converging B2-B1 world, which results in higher population growth than in the pure B1 scenario but significant lower income and consumption rates.

The incidence of ciguatera increases steadily by 2020 (as in all scenarios) with the pressure on marketing as discussed before. As in B1, greater appreciation of the functional roles of reef fish with coral reef ecosystems leads to a drop in market appeal for eating reef fish. The industry is smaller than it was in 1990 as the local market switches to more 'ethical' (their words) sources of fish, such as sustainable recirculation aquaculture.

Environmental practices are accelerated so that coastal water quality steadily improves up to 2020 (similar to B1). Fishing within the Reef is highly restricted to 25% of the Marine Park. Public education on the key roles that fish play within coral reef ecosystems strengthens efforts to keep them and drives a new ethical standard where fishing is more 'Rex Hunt' style ('catch, kiss and release'). Fishing is seen as a privilege, not a right, though it is appreciated that the strong presence of recreational fishers in the coastal communities needs to be catered for. Their strong environmental ethics transform their public profile into environmental wardens as opposed to previous perspectives.

As in other scenarios, fisheries move southwards and northerly species from PNG and Southeast Asia invade the northern waters. This is almost indistinguishable up to 2025 but slows after this period. This scenario does not end in the extent of collapse predicted for others as waters don't get too warm for species to continue to prosper. The plateau of sea temperatures at 2^{o}C higher than 1990 sea temperatures has a very different impact as opposed to scenarios that end at much high plateau sea temperatures.

Australia's efforts to solve the problem at the heart of the international fishing disputes and infringements start to pay off by 2010. Sustainable, organic aquaculture practices are supported and nurtured through large parts of Southeast Asian villages, using Australian and international aid funding and Australian technical advice. Education programs and international treaties lead to a gradual reduction in Southeast Asian demand for live fish caught in Australian waters.

Large scale extractive fishing is seen as unsustainable and in conflict with the important ecological role that fish provide in terms of environmental service by 2020, consistent with a 10% reduction in benthic and a 5% fall in pelagic fisheries between 2010 and 2020 (Table D26). Reduced markets and the rise of problems like ciguatera lead to greater decline of reef-based fisheries by 2030.

Pelagic fisheries

Continued warming sees similar ecological phenomena as in the other scenarios with warm-water species gradually moving polewards. Pelagic fishes undergo community change and require increasingly complex technologies to track and catch. As with the other scenarios, keeping pace with changing stocks requires a flexible industry (long-term gear investments for a particular species make little sense) and an increasing level of technological sophistication to track and monitor fish species with varying population dynamics and distributions.

There is still considerable risk of warm anoxic upwelling events. The slower pace of climate change means that this risk is lower for the first half of the century. The risk of climate events is significantly less than those of other scenarios by 2050.

Trawling

Coastal politicians are lobbied by an increasingly powerful and environmentally conscious tourism industry. This leads to completion, by 2010, of Federal initiatives started in 2001 to remove trawling from the Marine Park. New technologies have been developed and trialled to harvest wild-caught prawns without causing seafloor damage, and to reduce bycatch. Assistance packages were developed in the first decade of the century to assist trawlers to move to the new fishing methods, and then to help them move out of the Marine Park altogether. The relatively small size of the industry relative to the larger (by over 15-fold by 2020) and more prosperous sustainable tourist industry hastens this move.

Aquaculture

As in B1, aquaculture under B2 is a community based exercise in which major breakthroughs in recirculation systems, polyculture and vegetable foods make low environmental impact aquaculture possible. This leads to small farm aquaculture developing along the coast of Queensland with stringent effluent control. Healthy ecosystems allow hybrid farming in which habitats are stocked with aquaculture-grown juveniles and re-harvested under licence. Competition from less scrupulous suppliers from overseas aquaculture companies is controlled through an Aquaculture Green Accreditation scheme which allows consumers to choose low environmental impact aquaculture products. The 'Proud to be a sustainable Aussie' campaign takes off in the 2010s. This, incidentally, leads to the collapse of ecologically expensive salmon aquaculture products (such as imported Scottish salmon). These trends are very much in line with the extensive environmental and energy accounting that develops from 2010 across Australia.

The slow rise in sea temperatures still brings in the issues of disease and more northerly species invading as southern waters undergo warming. High technology investments from the past decades pay off handsomely as the industry has a worldwide reputation as the most modern and best practice available globally.

High technology aquaculture is adopted across the board with the twist that only those technologies (polyculture, recirculation, vegetable foods) are adopted and genetically manipulated stock is abandoned. This is primarily driven by coastal communities that are highly selective at the supermarket and avoids genetic modification in any shape or form. Mandatory package labelling prevents unscrupulous supply cheating.

Summary of commercial fisheries prospects

The issue of trawling was brought to the fore earlier in this scenario than in any other, including B1. Despite the development of new technology, the decision was made to prohibit trawling within the Marine Park from 2014. On the other hand, pelagic and benthic fisheries were virtually unaffected until 2014, though moderate reductions then occurred during the ensuing decade. As in other scenarios, conditions for these fisheries become more difficult from the 2020s.

Aquaculture ventures along the Reef are not delayed beyond the 2020s as in scenario B1. There are two main reasons for this. First, trawling was phased out more quickly than in B1, leaving an unsatisfied demand for prawns in particular. Secondly, in the spirit of the intense community concern and cooperative efforts in the B2 world, methods and technologies could be much more thoroughly supervised and policed than under the more centrally dominated B1 scenario. Notably, the strong local communities developed in the first half of the century will coexist with higher-level decision-making bodies in the second half.

Recreational fishing

As in the B1 scenario, recreational fishing is better protected than under the A1 and A2 scenarios. They also have relatively great influence in the community-based world developing in the first half of the century. The greater appreciation of the quality of coastal ecosystems leads to a greater all-round experience for the recreational fisher. The larger protection afforded under no-take zones leads to retraction of potential recreational fishing areas but leads to a more exciting fishing catch rate. Recreational fishers are strong advocates of preserving local environments by 2020 (seen as environmental wardens by the public), a consequence of proof that greater preservation leads to better experiences as far as recreational fishing is concerned and the better education of the public about the pros and cons.

Local economies before Reef damage

The economic drivers of the five regions produce much the same growth impetus in this scenario as in B1: their combined gross product increases from $18.3 billion in 2001 to $20.1 billion in 2010 and 22.5 billion in 2020, which amounts to 1.1% per annum throughout (Tables D18 and D19). The main growth industries in the absence of a degrading Reef are again aquaculture and international tourism. Projected growth rates are only modest for mainland export industries: sugar, beef, horticulture, mining and mineral processing (totalling 1.0% pa to 2010, reducing to 0.5% pa in the following decade).

Employment in the eight 'driving industries', before adding the impact of a deteriorating Marine Park, is projected to decline from 88,900 in 2001 to 85,600 in 2010, and then increase to 90,600 by 2020.

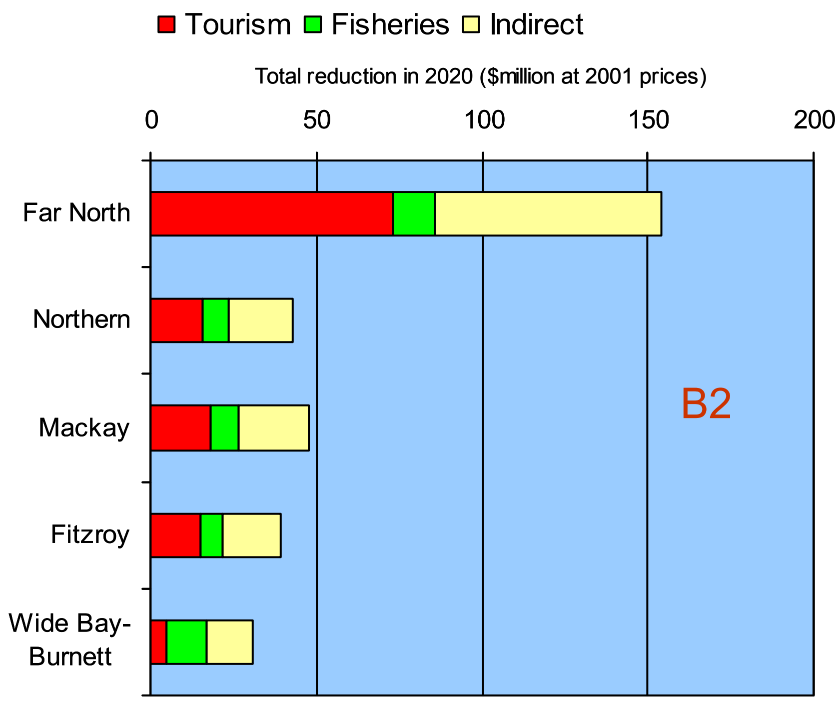


Figure 62: The total estimated GRP reduction in 2020 is $315 million, with 49% of this in the Far North. The reduction in total projected GRP in 2020 is the lowest of the four scenarios (2.7%)

Impact on coastal regions

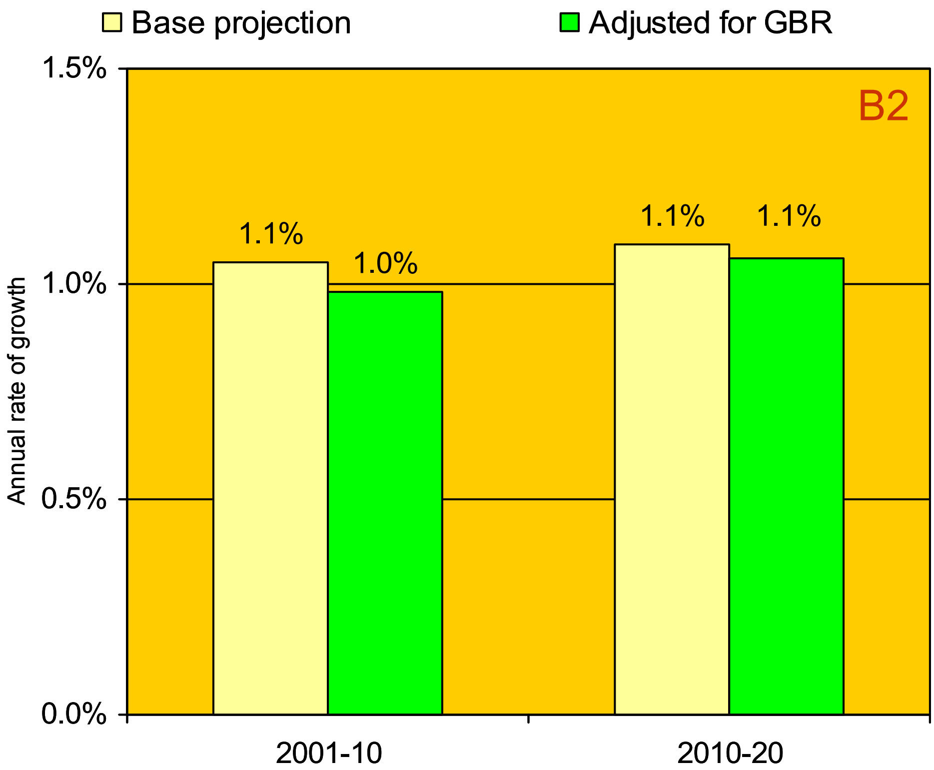


Figure 63: Scenario B2 has similar economic growth rates for the GBR regions to B1. However, the reduction due to reef deterioration is significantly reduced in the more modest economic expansion situation, reducing to by only 0.3 percentage points between 2010 and 2020. The loss rate is expected to be further reduced beyond 2020.

This is the most successful scenario in terms of reef-based tourism policies, stakeholder cooperation and introduction of alternatives to direct reef experiences. The competitive position of the Reef is even better than in scenario B1, justifying a total downward adjustment of only four percentage points to tourism GRP (Table D25).

With trawling removed even earlier than under B1, fisheries GRP will be minimised from 2010 despite sustained benthic and pelagic catches (Table D26). Aquaculture growth is assumed to follow the base ABARE projection and will not be postponed as under B1, with concerted responsible community efforts persisting in compliance with strict environmental safety measures.

The relatively modest loss due to climate change (due to the protection of reef resilience) and other factors having an impact on the Marine Park is illustrated by Figure 62, showing a total loss of gross regional product of $315 million in 2020 (Table C30). The total estimated loss over two decades is $3.5 billion expressed in 2001 Australian dollars (discounted at 5%: $1.9 billion). The Far North as usual bears the main burden of the loss, though the proportion (49%) is smaller than for the other scenarios.

This economy is basically steady with 1.1% annual growth before considering degradation of the Reef, though employment is shed in the first decade as shown under the previous heading. Figure 63 summarises growth in gross product in the five regions along the Great Barrier Reef, before and after allowing for deterioration of the Reef. The difference is smaller than for the other scenarios, amounting to a mere 0.03% pa in the second decade.

One caveat is appropriate: We have mainly considered scenario B2 over the half-century to 2050 though with a couple of forays into the second half of this century in the Great Barrier Reef and fisheries sections. In the longer run, problems would arise if the transition from a B2 to a B1 world as defined by IPCC (2000) did not come about, which would bring with it inevitable increases in CO_2 levels. This would cause the Reef to be put under great additional stress. It is hoped that the respective advantages of the B1 and B2 worlds: strong international consensus backed by world bodies such as the United Nations in B1 and outstanding local community commitment to the environment in B2, will indeed eventually merge to enable the sustainable new world developing in the first decades to persist for the rest of the 21st Century.

Synthesis of Part 3 – towards sustainable long-term policies

Scenario planning enables policy makers to consider a range of plausible, long-term futures which require plausible, long-term strategies and policies. It is a difficult process but one that is rewarding in terms of asking the difficult question. What will happen if we take one pathway to the future over another? The four scenarios in Part 3 all start with a worldwide story which was developed in a universally recognised international forum of experts, the Intergovernmental Panel of Climate Change, for its Third Assessment Report in 2001. Each of the scenarios ends with specific projections relating to the future of the Great Barrier Reef.

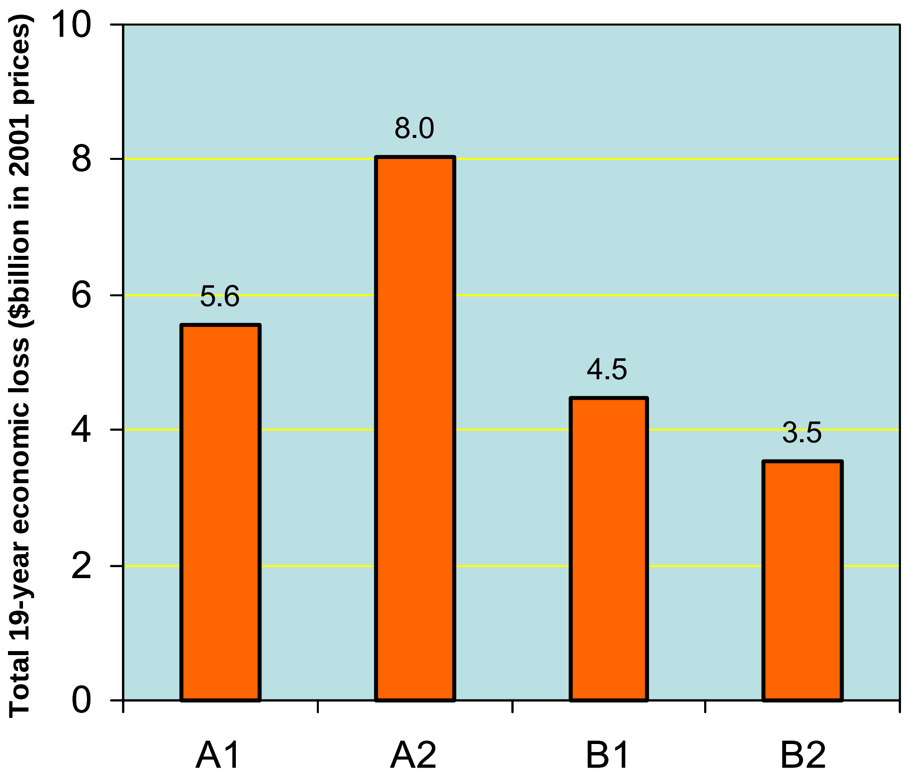


Figure 64: Total estimated economic loss according to the four scenarios over the first two decades of the 21st Century. Further losses will follow in subsequent decades which will increase the differences, as the annual loss accelerates in the A2 scenario indefinitely, and in A1 at least into the second half of the century. Annual losses will grow at a decreasing rate in the B1 and B2 scenarios, and may stabilise from mid-century. Discounted at 5% pa, the four values become $2.9, 4.3, 2.4 and 1.9 billion, respectively (for 19 years only, without any residual value calculation). The chart shows industry losses only; there is no attempt to value ecosystem services and other indirect and future use, or any bequest and other non-use functions of the World Heritage Area.

The present provides no clue as to whether the world in 2020 and 2050 will be dominated by global economic growth assisted by the free movement of physical and human capital and ideas across national boundaries (A1), or will fragment into a number of potentially antagonistic blocks (A2), or will give prominence to the need for sustainable development through international cooperation (B1) or driven to a greater extent by grassroots community concerns (B2). As Figure 64 amply illustrates, even the most benign scenario shows that climate change will cost the local economies dearly – a minimum of $3.5 billion over 19 years to 2020 expressed in constant Australian dollars, and more to come after that. It is also clear from Figure 64 that the different scenarios carry very different levels of costs, and these are only over two decades and only the costs associated with industry losses in the five regions. No costing of ecosystem services and the damage done to these, and no assessment of heritage and other values (to the extent that these can be measured at all), are included in Figure 64.

The present world contains a plethora of warning signals, and some promises of better things to come, which together with future events at which we can only guess can trigger a range of different futures. There are, however, some common factors for the four scenarios, of which one stands out: **The trend in global warming is irreversible in the short to medium term (to 2040 or 2050).** Even in the best case IPCC scenario, CO_2 levels, and hence temperatures, will rise over the next two or three decades (in the absence of some implausible technological breakthrough over the next few years enabling atmospheric CO_2 to be extracted back from the atmosphere).

Given the findings in previous parts of the report, the effort must therefore be concentrated on alleviating the stresses on the various interconnected ecosystems within the Great Barrier Reef World Heritage Park to enable them to retain or regain their resilience until such time when greenhouse gas emissions have peaked. Without maximum resilience (the ability to recover from a stress event), coral reefs like the Great Barrier Reef are unlikely to be able to survive the coming shocks of future climate change without undergoing major changes.

The lesson is clear: Lest the world's coral reefs are to become 'collateral damage' in a world hell-bent on retaining its short-term perspective on economic growth versus sustainable development, there is little time left to prepare for their long-term survival. The damage may go much further than the destruction of coral reefs, given their unrivalled ability to create an incredibly rich environment in the nutrient-depleted tropical oceans (Chapter 3). And given their central importance (i.e. sheltering waters in which other ecosystems like seagrass meadows and mangrove forests flourish), the loss of coral reefs is likely to have ramifications that science currently knows little about. Science knows little about the potential damage to other ecosystems if the world were to lose the biodiversity of the coral reef systems.

To avoid the worst future, and plan for the best, basically means preventing scenario A2 or a similar future from developing, or an unbridled 'A1' fossil-fuel dominated growth scenario. The best the world can hope for to curb climate change in the long term is to plan and work towards a fully sustainable environment, where a 'B1/B2' combination of global cooperation and community involvement at all levels would seem the happiest solution.

There are two major conclusions as far as the Great Barrier Reef is concerned:

- **Continue to develop and implement an integrated set of policies to allow the Reef to retain maximum ecological resilience over the coming quarter century of increasing climate-induced stress.**

- **Work to reduce worldwide and domestic greenhouse gas emissions now, not in five or ten years' time. This is likely to deliver major benefits to our societies beyond 2050.**

Part 4 contains the main policy recommendations flowing from the findings of this report.

Part 4: Policy implications

Significance of the Great Barrier Reef

This report has focused on one particular aspect of climate change – its impact on the largest and currently best preserved coral reef system in the world. Part 1 of the report deliberately started from a wide scientific perspective – not just from coral and the Great Barrier Reef – to ensure that this would not be seen as a narrow focus. Quite apart from the economic use value of the Great Barrier Reef and its undisputed but incalculable heritage value, there are two important reasons why implications of this study extend beyond an iconic coral reef system:

- The connection between coral reef ecosystems and other oceanic systems through food chains and other channels is not well understood, but is likely to be vital to far greater areas than just the reefs and could have vast and inestimable impacts.

- Coral reefs have been called 'global canaries' (UNEP 2000, Hughes et al. 2002): like the caged canaries carried into 19th Century underground mines to check oxygen levels they provide an early warning system against greater dangers ahead.

International policy implications

The daunting task of formulating policies to save the future of coral reefs must start at the highest international level – because it is not just about coral reefs. The *Third Assessment Report* (IPCC 2001a) established, for the first time, the strongest possible scientific consensus that the bulk of greenhouse gas emissions is caused by human activity, and that the main culprit is CO_2 from oil and coal. Australia as a nation should assume that a reasoned and vigorous commitment to the environment can make an impact on the international stage – we can be leaders rather than followers in a worldwide campaign to change entrenched concepts.

Australia's commitment to the first round of emission targets in the Kyoto Protocol is an important first step, because the evidence is mounting that climate change is exacerbating the impact on already damaged ecosystems and future rounds of international negotiations will have to face the need for significantly stronger provisions. It no longer seems appropriate to rely exclusively on conventional economic modelling (as in ABARE 2001, McKibbin 2001, Jakeman et al. 2002) to test whether Australia's economic growth would suffer if we signed. Although there may be a valid argument that Australia would be economically disadvantaged for a while if it joined and the United States didn't, Australia should sign up and then join the international community in trying to persuade the United States to do likewise.

The world may be entering a stage of lower economic growth which may limit the long-term accumulation of greenhouse gases but will not reduce them. Temperatures will continue to increase over the near future due to long residence time of CO_2 – past emissions from many decades ago are still present in the atmosphere. The IPCC-based scenarios in Chapter 12 provide persuasive evidence that a quantum leap in ecological understanding and environmental protection is required to allow some hope that icons such as the Great Barrier Reef will recover from the damage it will have received by 2040 or before.

Learning to live with lower economic growth will not prove easy, and there will be massive structural change. Nevertheless, a 'dematerialising' world is considered to be a realistic possible outcome by scenario builders and others envisaging possible futures for humankind. That embodied energy can be radically reduced according to responsible and highly qualified people, and 'there is money in green technology', not to mention Shell's publicised scenario planning for a future with drastically reduced crude oil supplies, and other oil companies' moves in that direction, all represent beacons into a greening future.

As well as using direct regulation, governments from the industrialised world, backed by international organisations such as the United Nations and the OECD, can encourage this development through taxation and subsidy systems, rewarding reductions in greenhouse gas usage. Some measures can be quite straightforward, such as the introduction of carbon taxes, mandatory fuel efficiency standards for vehicles, and reduced taxes on the most fuel-efficient vehicles (Hamilton et al. 1997). Europe has been leading in the reform to protect the environment, with transport again providing a main example not just of the imposition of carbon and other energy taxes but also a range of measures to reduce congestion and encourage alternative fuels, and specific tax rewards for fuel-efficient vehicles (Hamilton et al. 2002).

Apart from ratifying the Kyoto Protocol and helping to persuade the United States to do likewise, Australia should get behind and promote the following policies in the international forum:

- The Australian Government should actively engage in discussion on how to achieve deeper cuts in greenhouse gas emissions in the second commitment period of the Kyoto Protocol. This discussion would address the development needs of developing countries as well as acknowledging the need for emissions to be slowed throughout the world.

- The Australian Government can take a positive role in promoting and helping to fund the replacement of oil and coal-based energy technologies with clean, renewable and affordable energy sources in developing countries.

Policy implications for Australia

These policy directions have their national and regional counterparts within Australia:

- The Australian Government's national Mandatory Renewable Energy Target (MRET) is an excellent initiative but it should be strengthened. An increase in the target to 10% renewable energy by 2010 would not only assist in turning the tide in the battle with CO_2 emissions but could also have net benefits for rural and regional Australia.

- The Australian Government could use the MRET model to promote other important clean energy technologies that help to reduce national greenhouse gas levels. For example a national target for the uptake of co-generation for large industrial energy users would provide an incentive for some of the biggest users of coal-fired electricity to install gas-fired generators on site.

- State Governments are responsible for the future direction of Australia's electricity infrastructure and their decisions about the emission levels of new power stations are crucial to national emission levels. State Governments need to ensure that any new fossil fuel power stations must be required to meet best-practice emissions intensity at the level of a combined cycle gas turbine.

- Australia has great potential to improve the end use efficiency of its energy. The Australian Government is best placed to take the lead on this so that standards are nationally consistent. The first step could be the introduction of mandatory energy efficiency standards for all new and existing buildings. Energy performance standards for appliances and equipment should also be tightened and a levy placed on energy-wasting appliances.

- A national carbon tax or national greenhouse gas emissions trading scheme with a tight cap on emissions and auctioning of tradeable permits would be a very positive step to reduce greenhouse emissions using market mechanisms. Reform of the tax system should go even further to include other environmentally motivated reforms associated with water use and quality, solid and industrial wastes, and the use of other natural amenities.

- If transport emissions are to be controlled, the Australian, State and Territory Governments need to substantially increase funding for public transport and rail freight. It is also important that mandatory fuel efficiency standards for new cars and commercial vehicles are introduced.

- The Australian Bureau of Statistics should be funded to develop comprehensive accounts of the environmental cost of producing goods and services, whether for domestic use or export.

- Large-scale land clearing should be brought to an immediate end with regulation and incentives and revegetation programs should be vigorously pursued.

- Care must be exercised that no one single industry or sector bears the costs or socio-economic consequences of climate change or the policies enacted to reduce its impacts.

The Great Barrier Reef

Relative to the Great Barrier Reef, with all three levels of government playing an active role, the main policy recommendation is that Australian authorities must take a comprehensive, rather than piecemeal ('band-aid'), approach to pollution of the Great Barrier Reef lagoon. The threat to the Reef is so severe that an integrated effort is needed to ensure the most efficient reduction of runoff from grazing and cropping lands and urban development. The effort may differ from region to region and within regions to cope with local issues, as acknowledged both by Baker (2003) and the Productivity Commission (PC 2003) – but the whole effort will need to be planned and executed on a comprehensive basis. Practically all leading scientists who have studied the Reef agree that in the absence of rigorous coastal management, inshore reefs and associated inshore ecosystems will become seriously degraded, which will add greatly to the stress from climate change.

While we were first able to discuss the need for a comprehensive approach during the Townsville scenario planning workshop in August 2002, it is important that the panel of Queensland-based scientists reporting on land-sourced pollutants and their impact on water quality on and adjacent to the Great Barrier Reef (Baker 2003) advocated a similar approach. Having found 'that there is clear evidence that land practices are impacting some rivers, estuaries and inshore areas [and that] coral reefs at a number of inshore locations along the coast have been disturbed and have remained in a disturbed state', they conclude (p 20):

> *The Panel believes that an integrated resource management approach to dealing with the issue is the best approach and supports the concepts of risk assessment and target setting. To this end the Panel found that the GBRMPA Action Plan has value on a broad basis, but requires significant refinement, particularly at a sub-catchment level. The future development of water quality targets and risk classification must include community input and is best achieved through existing regional structures using specific local water quality data.*

The Baker report bases its detailed policy recommendations (Baker 2003:17-19), which we generally endorse, on the six principles of 'user pays', 'polluter pays'; 'cost sharing' (based on all direct and indirect costs and benefits arising from the use of natural resources); 'sense of community, ownership and stewardship'; 'adaptive systems' (designing incentive instruments so that better information, as it becomes available, can be easily incorporated into the application of the mechanism); and 'ecosystem approach'.

Our main comments are that polluters may not be able to afford to pay for a resource that must be sustained for future generations, and that the ecosystem approach is fundamental to the other principles, given that 'the underlying causes of a problem and its physical reality need to be understood in a holistic manner' (p 114). This again supports the need to take an integrated policy approach to managing the Great Barrier Reef resource.

The following specific recommendations support the general principle of integrated resource management under climate change:

- The Australian Government's new zoning plan for the Great Barrier Reef Marine Park which was tabled in Parliament on 3rd December 2003 includes a comprehensive and representative network of no-take zones throughout all bioregions of the Marine Park. The zoning plan will enhance the resilience of the reef ecosystem and help reduce biodiversity losses due to global warming. The plan should be brought into effect as soon as possible and should be reviewed and strengthened if the impacts from climate change are worse than envisaged under the mid-range scenarios.

- The Australian and Queensland Governments Reef Water Quality Protection Plan, which aims to halt and reverse the decline in water quality entering the World Heritage Area within 10 years, should be adequately funded by both governments and efficiently implemented to maximise on-the-ground outcomes.

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Appendix A: General Economy

Table A1: Estimated growth in gross regional product at factor cost

Region	$million at 2000-01 prices[1] 1989-90	1994-95	1998-99	Annual growth[2] 1990-95	1995-99
Far North	3,342	4,465	5,637	6.0%	6.0%
Northern	4,179	4,607	5,286	2.0%	3.5%
Mackay	3,952	4,236	4,861	1.4%	3.5%
Fitzroy	4,981	5,582	6,405	2.3%	3.5%
Wide Bay-Burnett	3,167	4,116	4,816	5.4%	4.0%
Brisbane/Gold & Sunshine Coast	35,939	45,417	56,264	4.8%	5.5%
Darling Downs/Outback	6,455	6,773	7,623	1.0%	3.0%
Total Queensland	62,015	75,196	90,892	3.9%	4.9%

[1] Levels for 1989-90 and 1994-95 adjusted to match revised State Product series and estimated regional growth rates 1995-99. Note: GRP growth estimates at constant prices shown in Government Statistician 1998:27 were reduced accordingly.

[2] Growth rates 1995-99 estimated to fit known State Product trend

Source: Government Statistician 1998, OESR 2002a, ABS 2002b (GSP deflator)

Table A2: Employment in base industries (primary and processing) 2000-01

Persons

Base industry group	Far North	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total GBR regions
Sugar cane and processing	2,978	4,144	4,075	12	2,637	13,846
Beef and meat processing	1,025	1,058	1,627	4,436	2,932	11,078
Horticulture and processing	3,315	634	1,191	574	3,599	9,313
Fishing, aquaculture and seafood processing	478	144	89	135	353	1,199
Mining and mineral processing	1,334	2,112	4,418	5,645	789	14,298
Tourism	19,500	7,090	7,580	6,040	7,450	47,660
Total of above	28,630	15,182	18,980	16,842	17,760	97,394
Total employed persons	96,182	83,741	59,604	76,513	80,541	396,581
Above industries ratio of employed persons	29.8%	18.1%	31.8%	22.0%	22.1%	24.6%

Source: PC 2003: Appendix E (Industry analysis by Australian Bureau of Agricultural and Resource Economics (ABARE))

Table A3: Employed persons classified by industry, 1996 Census

Industry	Statistical Division[1]					Total GBR regions
	Far North	Northern	Mackay	Fitzroy	Wide Bay-Burnett	
Agriculture, Forestry and Fishing	8,458	4,961	6,647	5,489	11,201	36,756
Mining	1,764	1,395	5,198	4,810	674	13,841
Manufacturing	7,185	7,238	5,667	7,804	8,280	36,174
Electricity, Gas and Water Supply	582	784	445	1,573	902	4,286
Construction	7,055	4,918	4,448	5,687	5,049	27,157
Wholesale Trade	4,125	3,944	3,294	3,311	3,520	18,194
Retail Trade	13,397	10,888	7,676	10,128	11,353	53,442
Accommodation, Cafes and Restaurants	9,020	3,605	4,738	3,805	3,838	25,006
Transport and Storage	6,551	3,562	4,192	4,501	2,930	21,736
Communication Services	1,154	1,153	625	969	932	4,833
Finance and Insurance	2,055	1,585	1,272	1,509	1,529	7,950
Property and Business Services	7,216	5,611	3,623	5,060	4,729	26,239
Government Administration and Defence	6,274	7,355	1,526	3,025	3,216	21,396
Education	5,898	6,259	3,525	5,988	6,063	27,733
Health and Community Services	8,597	7,391	3,943	6,188	7,459	33,578
Cultural and Recreational Services	2,359	2,199	882	1,042	1,023	7,505
Personal and Other Services	3,395	2,666	1,576	2,358	2,288	12,283
Total specified by industry	95,085	75,514	59,277	73,247	74,986	378,109
Non-classifiable economic units	1,354	980	905	1,050	1,185	5,474
Not stated	2,112	1,581	1,125	1,406	1,897	8,121
Total employed persons[2]	98,551	78,075	61,307	75,703	78,068	391,704

[1] Adjusted for transfer of Bowen from Northern to Mackay between 1996 and 2001

[2] Excluding overseas visitors

Source: ABS 2000

Table A4: Employed persons classified by industry, 2001 Census

Industry	Statistical Division					Total GBR regions
	Far North	Northern	Mackay	Fitzroy	Wide Bay-Burnett	
Agriculture, Forestry and Fishing	8,458	5,032	6,585	6,021	11,625	37,721
Mining	1,095	1,481	4,695	3,670	572	11,513
Manufacturing	6,995	7,738	5,438	8,479	8,730	37,380
Electricity, Gas and Water Supply	735	785	466	1,586	959	4,531
Construction	6,431	5,875	4,242	5,488	5,077	27,113
Wholesale Trade	3,982	3,643	3,476	4,001	3,732	18,834
Retail Trade	14,981	12,786	8,873	11,225	13,241	61,106
Accommodation, Cafes and Restaurants	9,400	4,075	4,339	4,152	4,121	26,087
Transport and Storage	6,566	4,111	3,984	4,617	3,186	22,464
Communication Services	1,007	1,112	563	721	860	4,263
Finance and Insurance	1,821	1,499	1,122	1,344	1,353	7,139
Property and Business Services	7,472	6,240	4,384	5,351	4,660	28,107
Government Administration and Defence	8,091	8,338	1,620	2,800	3,245	24,094
Education	6,901	6,979	3,945	6,599	6,627	31,051
Health and Community Services	8,477	8,369	4,490	6,493	8,416	36,245
Cultural and Recreational Services	2,466	1,884	888	1,219	1,193	7,650
Personal and Other Services	3,553	3,055	1,706	2,589	2,360	13,263
Total specified by industry	98,431	83,002	60,816	76,355	79,957	398,561
Non-classifiable economic units	448	361	317	376	297	1,799
Not stated	2,085	1,452	1,181	1,401	1,773	7,892
Total employed persons[1]	100,964	84,815	62,314	78,132	82,027	408,252

[1] Excluding overseas visitors

Source: ABS 2002a

Table A5: Annual change in employment, 1996-2001

Industry	Statistical Division					Total GBR regions
	Far North	Northern	Mackay	Fitzroy	Wide Bay-Burnett	
Agriculture, Forestry and Fishing	0.0%	0.3%	-0.2%	1.9%	0.7%	0.5%
Mining	-9.1%	1.2%	-2.0%	-5.3%	-3.2%	-3.6%
Manufacturing	-0.5%	1.3%	-0.8%	1.7%	1.1%	0.7%
Electricity, Gas and Water Supply	4.8%	0.0%	0.9%	0.2%	1.2%	1.1%
Construction	-1.8%	3.6%	-0.9%	-0.7%	0.1%	0.0%
Wholesale Trade	-0.7%	-1.6%	1.1%	3.9%	1.2%	0.7%
Retail Trade	2.3%	3.3%	2.9%	2.1%	3.1%	2.7%
Accommodation, Cafes and Restaurants	0.8%	2.5%	-1.7%	1.8%	1.4%	0.9%
Transport and Storage	0.0%	2.9%	-1.0%	0.5%	1.7%	0.7%
Communication Services	-2.7%	-0.7%	-2.1%	-5.7%	-1.6%	-2.5%
Finance and Insurance	-2.4%	-1.1%	-2.5%	-2.3%	-2.4%	-2.1%
Property and Business Services	0.7%	2.1%	3.9%	1.1%	-0.3%	1.4%
Government Administration and Defence	5.2%	2.5%	1.2%	-1.5%	0.2%	2.4%
Education	3.2%	2.2%	2.3%	2.0%	1.8%	2.3%
Health and Community Services	-0.3%	2.5%	2.6%	1.0%	2.4%	1.5%
Cultural and Recreational Services	0.9%	-3.0%	0.1%	3.2%	3.1%	0.4%
Personal and Other Services	0.9%	2.8%	1.6%	1.9%	0.6%	1.5%
Total specified by industry	0.7%	1.9%	0.5%	0.8%	1.3%	1.1%
Non-classifiable economic units	-19.8%	-18.1%	-18.9%	-18.6%	-24.2%	-20.0%
Not stated	-0.3%	-1.7%	1.0%	-0.1%	-1.3%	-0.6%
Total employed persons[1]	0.5%	1.7%	0.3%	0.6%	1.0%	0.8%

[1] Excluding overseas visitors

Source: ABS 2000, 2002a

Table A6: Industry distribution of employed persons, 2001

Industry	Statistical Division					Total GBR regions
	Far North	Northern	Mackay	Fitzroy	Wide Bay-Burnett	
Agriculture, Forestry and Fishing	8.6%	6.1%	10.8%	7.9%	14.5%	9.5%
Mining	1.1%	1.8%	7.7%	4.8%	0.7%	2.9%
Manufacturing	7.1%	9.3%	8.9%	11.1%	10.9%	9.4%
Electricity, Gas and Water Supply	0.7%	0.9%	0.8%	2.1%	1.2%	1.1%
Construction	6.5%	7.1%	7.0%	7.2%	6.3%	6.8%
Wholesale Trade	4.0%	4.4%	5.7%	5.2%	4.7%	4.7%
Retail Trade	15.2%	15.4%	14.6%	14.7%	16.6%	15.3%
Accommodation, Cafes and Restaurants	9.5%	4.9%	7.1%	5.4%	5.2%	6.5%
Transport and Storage	6.7%	5.0%	6.6%	6.0%	4.0%	5.6%
Communication Services	1.0%	1.3%	0.9%	0.9%	1.1%	1.1%
Finance and Insurance	1.9%	1.8%	1.8%	1.8%	1.7%	1.8%
Property and Business Services	7.6%	7.5%	7.2%	7.0%	5.8%	7.1%
Government Administration and Defence	8.2%	10.0%	2.7%	3.7%	4.1%	6.0%
Education	7.0%	8.4%	6.5%	8.6%	8.3%	7.8%
Health and Community Services	8.6%	10.1%	7.4%	8.5%	10.5%	9.1%
Cultural and Recreational Services	2.5%	2.3%	1.5%	1.6%	1.5%	1.9%
Personal and Other Services	3.6%	3.7%	2.8%	3.4%	3.0%	3.3%
Total specified by industry	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

[1] Excluding overseas visitors

Source: ABS 2002a

Table A7: Agricultural production, 1998-99

$million, current prices

Statistical Division	Crops	Livestock production	Livestock disposals	Total
Far North GBR coast	384.2	26.4	1.2	411.8
Far north other	112.7	90.0	56.0	258.7
Total Far North	496.9	116.4	57.2	670.5
Northern GBR coast	381.4	18.3	4.2	403.9
Northern other	1.2	52.5	0.1	53.8
Total Northern	382.6	70.8	4.3	457.7
Mackay GBR coast	373.1	101.9	3.2	478.2
Mackay other	89.7	71.6	3.6	164.9
Total Mackay	462.8	173.5	6.8	643.1
Fitzroy GBR coast	20.3	64.6	9.1	94.0
Fitzroy other	251.4	295.4	3.2	550.0
Total Fitzroy	271.7	360.0	12.3	644.0
Wide Bay-Burnett GBR coast	232.6	14.4	4.1	251.1
Wide Bay-Burnett other	184.9	215.7	66.7	467.3
Total Wide Bay-Burnett	417.5	230.1	70.8	718.4
Total GBR coast	1,391.6	225.6	21.8	1,639.0
GBR regions other	639.9	725.2	129.6	1,494.7
Total GBR regions	2,031.5	950.8	151.4	3,133.7
Total Queensland	3,542.8	2,274.2	567.3	6,384.3

Source: OESR 2002b (from ABS Agriculture (Cat 7113.0), unpublished data)

Table A8: Social indicators, Statistical Divisions 1996

Indicator	Far North	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Queens-land
People aged 0-14	24.0%	23.5%	25.0%	25.1%	23.5%	22.3%
People aged 65+	8.6%	9.5%	8.0%	9.1%	14.0%	11.2%
Born in non-English speaking countries	8.4%	5.4%	3.7%	3.0%	3.6%	7.5%
People of Indigenous origin	13.2%	5.7%	3.2%	4.2%	2.6%	3.0%
Couples with dependent children	39.7%	41.9%	44.6%	43.7%	37.7%	39.8%
One-parent families with dependent children	12.3%	10.5%	8.9%	9.8%	9.7%	10.4%
Lone-person households	22.1%	20.8%	19.7%	20.6%	21.5%	21.7%
16-year olds still at school	75.7%	78.9%	74.4%	76.3%	70.7%	78.4%
People with degrees or higher qualifiactions	6.7%	7.7%	5.4%	6.5%	4.2%	8.6%
Labour force participation rate	67.9%	65.6%	67.3%	64.3%	54.9%	63.2%
Unemployment rate	8.0%	8.4%	7.5%	9.1%	15.1%	9.7%
Weekly household income per capita	$ 294	$ 294	$ 332	$ 292	$ 222	$ 293
Index of relative disadvantage (Australia = 1000)	978	981	984	972	924	988

Source: ABS 1998b

Table A9: Social indicators related to total population, 2001

Local Government Area and Statistical Division	Total persons	Population 15+	Population 65+	Aboriginal and TSI	NESC[1] birthplace	Overseas visitors	Moved last five years[2]
Cook	9,700	77.3%	7.5%	29.4%	3.7%	3.0%	44.7%
Douglas	17,887	84.4%	11.2%	5.5%	7.7%	21.9%	51.3%
Cairns	133,199	79.0%	9.5%	8.3%	8.1%	8.4%	54.2%
Johnstone	19,954	77.4%	14.8%	8.2%	8.3%	2.2%	40.4%
Cardwell	11,443	80.0%	12.9%	6.3%	6.0%	7.1%	45.8%
Other Far North	52,603	75.5%	12.1%	22.2%	6.5%	1.0%	41.8%
Total Far North	244,786	78.5%	10.7%	11.8%	7.4%	7.0%	49.2%
Hinchinbrook	14,611	77.2%	15.9%	17.5%	7.3%	0.6%	30.7%
Townsville	94,739	81.1%	11.2%	4.8%	5.3%	2.2%	56.2%
Thuringowa	51,140	72.5%	5.9%	5.6%	3.3%	0.3%	54.8%
Burdekin	18,486	78.4%	13.9%	4.4%	5.6%	1.4%	35.2%
Other Northern	12,345	75.6%	12.7%	6.7%	2.0%	0.9%	48.7%
Total Northern	191,321	77.9%	10.5%	6.1%	4.7%	1.4%	51.3%
Bowen	13,698	80.8%	16.1%	5.5%	5.2%	1.9%	44.1%
Whitsunday	20,990	84.2%	9.5%	1.2%	5.4%	12.7%	56.2%
Mackay	75,020	77.1%	11.1%	3.7%	3.8%	0.6%	48.6%
Sarina	9,637	75.8%	11.1%	3.9%	2.7%	0.3%	45.8%
Broadsound	6,601	77.4%	4.5%	2.0%	3.1%	0.6%	48.2%
Other Mackay	17,632	74.9%	6.7%	2.1%	2.4%	0.3%	47.8%
Total Mackay	143,578	78.1%	10.5%	3.3%	3.8%	2.4%	48.8%
Livingstone	27,017	78.5%	14.3%	2.8%	3.1%	1.6%	50.1%
Fitzroy	9,553	72.8%	9.3%	3.4%	1.3%	0.2%	39.8%
Rockhampton	58,382	78.8%	13.7%	5.1%	2.5%	0.9%	47.7%
Gladstone	26,835	75.3%	7.9%	3.5%	3.7%	0.4%	51.5%
Calliope	15,091	74.9%	9.3%	2.4%	3.9%	1.5%	50.9%
Other Fitzroy	45,291	75.6%	8.5%	5.4%	2.6%	0.8%	51.5%
Total Fitzroy	182,169	76.8%	11.0%	4.3%	2.8%	0.9%	49.4%
Miriam Vale	4,914	79.6%	11.7%	2.0%	4.5%	2.1%	42.5%
Burnett	23,598	78.0%	14.5%	1.4%	4.6%	1.0%	45.3%
Bundaberg	43,549	78.0%	16.9%	3.2%	3.1%	0.9%	47.1%
Isis	6,045	81.2%	17.5%	1.9%	4.4%	1.5%	39.5%
Hervey Bay	45,959	81.4%	21.1%	2.3%	5.2%	2.5%	51.3%
Maryborough	24,820	78.9%	16.9%	2.5%	2.5%	1.4%	42.6%
Other Wide Bay-Burnett	87,362	77.2%	13.7%	3.9%	3.2%	0.6%	42.2%
Total Wide Bay-Burnett	236,247	78.6%	16.2%	3.0%	3.7%	1.2%	45.2%
Total GBR	998,101	78.0%	12.0%	6.0%	4.6%	2.8%	48.6%
Queensland	3,655,139	78.9%	12.3%	3.1%	7.4%	1.9%	50.5%

[1] Non-English speaking country

[2] Different address five years ago (relative to population aged 5 years and more)

Source: ABS 2002a

Table A10: Other selected social indicators, 2001

LGA and Statistical Division	Completed Year 12[1]	Computer at home	Internet user[2]	Families with dependents[3] Couples	Families with dependents[3] One-parent	Unemploy-ment rate	Participa-tion rate[4]	Tentative index[5]
Cook	31.6%	23.4%	22.7%	40.3%	15.8%	6.5%	68.3%	884
Douglas	44.1%	33.7%	33.8%	33.3%	10.2%	4.7%	66.5%	1,060
Cairns	42.7%	39.9%	38.5%	37.1%	15.0%	7.8%	69.2%	1,004
Johnstone	28.6%	30.5%	23.5%	38.2%	10.4%	7.7%	59.8%	851
Cardwell	33.2%	28.7%	24.0%	37.5%	9.6%	4.6%	63.6%	953
Other Far North	32.8%	28.1%	23.4%	36.8%	13.6%	8.5%	58.9%	840
Total Far North	38.5%	34.8%	32.0%	37.1%	13.8%	7.5%	65.6%	950
Hinchinbrook	26.7%	26.3%	20.0%	37.2%	9.0%	6.2%	53.3%	819
Townsville	45.9%	43.2%	40.2%	36.5%	12.6%	8.8%	65.7%	1,023
Thuringowa	36.5%	44.4%	36.1%	45.6%	12.7%	8.0%	69.7%	1,024
Burdekin	27.4%	32.0%	24.6%	39.0%	7.4%	5.3%	64.2%	920
Other Northern	30.3%	32.1%	25.6%	39.3%	10.9%	7.2%	60.5%	903
Total Northern	39.3%	40.4%	35.0%	39.7%	11.7%	8.0%	65.3%	989
Bowen	24.9%	26.3%	20.8%	35.8%	10.0%	7.3%	58.1%	833
Whitsunday	40.3%	36.9%	35.1%	36.4%	9.9%	6.6%	69.4%	1,060
Mackay	33.1%	40.0%	33.2%	40.9%	11.5%	8.5%	63.8%	943
Sarina	25.4%	34.5%	25.4%	39.4%	10.5%	9.4%	58.2%	870
Broadsound	31.8%	43.1%	31.8%	50.4%	4.2%	2.8%	74.5%	1,153
Other Mackay	30.1%	43.0%	32.3%	48.7%	7.2%	4.2%	71.6%	1,077
Total Mackay	32.3%	38.4%	31.5%	41.2%	10.3%	7.3%	65.0%	969
Livingstone	33.9%	40.8%	34.0%	36.9%	10.8%	8.6%	55.4%	928
Fitzroy	26.1%	40.4%	30.1%	42.9%	11.1%	7.0%	65.3%	935
Rockhampton	35.7%	39.6%	34.3%	35.8%	14.1%	9.3%	61.4%	898
Gladstone	34.1%	43.5%	36.0%	42.1%	12.4%	9.5%	68.3%	979
Calliope	30.4%	45.1%	35.9%	45.7%	8.6%	7.7%	63.9%	1,006
Other Fitzroy	31.5%	38.0%	28.8%	45.4%	8.3%	5.5%	69.0%	1,026
Total Fitzroy	33.2%	40.5%	33.1%	40.5%	11.3%	8.0%	63.7%	957
Miriam Vale	24.0%	30.4%	20.7%	34.3%	9.7%	15.6%	51.9%	748
Burnett	27.1%	38.3%	28.7%	36.2%	8.5%	11.4%	53.4%	855
Bundaberg	26.6%	34.6%	26.8%	33.4%	14.5%	12.6%	54.5%	750
Isis	24.9%	31.2%	22.0%	31.0%	7.6%	11.1%	47.9%	790
Hervey Bay	27.3%	34.4%	26.5%	28.3%	12.6%	15.0%	44.2%	705
Maryborough	26.0%	34.2%	26.2%	32.5%	12.7%	11.6%	53.3%	770
Other Wide Bay-Burnett	25.6%	33.2%	24.0%	35.2%	10.8%	9.6%	56.9%	836
Total Wide Bay-Burnett	26.3%	34.2%	25.6%	33.3%	11.7%	11.6%	52.9%	789
Total GBR	33.8%	37.3%	31.2%	37.8%	11.9%	8.5%	62.0%	925
Queensland	41.2%	42.8%	37.3%	37.4%	11.7%	8.2%	63.1%	987

[1] Relative to population aged 15 years and over
[2] At home, and/or at work, and/or elsewhere
[3] Couple and single-parent families with dependent children and/or students
[4] Total labour force relative to total population aged 15 years and over
[5] Tentative index described in text. Australia = 1,000

Source: ABS 2002a

Appendix B: Tourism

Table B1: Total visitor expenditure in main regions of Queensland

$million at 2000-01 prices

Year	Far North	Northern	Whit-sundays	Mackay	Fitzroy	Bundaberg/ Hervey Bay
1985	612	386	246	174	312	249
1986	844	434	291	206	355	259
1987	824	418	248	208	352	216
1988	947	490	228	300	357	253
1989	879	463	176	344	364	270
1990	1,149	466	233	314	461	399
1991	1,367	446	238	236	470	433
1992	1,411	403	239	236	388	324
1993	1,484	435	309	252	347	283
1994	1,530	505	386	250	362	353
1995	1,664	564	413	298	393	413
1996	1,809	518	361	303	370	425
1997	1,858	536	396	310	383	431
1998	1,888	557	499	306	412	546
1999	1,957	656	550	326	447	564
Trend pa	8.2%	2.7%	6.2%	2.9%	1.2%	6.0%

Year	GBR regions	SEQ	All other	Queens-land	GBR regions	Southeast Queensland
1985	1,979	3,289	429	5,698	34.7%	57.7%
1986	2,389	4,018	502	6,909	34.6%	58.2%
1987	2,265	4,519	537	7,321	30.9%	61.7%
1988	2,576	5,686	661	8,923	28.9%	63.7%
1989	2,496	4,440	658	7,594	32.9%	58.5%
1990	3,021	4,257	539	7,817	38.6%	54.5%
1991	3,189	4,128	567	7,884	40.5%	52.4%
1992	3,002	3,925	528	7,455	40.3%	52.7%
1993	3,110	4,547	447	8,104	38.4%	56.1%
1994	3,386	5,259	465	9,110	37.2%	57.7%
1995	3,744	5,596	492	9,832	38.1%	56.9%
1996	3,786	6,045	499	10,331	36.7%	58.5%
1997	3,914	6,578	570	11,062	35.4%	59.5%
1998	4,208	6,889	659	11,756	35.8%	58.6%
1999	4,500	7,121	727	12,348	36.4%	57.7%
Trend % pa	5.4%	4.4%	1.1%	4.5%		

Note: SEQ consists of Brisbane, Gold Coast and Sunshine Coast tourism regions

Source: OESR 2002a; ABS 2002b

Table B2: Expenditure by tourists in main regions of Queensland

$million at 2000-01 prices

Year	TNQ	Northern	Whit-sundays	Mackay	Fitzroy	Bundaberg Hervey Bay	Total GBR
Tourists (including 'visiting friends and relatives' (VFR))							
1985	492	260	210	118	185	205	1,470
1986	659	294	236	151	213	216	1,769
1987	615	281	197	139	220	171	1,624
1988	758	359	208	201	249	201	1,975
1989	686	314	157	242	242	208	1,849
1990	930	321	213	248	314	306	2,332
1991	1,126	306	220	187	318	336	2,493
1992	1,178	276	221	169	256	262	2,362
1993	1,264	289	285	177	231	238	2,485
1994	1,296	329	352	182	233	290	2,680
1995	1,389	358	367	215	237	329	2,895
1996	1,560	338	323	208	228	346	3,004
1997	1,578	345	356	213	237	346	3,076
1998	1,585	324	441	211	273	441	3,275
1999	1,628	350	483	217	280	447	3,406
Trend pa	9.0%	1.4%	6.7%	2.7%	1.2%	6.0%	5.9%
Stated holiday only (excluding VFR)							
1985	438	214	208	95	133	170	1,258
1986	585	248	234	123	163	178	1,530
1987	534	243	197	109	171	132	1,386
1988	672	305	206	164	189	155	1,692
1989	581	228	156	179	160	164	1,468
1990	825	247	211	187	238	264	1,973
1991	1,013	230	216	127	227	269	2,082
1992	1,067	212	217	120	173	201	1,989
1993	1,136	224	279	125	162	183	2,109
1994	1,148	246	346	135	149	203	2,227
1995	1,211	253	360	162	134	216	2,336
1996	1,365	240	315	153	137	240	2,451
1997	1,378	253	347	161	148	250	2,538
1998	1,406	218	428	142	189	312	2,696
1999	1,458	248	468	143	210	320	2,847
Trend % pa	9.0%	-0.1%	6.5%	1.6%	0.1%	4.6%	5.6%

Source: OESR 2002a; ABS 2002b

Table B3: Spending by people visiting friends and relatives relative to the estimated resident population in each tourism region

Tourism region	Resident persons	VFR 1999 $m	VFR / person
Whitsundays	15,201	14	$ 0.92
Tropical North Queensland	222,451	162	$ 0.73
Sunshine Coast	231,256	163	$ 0.70
Gold Coast	438,420	308	$ 0.70
Mackay	110,766	70	$ 0.63
Outback	73,649	44	$ 0.60
Hervey Bay/Maryborough	139,768	77	$ 0.55
Northern	197,302	97	$ 0.49
Bundaberg	93,219	43	$ 0.46
Darling Downs	201,446	84	$ 0.42
Fitzroy	181,202	67	$ 0.37
Brisbane	1,607,666	576	$ 0.36
Total Queensland	3,512,346	1,705	$ 0.49

Source: OESR 2001

Table B4: Average annual expenditure classified by origin of total visitors

	$million at 2000-01 prices				Ratios			
	Overseas	Interstate	Intrastate	Total	Overseas	Interstate	Intrastate	Total
Tropical North Queensland								
Average 1985-87	91	427	242	760	12.0%	56.1%	31.9%	100.0%
Average 1988-90	274	363	354	992	27.7%	36.6%	35.7%	100.0%
Average 1991-93	489	548	383	1,421	34.4%	38.6%	27.0%	100.0%
Average 1994-96	634	683	351	1,668	38.0%	40.9%	21.0%	100.0%
Average 1997-99	676	799	426	1,901	35.5%	42.0%	22.4%	100.0%
Northern								
Average 1985-87	33	173	207	412	7.9%	41.9%	50.2%	100.0%
Average 1988-90	73	138	262	473	15.5%	29.1%	55.4%	100.0%
Average 1991-93	64	137	227	428	14.9%	32.1%	53.0%	100.0%
Average 1994-96	68	177	284	529	12.8%	33.4%	53.8%	100.0%
Average 1997-99	72	203	308	583	12.3%	34.9%	52.8%	100.0%
Whitsunday								
Average 1985-87	15	202	45	261	5.6%	77.2%	17.2%	100.0%
Average 1988-90	35	136	41	212	16.5%	64.2%	19.3%	100.0%
Average 1991-93	65	151	45	262	24.9%	57.8%	17.3%	100.0%
Average 1994-96	81	221	85	387	20.9%	57.2%	21.9%	100.0%
Average 1997-99	94	282	106	482	19.5%	58.6%	21.9%	100.0%
Mackay								
Average 1985-87	11	81	104	196	5.5%	41.3%	53.1%	100.0%
Average 1988-90	24	85	210	319	7.6%	26.6%	65.8%	100.0%
Average 1991-93	31	60	151	241	12.9%	24.7%	62.4%	100.0%
Average 1994-96	19	102	162	284	6.9%	36.1%	57.0%	100.0%
Average 1997-99	16	126	173	314	5.0%	40.0%	55.0%	100.0%
Fitzroy								
Average 1985-87	26	118	196	340	7.6%	34.8%	57.6%	100.0%
Average 1988-90	44	110	240	394	11.2%	28.0%	60.8%	100.0%
Average 1991-93	33	125	244	402	8.3%	31.1%	60.6%	100.0%
Average 1994-96	28	100	247	375	7.5%	26.6%	66.0%	100.0%
Average 1997-99	41	124	249	414	10.0%	30.0%	60.0%	100.0%
Bundaberg/Hervey Bay/Maryborough								
Average 1985-87	12	114	115	241	4.9%	47.4%	47.7%	100.0%
Average 1988-90	23	115	170	307	7.3%	37.4%	55.2%	100.0%
Average 1991-93	37	116	193	347	10.7%	33.5%	55.8%	100.0%
Average 1994-96	48	141	208	397	12.2%	35.5%	52.3%	100.0%
Average 1997-99	66	141	307	514	12.9%	27.4%	59.7%	100.0%
Total GBR regions								
Average 1985-87	187	1,115	910	2,211	8.4%	50.4%	41.1%	100.0%
Average 1988-90	474	947	1,277	2,698	17.6%	35.1%	47.3%	100.0%
Average 1991-93	720	1,138	1,243	3,100	23.2%	36.7%	40.1%	100.0%
Average 1994-96	878	1,424	1,337	3,639	24.1%	39.1%	36.7%	100.0%
Average 1997-99	965	1,675	1,567	4,207	22.9%	39.8%	37.3%	100.0%
Total Queensland								
Average 1985-87	650	3,592	2,401	6,642	9.8%	54.1%	36.1%	100.0%
Average 1988-90	1,321	3,920	2,870	8,111	16.3%	48.3%	35.4%	100.0%
Average 1991-93	1,663	3,561	2,590	7,814	21.3%	45.6%	33.1%	100.0%
Average 1994-96	2,130	4,570	3,058	9,758	21.8%	46.8%	31.3%	100.0%
Average 1997-99	2,392	5,533	3,797	11,722	20.4%	47.2%	32.4%	100.0%

Source: OESR 2002a; ABS 2002b

Table B5: Share of total GBR region tourist expenditure

Year	TNQ	Northern	Whit-sundays	Mackay	Fitzroy	Bundaberg Hervey Bay	Total GBR
1985	33.5%	17.7%	14.3%	8.1%	12.6%	13.9%	100.0%
1986	37.3%	16.6%	13.3%	8.5%	12.0%	12.2%	100.0%
1987	37.9%	17.3%	12.1%	8.6%	13.6%	10.5%	100.0%
1988	38.4%	18.2%	10.5%	10.2%	12.6%	10.2%	100.0%
1989	37.1%	17.0%	8.5%	13.1%	13.1%	11.3%	100.0%
1990	39.9%	13.8%	9.1%	10.6%	13.5%	13.1%	100.0%
1991	45.2%	12.3%	8.8%	7.5%	12.7%	13.5%	100.0%
1992	49.9%	11.7%	9.4%	7.2%	10.8%	11.1%	100.0%
1993	50.9%	11.6%	11.5%	7.1%	9.3%	9.6%	100.0%
1994	48.3%	12.3%	13.1%	6.8%	8.7%	10.8%	100.0%
1995	48.0%	12.4%	12.7%	7.4%	8.2%	11.4%	100.0%
1996	52.0%	11.3%	10.8%	6.9%	7.6%	11.5%	100.0%
1997	51.3%	11.2%	11.6%	6.9%	7.7%	11.3%	100.0%
1998	48.4%	9.9%	13.5%	6.5%	8.3%	13.5%	100.0%
1999	47.8%	10.3%	14.2%	6.4%	8.2%	13.1%	100.0%

Source: OESR 2002a; ABS 2002b

Table B6: Tourism-employed persons and Tourism GDP, Australia

	1997-98	1998-99	1999-00	2000-01
Total tourism-employed persons (000)	512.9	520.6	534.7	551.0
Total employed persons (000)	8,574.6	8,690.8	8,937.8	9,123.0
Tourism share of total employment	6.0%	6.0%	6.0%	6.0%
Tourism GVA at basic prices ($million)	22,389	23,667	24,819	26,284
Plus: Net taxes on tourism products ($million)	2,785	2,945	3,050	5,529
Equals: Tourism GDP ($million)	25,174	26,613	27,868	31,814
Total GDP ($million)	561,229	591,592	629,212	672,046
Tourism share of total GDP	4.5%	4.5%	4.4%	4.7%
GDP deflator	93.7	94.6	96.0	100.0
Tourism GDP at 2000-01 prices ($million)	26,881	28,125	29,044	31,814
GDP at 2000-01 prices ($million)	599,284	625,196	655,771	672,046
Tourism GDP at 2000-01 prices per person	$ 52,410	$ 54,024	$ 54,319	$ 57,739
GDP at 2000-01 prices per person	$ 69,891	$ 71,938	$ 73,370	$ 73,665
Annual change: tourism GDP per person		3.1%	0.5%	6.3%
Annual change: GDP per person		2.9%	2.0%	0.4%

Note: The 2000-01 Tourism GDP estimates are preliminary.

Source: ABS 2002d

Table B7: Regional and tourism GRP and employment 1998-99

$million in 2000-01 prices	Tourism GRP $m	Total GRP $m	Tourism share	Employment (thousand persons) Tourism FTE	Total region	Tourism share
Far North	870	6,062	14.4%	17.1	105.1	16.3%
Northern	290	5,645	5.1%	5.9	81.9	7.2%
Mackay	314	5,110	6.1%	6.2	53.5	11.6%
Fitzroy	246	6,752	3.6%	4.7	75.1	6.3%
Wide Bay-Burnett	304	5,118	5.9%	6.0	83.5	7.2%
Total Great Barrier Reef	2,024	28,687	7.1%	39.9	399.1	10.0%
Brisbane	1,766	46,612	3.8%	30.2	691.9	4.4%
Gold & Sunshine Coast	2,121	14,180	15.0%	42.2	220.8	19.1%
Inland	381	8,076	4.7%	7.1	99.8	7.1%
Total Queensland	6,292	97,555	6.4%	119.4	1,411.6	8.5%

Source: OESR 2002a

FTE = full-time equivalent

Table B8: Visitor expenditure levels by source of visitor, 1998-99

$million at 2000-01 prices

Region	Residents visiting within region	Visitors from other Queensland regions	Interstate visitors	International visitors	Total visitors	Tourists ratio of total visitors[1]
Tropical North Queensland	226	288	618	869	2,001	84.5%
Northern	146	260	178	75	659	64.0%
Mackay/Whitsundays	135	189	304	111	740	80.4%
Fitzroy	195	190	113	47	545	71.3%
Wide Bay-Burnett	157	297	134	72	660	82.1%
Brisbane	322	873	1,236	1,081	3,512	68.2%
Gold & Sunshine Coast	143	1,642	2,224	871	4,879	89.1%
Inland	230	388	206	37	862	67.0%
Total Queensland	1,553	4,128	5,014	3,163	13,857	79.1%
Proportion of total visitor expenditure						
Tropical North Queensland	11.3%	14.4%	30.9%	43.4%	100.0%	
Northern	22.1%	39.5%	27.0%	11.4%	100.0%	
Mackay/Whitsundays	18.3%	25.6%	41.1%	15.0%	100.0%	
Fitzroy	35.7%	34.9%	20.8%	8.6%	100.0%	
Wide Bay-Burnett	23.8%	45.0%	20.3%	10.9%	100.0%	
Brisbane	9.2%	24.9%	35.2%	30.8%	100.0%	
Gold & Sunshine Coast	2.9%	33.7%	45.6%	17.9%	100.0%	
Inland	26.7%	45.0%	23.9%	4.3%	100.0%	
Total Queensland	11.2%	29.8%	36.2%	22.8%	100.0%	

[1] Tourists are defined as holiday-makers and visiting friends and relatives. Non-tourists are on business trips and other purposes. The ratio includes an allowance for residents' expenditure before or after travelling from their region.

Source: OESR 2002a

Table B9: Visitors counted in 1996 and 2001 Census

	Far North Queensland			Northern		
	1996 Census	2001 Census	Annual change	1996 Census	2001 Census	Annual change
Counted at home/from same local area	194,525	203,054	0.9%	165,747	175,944	1.2%
Visitors from rest of Queensland	12,654	11,110	-2.6%	8,041	8,005	-0.1%
Interstate visitors	14,322	13,487	-1.2%	4,339	4,718	1.7%
Overseas visitors	12,347	17,135	6.8%	1,638	2,654	10.1%
Total persons counted	233,848	244,786	0.9%	179,765	191,321	1.3%

	Whitsundays			Mackay excluding Whitsundays		
	1996 Census	2001 Census	Annual change	1996 Census	2001 Census	Annual change
Counted at home/from same local area	25,091	25,918	0.7%	98,901	100,835	0.4%
Visitors from rest of Queensland	2,381	2,293	-0.8%	4,866	4,857	0.0%
Interstate visitors	3,497	3,548	0.3%	2,799	2,627	-1.3%
Overseas visitors	1,723	2,929	11.2%	514	571	2.1%
Total persons counted	32,692	34,688	1.2%	107,080	108,890	0.3%

	Fitzroy			Wide Bay-Burnett		
	1996 Census	2001 Census	Annual change	1996 Census	2001 Census	Annual change
Counted at home/from same local area	165,336	167,753	0.3%	209,129	218,456	0.9%
Visitors from rest of Queensland	8,499	8,385	-0.3%	8,130	8,181	0.1%
Interstate visitors	4,948	4,360	-2.5%	7,662	6,805	-2.3%
Overseas visitors	1,412	1,669	3.4%	1,659	2,805	11.1%
Total persons counted	180,195	182,167	0.2%	226,580	236,247	0.8%

	Total GBR regions			Rest of Queensland		
	1996 Census	2001 Census	Annual change	1996 Census	2001 Census	Annual change
Counted at home/from same local area	858,729	891,960	0.8%	2,249,734	2,487,100	2.0%
Visitors from rest of Queensland	44,571	42,831	-0.8%	67,805	69,490	0.5%
Interstate visitors	37,567	35,545	-1.1%	60,780	58,711	-0.7%
Overseas visitors	19,293	27,763	7.6%	30,371	41,737	6.6%
Total persons counted	960,160	998,099	0.8%	2,408,690	2,657,038	2.0%

Source: ABS 2000 and ABS 2002a

Table B10: Marker tourism indicator in coastal local government areas, 1996 and 2001

Marker: Ratio of persons employed in accommodation, cafés and restaurants ('hospitality jobs') to total employed labour force[1]

Local Government Area and Statistical Division	Number of people in hospitality jobs			Ratio of hospitality jobs to total employed persons	
	1996 Census	2001 Census	Annual change	1996	2001
Cook	181	280	9.1%	6.6%	6.9%
Douglas	1,409	1,455	0.6%	23.5%	22.0%
Cairns	5,794	5,865	0.2%	10.4%	10.4%
Johnstone	355	331	-1.4%	4.5%	4.2%
Cardwell	376	452	3.8%	8.3%	9.5%
Inland Far North Queensland	905	829	-1.7%	4.6%	5.4%
Far North Queensland	**9,020**	**9,400**	**0.8%**	**9.4%**	**9.5%**
Hinchinbrook	209	195	-1.4%	3.5%	3.7%
Townsville/Thuringowa	2,944	3,454	3.2%	5.1%	5.3%
Burdekin	240	204	-3.2%	2.8%	2.5%
Inland Northern	215	222	0.6%	4.6%	4.6%
Total Northern	**3,608**	**4,075**	**2.5%**	**4.7%**	**4.9%**
Bowen	256	261	0.4%	4.4%	4.8%
Whitsunday	2,068	1,761	-3.2%	24.5%	19.8%
Mackay	1,713	1,652	-0.7%	5.7%	5.2%
Sarina	154	176	2.7%	4.3%	4.9%
Broadsound	145	109	-5.5%	4.1%	3.3%
Inland Mackay/Whitsundays	402	380	-1.1%	4.6%	4.6%
Total Mackay/Whitsundays	**4,738**	**4,339**	**-1.7%**	**7.9%**	**7.1%**
Livingstone	830	869	0.9%	9.3%	8.7%
Rockhampton	1,237	1,353	1.8%	5.3%	5.7%
Fitzroy	165	152	-1.6%	4.3%	3.8%
Gladstone	463	543	3.2%	3.9%	4.6%
Calliope	261	338	5.3%	4.5%	5.4%
Inland Fitzroy	849	897	1.1%	4.2%	4.3%
Total Fitzroy	**3,805**	**4,152**	**1.8%**	**5.1%**	**5.4%**
Miriam Vale	87	135	9.2%	6.9%	8.9%
Burnett	355	355	0.0%	4.8%	4.3%
Bundaberg	722	739	0.5%	4.8%	4.9%
Isis	86	94	1.8%	4.6%	5.0%
Hervey Bay	1,015	1,184	3.1%	8.7%	9.3%
Maryborough	499	439	-2.5%	5.8%	5.2%
Inland & southern Wide Bay-Burnett	1,074	1,175	1.8%	3.5%	3.6%
Total Wide Bay Burnett	**3,838**	**4,121**	**1.4%**	**5.0%**	**5.1%**

[1] Marker industry termed 'hospitality' for short. Total employed labour force was adjusted for industry not statec

Source: ABS 2000 and 2000a

Table B11: Hotels, motels and serviced apartments, 1999-2002

	1999	2000	2001	2002
Cairns City				
Average room occupancy rate	68.4%	69.8%	71.3%	68.6%
Average room rate at 2000-01 prices	$ 110.17	$ 106.12	$ 97.29	$ 103.54
Average length of stay in days			3.30	3.24
Cairns Beaches				
Average room occupancy rate	63.4%	62.5%	58.5%	63.0%
Average room rate at 2000-01 prices	$ 114.75	$ 108.42	$ 104.23	$ 93.47
Average length of stay in days			5.63	5.95
Port Douglas				
Average room occupancy rate	68.7%	56.3%	49.9%	50.0%
Average room rate at 2000-01 prices	$ 137.04	$ 143.41	$ 136.81	$ 133.11
Average length of stay in days			7.06	6.46
Cairns City 3-star				
Average room occupancy rate			67.4%	61.9%
Average room rate at 2000-01 prices			$ 78.58	$ 72.36
Average length of stay in days			3.89	3.18
Cairns City 4-star				
Average room occupancy rate			73.0%	68.7%
Average room rate at 2000-01 prices			$ 98.14	$ 107.36
Average length of stay in days			3.79	3.68
Cairns City 5-star				
Average room occupancy rate			76.3%	78.4%
Average room rate at 2000-01 prices			$ 153.94	$ 152.47
Average length of stay in days			2.77	
Townsville				
Average room occupancy rate	68.5%	63.8%	62.7%	60.5%
Average room rate at 2000-01 prices	$ 83.89	$ 77.25	$ 80.88	$ 78.08
Average length of stay in days			2.54	2.34
Townsville 3-star				
Average room occupancy rate		64.8%	64.3%	63.0%
Average room rate at 2000-01 prices		$ 74.92	$ 73.50	$ 69.65
Average length of stay in days		2.01	2.05	1.97
Townsville 4-star				
Average room occupancy rate		57.5%	61.4%	59.3%
Average room rate at 2000-01 prices		$ 88.26	$ 90.87	$ 87.46
Average length of stay in days		3.30	3.04	2.59
Magnetic Island				
Average room occupancy rate		46.0%	34.3%	
Average room rate at 2000-01 prices		$ 64.70	$ 72.01	
Average length of stay in days			2.01	
Whitsundays Mainland				
Average room occupancy rate			57.6%	60.4%
Average room rate at 2000-01 prices			$ 91.21	$ 104.08
Average length of stay in days			2.24	2.56
Whitsundays Islands				
Average room occupancy rate			57.1%	52.8%
Average room rate at 2000-01 prices			$ 196.97	$ 182.48
Average length of stay in days			3.80	3.55

Note: Some missing monthly values have been estimated, and October-December 2002 estimated

Source: OESR 2000-02

Table B12: Other tourism activity indicators, 1999-2002

	1999	2000	2001	2002
Cairns to Port Douglas, proportion of maximum capacity:				
All tours and attractions	44.9%	47.9%	52.4%	51.0%
Reef-based tours and cruises	50.3%	48.7%	52.0%	49.0%
Major tourist attractions		54.0%	55.9%	54.3%
Major reef-based tours and cruises		53.0%	54.3%	51.0%
Bareboats, Whitsundays				
Average boat utilisation rate				44.1%
Average boat rate per night				$ 468.25
Total number of passengers				42,381
Crewed charter boats, Whitsundays				
Average berth utilisation rate				77.2%
Average bearh rate per night				$ 204.35
Total number of passengers				53,579

Note: Some missing monthly values have been estimated, and October-December 2002 estimated

Source: OESR 2000-02

Table B13: Accommodation establishments: Total guest nights 1997 - 2001-02

Thousand

Year	TNQ	Northern[1]	Whit-sundays[1]	Mackay	Fitzroy	Bundaberg/ Hervey Bay	Total	GBR[2]
1997	4,138	836	1,128	647	1,058	740	7,807	1,237
1998	4,119	867	1,096	611	1,027	782	7,720	1,273
1999	4,405	892	1,117	621	1,064	818	8,100	1,306
2000	4,384	820	1,069	573	1,051	775	7,896	1,231
2001	4,391	823	1,025	598	1,130	741	7,967	1,157
Change on previous year								
1998	-0.4%	3.7%	-2.9%	-5.6%	-3.0%	5.7%	-1.1%	2.9%
1999	6.9%	2.9%	2.0%	1.7%	3.6%	4.7%	4.9%	2.6%
2000	-0.5%	-8.0%	-4.4%	-7.7%	-1.3%	-5.4%	-2.5%	-5.8%
2001	0.2%	0.3%	-4.1%	4.4%	7.6%	-4.4%	0.9%	-6.0%
Year ended June								
2001	4,433	806	1,030	597	1,073	709	7,939	1,170
2002	4,362	824	984	607	1,136	783	7,913	1,182
Change	-1.6%	2.3%	-4.4%	1.7%	5.8%	10.5%	-0.3%	1.0%

[1] Whitsundays excluding and Northern including Bowen (transferred to Whitsundays Tourist Region in 2002)
[2] GBR covers island resorts from Lizard (N) to Lady Elliot (S). Also included in their respective RTOs.
1997 estimated from known statistics on room nights, assuming same ratio for each quarter as in 1998.

Table B14: Average employment in accommodation establishments, 1997 - 2001-02

Year	TNQ	Northern[1]	Whit-sundays[1]	Mackay	Fitzroy	Bundaberg/ Hervey Bay	Total	GBR[2]
1997	5,468	1,323	2,036	970	1,627	877	11,423	2,660
1998	5,370	1,451	2,074	914	1,580	890	11,388	2,676
1999	5,237	1,492	2,048	960	1,646	929	11,382	2,719
2000	5,312	1,481	1,963	941	1,615	909	11,311	2,511
2001	5,020	1,373	1,973	933	1,621	933	10,920	2,507
Change on previous year								
1998	-1.8%	9.7%	1.9%	-5.8%	-2.9%	1.5%	-0.3%	0.6%
1999	-2.5%	2.8%	-1.3%	5.1%	4.2%	4.4%	-0.1%	1.6%
2000	1.4%	-0.7%	-4.2%	-2.0%	-1.9%	-2.2%	-0.6%	-7.6%
2001	-5.5%	-7.3%	0.5%	-0.8%	0.3%	2.7%	-3.5%	-0.2%
Year ended June								
2001	5,163	1,435	1,903	947	1,615	906	11,062	2,437
2002	5,012	1,355	2,123	890	1,584	960	10,963	2,664
Change	-2.9%	-5.6%	11.6%	-6.0%	-1.9%	5.9%	-0.9%	9.3%

[1] Whitsundays excluding and Northern including Bowen (transferred to Whitsundays Tourist Region in 2002)

[2] GBR covers island resorts from Lizard (N) to Lady Elliot (S). Also included in their respective RTOs.

Source: ABS 1998-2002

Table B15: Takings by accommodation establishments, 1997 - 2001-02

$miilion at 2000-01 prices

Year	TNQ	Northern[1]	Whit-sundays[1]	Mackay	Fitzroy	Bundaberg/ Hervey Bay	Total	GBR[2]
1997	270.6	41.4	75.5	28.1	51.0	28.3	494.9	106.6
1998	255.0	42.9	77.7	25.5	50.0	30.0	481.1	109.4
1999	259.4	45.3	81.2	26.4	51.2	31.9	495.4	112.5
2000	264.0	44.0	84.2	25.2	52.6	31.9	501.9	113.2
2001	269.8	43.4	82.4	25.9	55.8	30.7	507.9	109.2
Change on previous year								
1998	-5.7%	3.5%	2.9%	-9.3%	-2.0%	6.0%	-2.8%	2.6%
1999	1.7%	5.6%	4.5%	3.6%	2.6%	6.3%	3.0%	2.8%
2000	1.8%	-2.9%	3.7%	-4.6%	2.6%	0.2%	1.3%	0.6%
2001	2.2%	-1.4%	-2.1%	2.7%	6.1%	-3.9%	1.2%	-3.5%
Year ended June								
2001	273.2	43.5	86.1	25.6	54.7	30.9	514.0	112.9
2002	266.9	42.7	80.2	26.2	54.8	31.5	502.3	109.7
Change	-2.3%	-1.8%	-6.9%	2.3%	0.2%	1.9%	-2.3%	-2.8%

[1] Whitsundays excluding and Northern including Bowen (transferred to Whitsundays Tourist Region in 2002)

[2] GBR covers island resorts from Lizard (N) to Lady Elliot (S). Also included in their respective RTOs.
Quarterly data adjusted by quarterly Households implicit deflator (National Accounts)

Source: ABS 1998-2002

Table B16: Accommodation establishments: Average takings per guest night

At 2000-01 prices

Year	TNQ	Northern[1]	Whit-sundays[1]	Mackay	Fitzroy	Bundaberg/ Hervey Bay	Total	GBR[2]
1997	$ 65.39	$ 49.53	$ 66.91	$ 43.48	$ 48.18	$ 38.23	$ 63.39	$ 86.16
1998	$ 61.92	$ 49.47	$ 70.89	$ 41.78	$ 48.65	$ 38.33	$ 62.32	$ 85.93
1999	$ 58.88	$ 50.80	$ 72.64	$ 42.57	$ 48.16	$ 38.94	$ 61.16	$ 86.15
2000	$ 60.24	$ 53.63	$ 78.75	$ 44.01	$ 50.03	$ 41.23	$ 63.56	$ 91.94
2001	$ 61.43	$ 52.71	$ 80.34	$ 43.31	$ 49.34	$ 41.44	$ 63.74	$ 94.37
Change on previous year								
1998	-5.3%	-0.1%	6.0%	-3.9%	1.0%	0.3%	-1.7%	-0.3%
1999	-4.9%	2.7%	2.5%	1.9%	-1.0%	1.6%	-1.9%	0.2%
2000	2.3%	5.6%	8.4%	3.4%	3.9%	5.9%	3.9%	6.7%
2001	2.0%	-1.7%	2.0%	-1.6%	-1.4%	0.5%	0.3%	2.6%
Year ended June								
2001	$ 61.63	$ 53.97	$ 83.64	$ 42.94	$ 50.96	$ 43.62	$ 64.75	$ 96.47
2002	$ 61.19	$ 51.79	$ 81.44	$ 43.20	$ 48.24	$ 40.22	$ 63.47	$ 92.87
Change	-0.7%	-4.0%	-2.6%	0.6%	-5.3%	-7.8%	-2.0%	-3.7%

[1] Whitsundays excluding and Northern including Bowen (transferred to Whitsundays Tourist Region in 2002)

[2] GBR covers island resorts from Lizard (N) to Lady Elliot (S). Also included in their respective RTOs.

1997 estimated from known statistics on room nights, assuming same ratio for each quarter as in 1998.

Source: ABS 1998-2002

Table B17: Segmentation of Queensland visitor statistics for 1994-95

	Main region[1]		
	FNQ	GSC	Dispersed
Intrastate visitors			
Active boating/beach fishing		26.7%	
Queensland friends			24.5%
Fixed site, low activity beach holiday		24.0%	
Queensland natural environment with reef interest	14.1%		
Warm weather, general sightseeing, touring			10.7%
Interstate visitors			
Queensland friends			33.0%
Developed facilities, beaches, nightlife		20.0%	
Queensland natural environment with reef interest	19.0%		
Beaches, warm weather, fishing/boating		15.0%	
Family-oriented theme parks and beaches		13.0%	
International visitors			
Developed facilities, weather, beaches		30.0%	
Queensland reef	26.0%		
Queensland friends			21.0%
Highly active, do everything	16.0%		
Queensland environment and reef	7.0%		

[1] FNQ = Far North Queensland (Tropical North Queensland). GSC = Gold and Sunshine Coasts

Source: Pearce, Green and Moscardo 1997

Table B18: Estimated reef-interested tourism, 1999

Type of tourist	TNQ	Northern	Whit-sundays	Mackay	Fitzroy	Wide Bay-Burnett	Total GBR
Estimated number of tourists interested in Reef (thousand)							
Intrastate	394	335	107	54	268	182	1,340
Interstate	369	113	157	114	92	77	922
Inbound	617	97	146	31	83	72	1,046
Total	1,380	545	410	199	443	331	3,308
Estimated total number of tourists (thousand)							
Intrastate	496	570	185	316	534	1,131	3,232
Interstate	403	164	202	153	159	267	1,348
Inbound	664	120	194	42	103	197	1,319
Total	1,563	854	581	511	796	1,595	5,899
Estimated ratio of reef-interested to total tourists							
Intrastate	79.4%	58.8%	57.8%	17.1%	50.2%	16.1%	41.5%
Interstate	91.6%	68.9%	77.7%	74.5%	57.9%	28.8%	68.4%
Inbound	93.0%	80.9%	75.2%	74.6%	80.5%	36.6%	79.3%
Total	88.3%	63.8%	70.5%	39.0%	55.6%	20.8%	56.1%
Average length of stay (days) - TQ Fact Sheets - Whitsundays based on total visitors							
Intrastate	4.1	4.1	3.6	3.4	3.6	3.4	3.7
Interstate	9.2	8.0	6.6	5.1	6.5	7.9	7.7
Inbound	6.6	5.0	4.9	3.4	2.9	4.5	5.5
Total	6.2	4.9	5.0	3.7	3.9	4.0	4.8
Thousand visitor days, reef-interested tourists							
Intrastate	1,619	1,383	386	184	962	611	5,146
Interstate	3,399	902	1,029	576	601	604	7,111
Inbound	4,059	487	717	104	243	326	5,936
Total	9,077	2,772	2,132	865	1,807	1,542	18,194
Thousand visitor days, all tourists							
Intrastate	2,038	2,353	667	1,079	1,918	3,796	11,851
Interstate	3,712	1,309	1,323	774	1,039	2,096	10,253
Inbound	4,366	602	954	140	302	892	7,255
Total	10,116	4,264	2,945	1,992	3,259	6,784	29,360
Estimated ratio of visitor nights for reef-interested to total tourists							
Intrastate	79.4%	58.8%	57.8%	17.1%	50.2%	16.1%	43.4%
Interstate	91.6%	68.9%	77.7%	74.5%	57.9%	28.8%	69.4%
Inbound	93.0%	80.9%	75.2%	74.6%	80.5%	36.6%	81.8%
Total	89.7%	65.0%	72.4%	43.4%	55.4%	22.7%	62.0%
Total tourist expenditure ($million at 2000-01 prices)							
Total	1,628	350	483	217	280	447	3,406
Estimated reef	1,461	227	349	94	155	102	2,389
Region ratio	89.7%	65.0%	72.4%	43.4%	55.4%	22.7%	70.2%
Ratio total State	15.9%	2.5%	3.8%	1.0%	1.7%	1.1%	26.1%
Total regional and tourism GRP ($million at 2000-01 prices)							
Total GRP	6,308	5,874	See Mackay	5,316	7,026	5,326	29,850
Tourism GRP	905	302		327	256	316	2,106
Estimated reef	812	196		207	142	72	1,429

Source: Derived from Pearce et al (1997), TQ 2002, OESR 2001

Appendix C: Commercial fisheries

Table C1: Commercial fisheries catch in Great Barrier Reef Marine Park, 1991-97

Species name	1991	1992	1993	1994	1995	1996	1997
Tonnage							
Prawn	5,134	4,070	5,107	4,560	5,803	6,478	5,444
Scallop	724	741	1,763	1,074	1,519	528	797
Coral trout	1,417	1,469	1,274	1,163	1,372	1,647	1,352
Crab	579	827	1,336	2,002	1,512	1,869	1,958
Lobsters	388	518	642	584	732	631	692
Mackerel - Spanish	465	415	442	449	344	454	655
Red throat emperor	513	545	544	545	471	572	759
Shark	143	161	196	219	267	248	309
Barramundi	208	133	167	140	135	128	152
All other	492	455	380	436	496	479	532
Total	**10,063**	**9,334**	**11,851**	**11,172**	**12,651**	**13,034**	**12,650**
Gross value of production ($million, current values)							
Prawn	62.8	51.1	65.8	58.1	75.4	82.5	68.1
Scallop	14.5	14.8	35.2	21.3	30.3	10.4	15.8
Coral trout	14.2	14.7	12.7	11.6	13.7	16.5	13.5
Crab	4.0	5.1	7.0	9.3	7.8	8.8	9.4
Lobsters	4.7	6.2	7.7	7.0	8.9	7.6	8.3
Mackerel - Spanish	3.3	2.9	3.1	3.1	2.4	3.2	4.6
Red throat emperor	2.6	2.7	2.7	2.7	2.4	2.9	3.8
Shark	0.9	1.0	1.2	1.3	1.6	1.5	1.9
Barramundi	1.5	0.9	1.2	1.0	0.9	0.9	1.1
All other	6.2	5.3	5.1	5.1	6.0	7.2	9.7
Total	**114.5**	**104.7**	**141.7**	**120.6**	**149.4**	**141.5**	**136.2**
Unit value per kg							
Prawn	$ 12.24	$ 12.55	$ 12.88	$ 12.73	$ 13.00	$ 12.74	$ 12.50
Scallop	$ 20.00	$ 19.95	$ 19.95	$ 19.86	$ 19.94	$ 19.69	$ 19.85
Coral trout	$ 10.00	$ 10.00	$ 10.00	$ 10.00	$ 10.00	$ 10.00	$ 10.00
Crab	$ 6.98	$ 6.12	$ 5.25	$ 4.67	$ 5.16	$ 4.73	$ 4.82
Lobsters	$ 12.01	$ 12.00	$ 12.01	$ 12.02	$ 12.14	$ 12.00	$ 12.00
Mackerel - Spanish	$ 7.00	$ 7.01	$ 7.00	$ 7.00	$ 7.00	$ 7.00	$ 7.00
Red throat emperor	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
Shark	$ 6.00	$ 6.00	$ 6.00	$ 6.00	$ 6.01	$ 6.01	$ 6.00
Barramundi	$ 6.99	$ 6.99	$ 6.99	$ 6.99	$ 6.98	$ 6.98	$ 7.01
All other	$ 12.53	$ 11.74	$ 13.49	$ 11.64	$ 12.12	$ 15.04	$ 18.29
Total	**$ 11.38**	**$ 11.22**	**$ 11.96**	**$ 10.80**	**$ 11.81**	**$ 10.85**	**$ 10.77**

Note: GBRMPA advised that recent catch data are confidential. See Tables C2 to C7 for updates.

Source: KPMG 2000 from records by Queensland Fisheries Management Authority (QFMA) analysed by the Fisheries Branch of the Department of Primary Industries.

Table C2: Annual commercial fisheries harvest on East Queensland Coast

Tonnes - average 1998-2000

Region (SD)	Trawl	Line	Net	Spanner	Pot	Total	Ratio
Far North Queensland	3,580	1,430	430	-	100	5,540	23%
Northern	1,340	950	510	-	120	2,920	12%
Mackay	540	1,200	280	-	20	2,040	8%
Fitzroy	1,280	710	240	360	240	2,830	12%
Wide Bay-Burnett	1,240	190	1,020	910	190	3,550	15%
Total GBR regions	7,980	4,480	2,480	1,270	670	16,880	70%
Brisbane and Moreton	3,270	150	2,490	750	550	7,210	30%
Total East Coast	11,250	4,630	4,970	2,020	1,220	24,090	100%
Great Barrier Reef proportion	71%	97%	50%	63%	55%	70%	

Locations (north to south) and approximate tonnages

Far North Queensland:	
Cape York	190
Orford Bay	340
Shelburne Bay	210
Temple Bay	230
Lloyd Bay	370
Cape Sidmouth	210
Roberts Point	410
Princess Charlotte Bay	670
Cape Bedford	490
Cooktown	240
Bloomfield	190
Cape Tribulation	310
Cairns	370
Babinda	220
Mission Beach	420
Cardwell	670
Northern:	
Ingham	750
Townsville	1,210
Burdekin	970
Mackay:	
Bowen	450
Repulse Bay	610
Mackay	550
Notch Point	420
Fitzroy:	
Shoalwater Bay	540
Byfield	570
Rockhampton	670
Gladstone	1,060
Wide Bay-Burnett:	
Town of 1770	1,010
Bundaberg	1,430
Hervey Bay	1,110
Brisbane and Moreton:	
Tin Can Bay	800
Noosa	900
Mooloolaba	1,290
Moreton Bay	2,990
Southport	820
Coolangatta	400

Source: Williams et al. 2002:2 (numbers read off graph; estimates rounded to reflect this) 7,200

Table C3: Annual commercial trawl fisheries harvest on East Queensland Coast

Tonnes - average 1998-2000

Region (SD)	Prawn	Whiting	Scallop	Bugs	Other	BS crabs	Total	Ratio
Far North Queensland	3,400	-	-	60	90	-	3,550	32%
Northern	940	-	130	210	40	-	1,320	12%
Mackay	400	-	10	100	30	-	540	5%
Fitzroy	770	-	380	100	30	20	1,300	12%
Wide Bay-Burnett	380	230	380	40	60	140	1,230	11%
Total GBR regions	5,890	230	900	510	250	160	7,940	71%
Brisbane and Moreton	2,060	800	70	30	240	70	3,270	29%
Total East Coast	7,950	1,030	970	540	490	230	11,210	100%
Great Barrier Reef proportion	74%	22%	93%	94%	51%	70%	71%	

Source: Williams and Dredge (2002).

Table C4: Annual commercial line fisheries harvest on East Queensland Coast

Tonnes - average 1998-2000

Region (SD)	Coral trout	Spanish mackerel	Red throat emperor	Other species	Total	Ratio
Far North Queensland	560	310	70	550	1,490	31%
Northern	310	180	220	250	960	20%
Mackay	540	50	240	360	1,190	25%
Fitzroy	90	60	90	480	720	15%
Wide Bay-Burnett	-	50	10	130	200	4%
Total GBR regions	1,500	650	630	1,770	4,560	96%
Brisbane and Moreton	-	30	-	150	180	4%
Total East Coast	1,500	680	630	1,920	4,740	100%
Great Barrier Reef proportion	100%	96%	100%	92%	96%	

Source: Williams (2002b).

Table C5: Species harvested in coral reef commercial reef fishery
Tonnes

Year	Coral trout	Red throat emperor	Spanish mackerel	All other	Total
1988	817	369	430	755	1,885
1989	925	414	592	902	2,371
1990	1,244	474	562	753	2,833
1991	1,426	508	464	646	3,033
1992	1,470	544	430	613	3,044
1993	1,298	551	456	686	3,057
1994	1,218	557	464	944	2,991
1995	1,435	489	367	1,517	3,183
1996	1,672	578	483	1,535	3,808
1997	1,387	774	673	1,641	4,268
1998	1,446	633	585	1,680	4,475
1999	1,442	617	709	1,327	4,344
2000	1,528	631	527 -	2,686	4,095

Source: Samoilys et al. (2002)

Table C6: Annual commercial inshore fisheries harvest on East Queensland Coast
Tonnes - average 1998-2000

Region (SD)	Net	Pot	Total	Ratio
Far North Queensland	310	130	440	9%
Northern	480	130	610	12%
Mackay	310	50	360	7%
Fitzroy	120	60	180	4%
Wide Bay-Burnett	990	50	1,040	20%
Total GBR regions	2,210	420	2,630	52%
Brisbane and Moreton	2,430	30	2,460	48%
Total East Coast	4,640	450	5,090	100%
Great Barrier Reef proportion	48%	93%	52%	

Source: Williams et al. (2002).

Table C7: Northern regions inshore commercial fishery

Tonnes

Year	Mud crab	Shark	Barra-mundi	Mackarel	Thread-fins	Other	Total
1989	238	176	152	150	140	268	1,124
1990	295	117	150	197	140	328	1,227
1991	271	130	209	70	186	356	1,222
1992	274	151	134	98	145	305	1,107
1993	284	185	16	93	163	410	1,151
1994	295	209	142	58	165	330	1,199
1995	274	233	136	71	140	413	1,267
1996	290	220	128	89	139	409	1,275
1997	333	302	152	197	157	432	1,573
1998	478	323	176	133	123	375	1,608
1999	545	350	199	101	150	380	1,725
2000	646	465	214	180	155	399	2,059

Source: Williams et al. (2002) (Northern inshore: Cape York to Town of 1770)

Table C8: Home Port of Operators Fishing the Great Barrier Reef region

	Fishing adjacent to Statistical Division				
Town resource centre (TCR)	**FNQ**	**Northern**	**Mackay**	**Fitzroy/WBB**	**Total GBR**
Cooktown					
Port Douglas	a				
Cairns	26.5%	c	d	e	10.6%
Innisfail	17.5%	9.1%		d	8.3%
Lucinda	d	6.4%	c		
Townsville	14.3%	23.6%	9.8%	c	9.9%
Ayr					
Bowen		10.0%	9.0%		b
Airlie Beach			b		
Mackay		7.3%	15.4%		6.9%
Yeppoon			8.5%	11.9%	6.3%
Gladstone		a	13.2%	17.4%	9.3%
Bundaberg	8.1%	10.5%	12.0%	35.6%	16.8%
Hervey Bay		e	6.4%	7.1%	d
Maryborough			e		
Total identified GBR	66.4%	66.9%	74.3%	72.0%	68.1%
Tin Can Bay	b		a	a	e
Mooloolaba	e	b	5.1%	5.5%	c
Brisbane	c	d	5.6%	5.9%	a
Southport		5.5%	6.0%	b	
Karumba					
Weipa					
Thursday Is					
Outside TRC/ns					
Total identified non-GBR	0.0%	5.5%	16.7%	11.4%	0.0%
Grand total identified	66.4%	72.4%	91.0%	83.4%	68.1%

Source: Fenton, Marshall and Edgar 2002.

Table C9: Characteristics of commercial fishers of the Great Barrier Reef area

	Fishing adjacent to:			
	FNQ	Northern	Mackay	Fitzroy/WBB
Proportion of total sample				
Trawlers	72%	62%	64%	59%
Line fishers	39%	43%	47%	43%
Crabbers	10%	18%	16%	22%
Netters	11%	20%	19%	21%
Operator details				
Mean age	44.4	44.4	43.8	44.3
Males	98.2%	98.2%	98.7%	98.4%
Mean years residence in home town	20.1	22.0	22.4	21.6
Mean years in fishing industry	21.8	21.2	21.1	21.1
Mean hours per week worked	77.4	78.0	76.2	72.8
Moved town to retain employment	32.1%	31.1%	31.7%	35.0%
Currently employed in other industry	13.2%	19.2%	15.8%	15.9%
Previously employed in other industry	65.8%	75.6%	73.4%	71.9%
Active fishing group member	48.9%	45.1%	45.0%	41.8%
Competed trade/TAFE certificate	37.2%	41.7%	38.5%	41.6%
Completed industry/business course	19.4%	19.1%	20.0%	19.4%
Married or in relationship	80.0%	82.6%	79.4%	82.6%
Partner also works	64.2%	59.3%	55.0%	58.9%
Mean hours worked by spouse as operator's employee	27.4	25.9	23.0	27.0
Mean family size	3.3	3.4	3.5	3.3
Mean income	$ 43,342	$ 41,294	$ 43,860	$ 43,621
Education				
Completed primary	7.1%	7.6%	7.5%	9.8%
Year 8	8.8%	8.1%	6.3%	8.6%
Year 9	12.4%	10.3%	14.2%	12.1%
Year 10	45.6%	47.1%	47.9%	47.3%
Year 11	10.2%	11.2%	9.2%	7.8%
Year 12	15.9%	15.7%	15.0%	14.5%
Housing tenure				
Own house	45.2%	47.8%	46.3%	51.6%
Mortgage	34.2%	29.0%	30.4%	29.3%
Rent	16.7%	19.2%	18.8%	15.2%
Other	3.9%	4.0%	4.6%	3.9%
Business details				
Mean length of ownership (yrs)	14.4	13.8	14.4	14.6
Mean length of operation (yrs)	18.6	17.7	18.3	18.7
Has current business plan	28.3%	27.4%	24.4%	25.4%
Product exported overseas	26.2%	21.2%	22.7%	22.8%
Assets not owned outright	24.5%	22.3%	18.5%	18.4%
Mean GVP (per business)	$ 345,152	$ 266,579	$ 289,005	$ 263,413
Mean expenditure on goods & services (excl wages)	$ 159,888	$ 122,851	$ 135,908	$ 123,379
Mean number of vessels owned	1.6	1.6	1.6	1.7
Mean maximum vessel length (m)	13.7	12.5	13.3	12.7
Employment:				
Mean number of FTE staff	3.5	3.0	3.3	3.1

Source: Fenton, Marshall and Edgar 2002

Appendix D: Projections

Table D1: Base projections for tourism

Tourism expenditure, base case

	2001			2010			2020		
$million at 2000-01 prices	Domestic	Inbound	Total	Domestic	Inbound	Total	Domestic	Inbound	Total
Far North	958	979	1,937	956	1,466	2,422	983	2,506	3,489
Northern	495	84	579	493	126	619	507	216	723
Mackay	532	125	657	531	188	719	546	321	867
Fitzroy	422	53	475	421	79	500	433	135	568
Wide Bay-Burnett	498	81	579	497	122	619	511	207	718
GBR catchment	2,905	1,322	4,227	2,898	1,981	4,879	2,980	3,385	6,365
Queensland	9,462	3,562	13,024	9,437	5,333	14,770	9,708	9,121	18,829
Australia	54,499	14,986	69,485	56,117	22,436	78,553	57,790	38,371	96,161

Tourism expenditure, low case

	2001			2010			2020		
$million at 2000-01 prices	Domestic	Inbound	Total	Domestic	Inbound	Total	Domestic	Inbound	Total
Far North	958	979	1,937	914	1,404	2,318	894	2,289	3,183
Northern	495	84	579	472	121	593	461	197	658
Mackay	532	125	657	508	180	688	497	293	790
Fitzroy	422	53	475	403	76	479	394	123	517
Wide Bay-Burnett	498	81	579	475	116	591	465	189	654
GBR catchment	2,905	1,322	4,227	2,772	1,897	4,669	2,711	3,091	5,802
Queensland	9,462	3,562	13,024	9,020	5,108	14,128	8,827	8,330	17,157
Australia	54,499	14,986	69,485	54,593	21,597	76,190	54,593	35,224	89,817

Tourism expenditure, high case

	2001			2010			2020		
$million at 2000-01 prices	Domestic	Inbound	Total	Domestic	Inbound	Total	Domestic	Inbound	Total
Far North	958	979	1,937	1,000	1,530	2,530	1,081	2,743	3,824
Northern	495	84	579	516	132	648	558	237	795
Mackay	532	125	657	555	196	751	601	352	953
Fitzroy	422	53	475	441	82	523	476	148	624
Wide Bay-Burnett	498	81	579	520	126	646	562	227	789
GBR catchment	2,905	1,322	4,227	3,032	2,066	5,098	3,278	3,707	6,985
Queensland	9,462	3,562	13,024	9,870	5,567	15,437	10,671	9,982	20,653
Australia	54,499	14,986	69,485	57,269	23,303	80,572	60,800	41,783	102,583

Source: PC 2003 (ABARE)

Table D2: Sugar cane and processing

Gross value of production, sugar cane and processing

$million at 2000-01 prices	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	182.9	235.0	165.6	303.2	254.3	171.0	328.1
Northern	176.9	254.8	179.5	328.7	275.6	185.4	355.6
Mackay	149.7	222.3	156.6	286.8	240.5	161.8	310.3
Fitzroy							
Wide Bay-Burnett	107.1	104.3	73.5	134.6	112.8	75.9	145.6
GBR catchment	616.6	816.4	575.2	1,053.3	883.2	594.0	1,139.6
Queensland	631.8	832.5	586.6	1,074.1	900.6	605.7	1,162.1
Australia	683.0	883.0	622.1	1,139.2	955.2	642.5	1,232.5

Value added, sugar cane and processing

$million at 2000-01 prices	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	138.8	192.8	135.8	248.7	208.5	140.3	269.1
Northern	135.7	204.2	143.9	263.5	220.9	148.6	285.0
Mackay	166.4	243.5	171.5	314.1	263.4	177.2	339.9
Fitzroy							
Wide Bay-Burnett	136.6	165.1	116.3	213.0	178.6	116.5	230.4
GBR catchment	577.4	805.5	567.5	1,039.3	871.4	582.5	1,124.4
Queensland	601.7	836.0	589.1	1,078.7	560.7	608.3	1,167.0
Australia	696.7	953.6	392.0	1,230.4	533.0	693.9	1,331.1

Employment, sugar cane and processing

	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	2,982	2,645	2,300	2,936	2,309	1,924	2,563
Northern	4,150	3,681	3,200	4,086	3,214	2,678	3,567
Mackay	4,017	3,616	3,143	4,013	3,156	2,631	3,504
Fitzroy							
Wide Bay-Burnett	1,641	2,343	2,037	2,601	2,045	1,704	2,270
GBR catchment	12,790	12,285	10,680	13,636	10,724	8,937	11,904
Queensland	14,588	12,939	11,252	14,363	11,296	9,414	12,539
Australia	16,037	14,224	12,369	15,390	12,418	10,348	13,785

Source: PC 2003 (ABARE)

Table D3: Beef

Gross value of production, beef

$million at 2000-01 prices	2001	2010			2020		
		Base	Low	High	Base	Low	High
Far North	138.5	155.0	154.1	155.8	173.7	170.8	176.9
Northern	130.5	146.1	145.3	146.9	163.7	161.0	166.7
Mackay	153.9	172.3	171.3	173.2	193.1	189.8	196.6
Fitzroy	544.3	609.1	605.8	612.5	682.7	671.3	695.2
Wide Bay-Burnett	285.1	319.0	317.3	320.8	357.6	351.6	364.1
GBR catchment	1,252.2	1,401.4	1,393.8	1,409.3	1,570.8	1,544.5	1,599.5
Queensland	2,801.9	3,151.6	3,134.5	3,169.3	3,569.5	3,509.6	3,634.7
Australia	6,216.0	6,992.5	6,954.7	7,031.8	7,922.2	7,789.1	8,066.9

Value added, beef

$million at 2000-01 prices	2001	2010			2020		
		Base	Low	High	Base	Low	High
Far North	76.2	91.6	90.2	92.1	111.2	109.3	113.2
Northern	71.8	86.3	85.8	86.8	104.8	103.0	106.7
Mackay	84.7	101.8	101.2	102.4	123.6	121.5	125.8
Fitzroy	299.3	359.9	358.0	361.9	436.9	429.5	444.9
Wide Bay-Burnett	156.8	188.5	187.5	189.6	228.8	225.0	233.0
GBR catchment	688.7	828.1	822.7	832.7	1,005.2	988.3	1,023.5
Queensland	1,541.1	1,862.2	1,852.2	1,872.7	2,284.1	2,245.8	2,325.8
Australia	3,418.8	4,131.8	4,109.4	155.1	5,069.4	4,984.3	5,162.0

Employment, beef

	2001	2010			2020		
		Base	Low	High	Base	Low	High
Far North	1,097	1,042	-	-	963	-	-
Northern	1,230	1,169	-	-	1,080	-	-
Mackay	1,260	1,197	-	-	1,106	-	-
Fitzroy	2,608	2,478			2,291		
Wide Bay-Burnett	1,274	1,211	-	-	1,119	-	-
GBR catchment	7,469	7,097	-	-	6,559	-	-
Queensland	16,483	15,785	-	-	14,704	-	-
Australia	38,568	36,692	-	-	33,961	-	-

Source: PC 2003 (ABARE)

Table D4: Horticulture

Gross value of production, horticulture

$million at 2000-01 prices	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	290.7	338.8	299.4	374.8	406.5	310.8	519.5
Northern	224.0	257.0	228.6	282.8	304.0	235.2	385.3
Mackay	19.0	21.6	19.3	23.8	25.5	19.7	32.3
Fitzroy	35.0	40.1	35.9	43.9	47.3	37.2	59.3
Wide Bay-Burnett	224.5	253.5	226.5	278.0	296.2	230.9	373.3
GBR catchment	793.1	911.0	809.7	1,003.3	1,079.5	833.8	1,369.8
Queensland	1,196.8	1,338.3	1,231.6	1,537.8	1,543.3	1,277.3	2,125.2
Australia	4,910.6	5,433.7	4,921.2	5,900.3	6,217.9	4,975.1	7,686.1

Value added, horticulture

$million at 2000-01 prices	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	171.8	197.9	168.5	218.9	257.1	180.7	328.6
Northern	132.3	151.0	129.7	166.2	193.4	138.2	245.1
Mackay	11.2	12.6	10.9	13.9	16.1	11.5	20.5
Fitzroy	20.7	23.5	20.4	25.7	30.0	21.9	37.6
Wide Bay-Burnett	132.6	148.6	128.4	163.0	188.0	135.7	237.0
GBR catchment	468.7	533.6	457.9	587.6	684.7	488.0	868.7
Queensland	707.2	784.0	695.7	901.0	978.9	745.8	1,348.4
Australia	2,901.7	3,196.9	2,799.0	3,455.5	3,961.8	2,948.4	4,875.6

Employment, horticulture

	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	4,063	4,645	4,245	4,977	5,389	4,457	6,374
Northern	2,826	3,231	2,953	3,462	3,749	3,100	4,434
Mackay	160	183	167	196	213	176	251
Fitzroy	683	781	713	836	906	749	1,071
Wide Bay-Burnett	3,011	3,442	3,146	3,688	3,994	3,303	4,723
GBR catchment	10,743	12,282	11,224	13,159	14,251	11,785	16,853
Queensland	19,968	21,655	20,862	24,457	23,984	21,902	31,323
Australia	63,452	72,534	66,293	77,719	84,158	69,597	99,535

Source: PC 2003 (ABARE)

Table D5: Commercial fishing

Gross value of production, commercial fishing

$million at 2000-01 prices	2001	2010			2020		
		Base	Low	High	Base	Low	High
Far North	47.7	43.5	33.9	53.9	36.5	27.0	47.7
Northern	19.2	19.3	15.0	23.9	16.2	12.0	21.1
Mackay	22.6	20.8	16.2	25.8	17.5	12.9	22.8
Fitzroy	27.9	27.2	21.2	33.7	22.8	16.9	29.8
Wide Bay-Burnett	9.5	8.6	7.8	11.0	7.3	6.9	10.6
GBR catchment	126.9	119.3	94.1	148.3	100.3	75.7	132.1
Queensland	254.6	191.9	146.4	239.0	159.3	113.8	211.4
Australia	1,831.5	1,474.1	1,114.3	1,773.5	1,237.5	888.6	1,568.7

Value added, commercial fishing

$million at 2000-01 prices	2001	2010			2020		
		Base	Low	High	Base	Low	High
Far North	9.1	10.8	8.8	18.0	11.8	8.8	25.2
Northern	4.5	5.8	4.7	9.2	6.0	4.4	13.0
Mackay	3.5	4.2	3.4	7.2	4.7	3.5	10.2
Fitzroy	4.9	5.8	4.7	9.2	6.3	4.7	13.4
Wide Bay-Burnett	6.5	7.8	6.3	13.1	8.5	6.3	18.3
GBR catchment	28.5	34.3	27.9	56.7	37.2	27.7	80.0
Queensland	41.6	49.5	40.2	83.3	54.3	40.3	116.6
Australia	NA						

Employment, commercial fishing

	2001	2010			2020		
		Base	Low	High	Base	Low	High
Far North	691	572	523	564	450	394	461
Northern	294	244	223	240	191	168	196
Mackay	363	300	274	296	236	207	242
Fitzroy	322	266	243	263	209	184	215
Wide Bay-Burnett	440	360	320	360	280	240	280
GBR catchment	2,110	1,742	1,583	1,723	1,366	1,193	1,394
Queensland	3,771	3,121	2,853	3,081	2,454	2,153	2,518
Australia	NA						

Source: PC 2003 (ABARE). Wide Bay-Burnett adjusted to show whole region.

Table D6: Recreational fishing and aquaculture

Expenditure (gross value of production), recreational fishing

$million at 2000-01 prices	2001	2010			2020		
		Base	Low	High	Base	Low	High
Far North	72.3	73.2	67.5	80.9	73.1	62.4	88.5
Northern	54.4	55.1	50.8	60.9	55.1	47.0	66.6
Mackay	35.8	36.3	33.5	4.1	36.2	30.9	43.8
Fitzroy	21.4	21.6	20.0	23.9	21.6	18.4	26.1
Wide Bay-Burnett	56.2	56.8	52.5	62.8	56.8	48.5	68.7
GBR catchment	240.1	243.0	224.2	232.6	242.8	207.1	293.8
Queensland	500.3	502.3	462.6	550.5	505.5	429.9	603.8

Gross value of production, aquaculture

$million at 2000-01 prices	2001	2010			2020		
		Base	Low	High	Base	Low	High
Far North	17	41	35	50	94	81	117
Northern	12	28	24	34	65	56	81
Mackay	6	16	13	19	36	31	45
Fitzroy	-	1	1	1	2	2	3
Wide Bay-Burnett	6	12	10	14	27	23	33
GBR catchment	41	98	83	118	224	193	279
Queensland	56	130	109	157	300	258	372
Australia	746	1,275	1,032	1,485	2,004	1,726	2,484

Employment, aquaculture

	2001	2010			2020		
		Base	Low	High	Base	Low	High
Far North	156	461	450	473	1,057	1,006	1,111
Northern	124	319	311	326	730	695	767
Mackay	49	176	171	180	403	383	423
Fitzroy	16	11	11	11	25	24	26
Wide Bay-Burnett	78	132	129	135	302	288	317
GBR catchment	423	1,099	1,072	1,125	2,517	2,396	2,644
Queensland	589	1,464	1,429	1,501	3,357	3,194	3,527
Australia	NA						

Source: PC 2003 (ABARE)

Table D7: Mining

Gross value of production, mining

$million at 2000-01 prices	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	271	271	267	282	266	250	297
Northern	755	757	745	786	741	698	827
Mackay	2,871	2,879	2,831	2,989	2,816	2,656	3,146
Fitzroy	2,840	2,847	2,801	2,957	2,785	2,627	3,112
Wide Bay-Burnett	173	173	171	180	170	160	190
GBR catchment	6,910	6,927	6,815	7,194	6,778	6,391	7,572
Queensland	10,909	10,442	9,842	11,539	9,813	8,976	11,789
Australia	51,754	56,811	54,872	58,809	62,755	57,678	68,251

Value added, mining

$million at 2000-01 prices	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	157	157	155	163	154	145	172
Northern	438	439	432	456	429	405	480
Mackay	1,665	1,670	1,642	1,734	1,633	1,540	1,825
Fitzroy	1,647	1,651	1,624	1,715	1,616	1,524	1,805
Wide Bay-Burnett	100	101	99	104	98	93	110
GBR catchment	4,007	4,018	3,952	4,172	3,930	3,707	4,392
Queensland	6,327	656	5,708	6,693	5,691	5,206	6,838
Australia	34,158	37,495	36,215	38,814	41,418	38,067	45,046

Employment, mining

	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	116	1,208	1,187	1,227	1,202	1,135	1,277
Northern	1,368	1,385	1,362	1,407	1,325	1,250	1,407
Mackay	4,190	3,081	3,030	3,131	2,793	2,634	2,967
Fitzroy	4,752	4,169	4,100	4,237	3,831	3,614	4,069
Wide Bay-Burnett	603	639	628	649	621	586	659
GBR catchment	11,029	10,482	10,307	10,651	9,772	9,219	10,379
Queensland	16,483	15,785	2,778	2,871	14,704	2,622	2,978
Australia	78,000	79,060	76,362	81,840	81,566	74,967	88,709

Source: PC 2003 (ABARE)

Table D8: Mineral processing

Gross value of production, mineral processing

$million at 2000-01 prices	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	33	38	36	40	43	40	47
Northern	1,468	2,109	1,386	2,461	1,936	1,659	2,133
Mackay	22	26	25	27	29	27	32
Fitzroy	2,752	3,022	2,460	3,932	3,791	2,372	4,606
Wide Bay-Burnett	12	13	13	14	15	14	17
GBR catchment	4,287	5,208	3,920	6,474	5,814	4,112	6,835
Queensland	7,532	8,868	7,474	10,273	9,938	8,013	10,273
Australia	32,136	34,526	32,197	39,284	36,866	31,672	41,534

Value added, mineral processing

$million at 2000-01 prices	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	9	11	10	11	12	11	13
Northern	339	486	320	568	447	383	492
Mackay	6	7	7	8	8	8	9
Fitzroy	634	696	567	905	873	546	1,060
Wide Bay-Burnett	3	4	4	4	4	4	5
GBR catchment	991	1,204	908	1,496	1,344	952	1,579
Queensland	1,664	1,960	1,643	2,280	2,195	1,759	2,492
Australia	7,435	7,920	7,409	9,053	8,414	7,239	9,512

Employment, mineral processing

	2001	2010 Base	2010 Low	2010 High	2020 Base	2020 Low	2020 High
Far North	31	37	35	39	44	41	48
Northern	1,394	2,054	1,349	2,397	1,979	1,696	2,181
Mackay	21	25	24	26	30	28	33
Fitzroy	2,612	2,943	2,395	3,830	3,876	2,425	4,709
Wide Bay-Burnett	11	13	13	14	16	15	17
GBR catchment	4,069	5,072	3,816	6,306	5,945	4,205	6,988
Queensland	7,150	8,636	7,278	10,004	10,160	8,192	11,517
Australia	46,825	51,608	48,125	58,720	57,853	49,701	65,179

Source: PC 2003 (ABARE)

Table D9: Gross value of base production projections for Scenario A1

$million in 2000-01 prices

Industry	Projection	Far North Queens-land	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total catch-ment
2001							
Sugar		183	177	150	-	107	617
Beef		139	131	154	544	285	1,253
Horticulture		291	224	19	35	225	794
Mining		271	755	2,871	2,840	173	6,910
Mineral processing		33	1,468	22	2,752	12	4,287
Subtotal		917	2,755	3,216	6,171	802	13,861
Tourism inbound		979	84	125	53	81	1,322
Tourism domestic		958	495	532	422	498	2,905
Commercial fisheries		55	34	37	30	53	208
Aquaculture		17	12	6	-	6	41
Total GVP		2,926	3,380	3,916	6,676	1,440	18,337
2010							
Sugar	High	308	329	287	-	135	1,059
Beef	High	156	147	173	613	321	1,410
Horticulture	Low	299	229	19	36	227	810
Mining	High	282	786	2,989	2,957	180	7,194
Mineral processing	High	40	2,461	27	3,932	14	6,474
Subtotal		1,085	3,952	3,495	7,538	877	16,947
Tourism inbound	High	1,466	126	188	79	122	1,981
Tourism domestic	Base	956	493	531	421	497	2,898
Commercial fisheries	A1 prices	61	37	40	33	58	229
Aquaculture	Base	41	28	16	1	12	98
Total GVP		3,609	4,636	4,270	8,072	1,566	22,153
2020							
Sugar	High	328	356	310	-	146	1,140
Beef	High	177	167	197	695	364	1,600
Horticulture	Low	311	235	20	37	231	834
Mining	High	297	827	3,146	3,112	190	7,572
Mineral processing	High	47	2,133	32	4,606	17	6,835
Subtotal		1,160	3,718	3,705	8,450	948	17,981
Tourism inbound	High	2,506	216	321	135	207	3,385
Tourism domestic	Base	983	507	507	433	511	2,941
Commercial fisheries	A1 prices	67	40	44	36	64	250
Aquaculture	Base	94	65	36	2	27	224
Total GVP		4,810	4,546	4,613	9,056	1,757	24,781

Source: PC 2003 (ABARE), except commercial fisheries

Table D10: Gross value of base production projections for Scenario A1: Annual change
$million in 2000-01 prices

Industry	Projection	Far North Queens-land	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total catch-ment
2001-2010							
Sugar	High	6.0%	7.1%	7.5%		2.6%	6.2%
Beef	High	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%
Horticulture	Low	0.3%	0.2%	0.0%	0.3%	0.1%	0.2%
Mining	High	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
Mineral processing	High	2.2%	5.9%	2.3%	4.0%	1.7%	4.7%
Subtotal		1.9%	4.1%	0.9%	2.2%	1.0%	2.3%
Tourism inbound	High	4.6%	4.6%	4.6%	4.5%	4.7%	4.6%
Tourism domestic	Base	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial fisheries	A1 prices	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%
Aquaculture	Base	10.3%	9.9%	11.5%		8.0%	10.2%
Total GVP		2.4%	3.6%	1.0%	2.1%	0.9%	2.1%
2010-2020							
Sugar	High	0.6%	0.8%	0.8%		0.8%	0.7%
Beef	High	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%
Horticulture	Low	0.4%	0.3%	0.5%	0.3%	0.2%	0.3%
Mining	High	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Mineral processing	High	1.6%	-1.4%	1.7%	1.6%	2.0%	0.5%
Subtotal		0.7%	-0.6%	0.6%	1.1%	0.8%	0.6%
Tourism inbound	High	5.5%	5.5%	5.5%	5.5%	5.4%	5.5%
Tourism domestic	Base	0.3%	0.3%	-0.5%	0.3%	0.3%	0.1%
Commercial fisheries	A1 prices	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%
Aquaculture	Base	8.7%	8.8%	8.4%	7.2%	8.4%	8.6%
Total GVP		2.9%	-0.2%	0.8%	1.2%	1.2%	1.1%

Source: PC 2003 (ABARE), except commercial fisheries

Table D11: Additional base projections for Scenario A1

Industry	Estimated value added $million in 2000-01 prices			Employment Persons		
	2001	2010	2020	2001	2010	2020
Sugar	577	1,039	1,124	12,790	13,636	11,904
Beef	689	833	1,024	7,469	7,097	6,559
Horticulture	469	458	588	10,743	11,224	11,785
Mining	4,007	4,172	4,392	11,029	10,651	10,379
Mineral processing	991	1,496	1,579	4,069	6,306	6,988
Subtotal 1	6,733	7,998	8,707	46,100	48,914	47,615
Tourism	2,100	2,600	3,200	39,000	42,000	48,500
Fisheries (GRP)	115	127	138	3,374	3,374	3,374
Aquaculture	23	54	123	423	1,099	2,517
Subtotal 2	2,238	2,781	3,461	42,797	46,473	54,391
Grand total	8,971	10,779	12,168	88,897	95,387	102,006
Tourism proportion	23%	24%	26%	44%	44%	48%

Source: PC 2003 with additional estimates. Tourism employment based on OESR 2002, fisheries on Fenton and Marshall 2001a

Table D12: Gross value of base production projections for Scenario A2

$million in 2000-01 prices

Industry	Projection	Far North Queens-land	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total catch-ment
2001							
Sugar		183	177	150	-	107	617
Beef		139	131	154	544	285	1,253
Horticulture		291	224	19	35	225	794
Mining		271	755	2,871	2,840	173	6,910
Mineral processing		33	1,468	22	2,752	12	4,287
Subtotal		917	2,755	3,216	6,171	802	13,861
Tourism inbound		979	84	125	53	81	1,322
Tourism domestic		958	495	532	422	498	2,905
Commercial fisheries		55	34	37	30	53	208
Aquaculture		17	12	6	-	6	41
Total GVP		2,926	3,380	3,916	6,676	1,440	18,337
2010							
Sugar	Low x 2	148	178	153	-	60	539
Beef	Low x 2	83	79	93	229	172	656
Horticulture	Low x 2	295	226	19	36	226	802
Mining	Low x 2	263	735	2,791	2,762	169	6,720
Mineral processing	Low x 2	35	1,304	24	2,166	12	3,541
Subtotal		824	2,522	3,080	5,193	639	12,258
Tourism inbound	Low x 2	1,192	102	152	65	98	1,609
Tourism domestic	Low x 2	872	459	484	384	452	2,651
Commercial fisheries	A2 prices	58	35	38	31	56	219
Aquaculture	Low	35	24	13	1	10	83
Total GVP		2,981	3,142	3,767	5,674	1,255	16,820
2020							
Sugar	Low x 2	151	181	156	-	60	548
Beef	Low x 2	93	87	103	265	192	740
Horticulture	Low x 2	301	230	19	36	228	814
Mining	Low x 2	229	641	2,441	2,414	147	5,872
Mineral processing	Low x 2	38	1,440	26	1,990	13	3,507
Subtotal		812	2,579	2,745	4,705	640	11,481
Tourism inbound	Low x 2	1,524	139	203	99	135	2,100
Tourism domestic	Low x 2	792	448	473	374	447	2,534
Commercial fisheries	A2 prices	58	35	38	31	56	219
Aquaculture	Low	81	56	31	2	23	193
Total GVP		3,267	3,257	3,490	5,211	1,301	16,527

Source: PC 2003 (ABARE), except commercial fisheries

Table D13: Gross value of base production projections for Scenario A2: Annual change
$million in 2000-01 prices

Industry	Projection	Far North Queens-land	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total catch-ment
2001-2010							
Sugar	Low x 2	-2.3%	0.1%	0.2%		-6.2%	-1.5%
Beef	Low x 2	-5.6%	-5.5%	-5.4%	-9.2%	-5.5%	-6.9%
Horticulture	Low x 2	0.2%	0.1%	0.0%	0.3%	0.0%	0.1%
Mining	Low x 2	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%
Mineral processing	Low x 2	0.7%	-1.3%	1.0%	-2.6%	0.0%	-2.1%
Subtotal		-1.2%	-1.0%	-0.5%	-1.9%	-2.5%	-1.4%
Tourism inbound	Low x 2	2.2%	2.2%	2.2%	2.3%	2.1%	2.2%
Tourism domestic	Low x 2	-1.0%	-0.8%	-1.0%	-1.0%	-1.1%	-1.0%
Commercial fisheries	A2 prices	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Aquaculture	Low	8.4%	8.0%	9.0%		5.8%	8.2%
Total GVP		0.2%	-0.8%	-0.4%	-1.8%	-1.5%	-1.0%
2010-2020							
Sugar	Low x 2	0.2%	0.2%	0.2%		0.0%	0.2%
Beef	Low x 2	1.1%	1.0%	1.0%	1.5%	1.1%	1.2%
Horticulture	Low x 2	0.2%	0.2%	0.0%	0.0%	0.1%	0.1%
Mining	Low x 2	-1.4%	-1.4%	-1.3%	-1.3%	-1.4%	-1.3%
Mineral processing	Low x 2	0.8%	1.0%	0.8%	-0.8%	0.8%	-0.1%
Subtotal		-0.1%	0.2%	-1.1%	-1.0%	0.0%	-0.7%
Tourism inbound	Low x 2	2.5%	3.1%	2.9%	4.3%	3.3%	2.7%
Tourism domestic	Low x 2	-1.0%	-0.2%	-0.2%	-0.3%	-0.1%	-0.5%
Commercial fisheries	A2 prices	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Aquaculture	Low	8.8%	8.8%	9.1%	7.2%	8.7%	8.8%
Total GVP							

Source: PC 2003 (ABARE), except commercial fisheries

Table D14: Additional base projections for Scenario A2

Industry	Estimated value added $million in 2000-01 prices			Employment Persons		
	2001	2010	2020	2001	2010	2020
Sugar	577	558	575	12,790	8,570	5,084
Beef	689	757	840	7,469	6,727	5,851
Horticulture	469	447	464	10,743	10,983	11,264
Mining	4,007	3,897	3,407	11,029	9,585	7,409
Mineral processing	991	835	857	4,069	3,563	3,758
Subtotal 1	6,733	6,494	6,143	46,100	39,428	33,366
Tourism	2,100	2,100	2,300	39,000	36,000	38,000
Fisheries (GRP)	115	121	121	3,374	3,374	3,374
Aquaculture	23	46	106	423	1,072	2,396
Subtotal 2	2,238	2,267	2,527	42,797	40,446	43,770
Grand total	8,971	8,761	8,670	88,897	79,874	77,136
Tourism proportion	23%	24%	27%	44%	45%	49%

Source: PC 2003 with additional estimates. Tourism employment based on OESR 2002, fisheries on Fenton and Marshall 2001a

Table D15: Gross value of base production projections for Scenario B1

$million in 2000-01 prices

Industry	Projection	Far North Queens-land	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total catch-ment
2001							
Sugar		183	177	150	-	107	617
Beef		139	131	154	544	285	1,253
Horticulture		291	224	19	35	225	794
Mining		271	755	2,871	2,840	173	6,910
Mineral processing		33	1,468	22	2,752	12	4,287
Subtotal		917	2,755	3,216	6,171	802	13,861
Tourism inbound		979	84	125	53	81	1,322
Tourism domestic		958	495	532	422	498	2,905
Commercial fisheries		55	34	37	30	53	208
Aquaculture		17	12	6	-	6	41
Total GVP		2,926	3,380	3,916	6,676	1,440	18,337
2010							
Sugar	Base	235	255	222	-	104	816
Beef	Base	155	146	172	609	319	1,401
Horticulture	Low	299	229	19	36	227	810
Mining	Base	271	757	2,879	2,847	173	6,927
Mineral processing	Base	38	2,109	26	3,022	13	5,208
Subtotal		998	3,496	3,318	6,514	836	15,162
Tourism inbound	Base	1,404	121	180	76	116	1,897
Tourism domestic	Low	914	472	508	403	475	2,772
Commercial fisheries	B1 prices	58	35	38	31	56	219
Aquaculture	Base	41	28	16	1	12	98
Total GVP		3,415	4,152	4,060	7,025	1,495	20,148
2020							
Sugar	Base	254	276	241	-	113	884
Beef	Base	174	164	193	683	358	1,572
Horticulture	Low	311	235	20	37	231	834
Mining	Base	266	741	2,816	2,785	170	6,778
Mineral processing	Base	43	1,936	29	3,791	15	5,814
Subtotal		1,048	3,352	3,299	7,296	887	15,882
Tourism inbound	Base	2,506	216	321	135	207	3,385
Tourism domestic	Low	894	461	497	394	465	2,711
Commercial fisheries	B1 prices	64	39	42	34	61	240
Aquaculture	Base	94	65	36	2	27	224
Total GVP		4,606	4,133	4,195	7,861	1,647	22,442

Source: PC 2003 (ABARE), except commercial fisheries

Table D16: Gross value of base production projections for Scenario B1: Annual change
$million in 2000-01 prices

Industry	Projection	Far North Queens-land	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total catch-ment
2001-2010							
Sugar	Base	2.8%	4.1%	4.5%		-0.3%	3.2%
Beef	Base	1.2%	1.2%	1.2%	1.3%	1.3%	1.2%
Horticulture	Low	0.3%	0.2%	0.0%	0.3%	0.1%	0.2%
Mining	Base	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mineral processing	Base	1.6%	4.1%	1.9%	1.0%	0.9%	2.2%
Subtotal		0.9%	2.7%	0.3%	0.6%	0.5%	1.0%
Tourism inbound	Base	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%
Tourism domestic	Low	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%
Commercial fisheries	B1 prices	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Aquaculture	Base	10.3%	9.9%	11.5%		8.0%	10.2%
Total GVP		1.7%	2.3%	0.4%	0.6%	0.4%	1.1%
2010-2020							
Sugar	Base	0.8%	0.8%	0.8%		0.8%	0.8%
Beef	Base	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
Horticulture	Low	0.4%	0.3%	0.5%	0.3%	0.2%	0.3%
Mining	Base	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
Mineral processing	Base	1.2%	-0.9%	1.1%	2.3%	1.4%	1.1%
Subtotal		0.5%	-0.4%	-0.1%	1.1%	0.6%	0.5%
Tourism inbound	Base	6.0%	6.0%	6.0%	5.9%	6.0%	6.0%
Tourism domestic	Low	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
Commercial fisheries	B1 prices	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%
Aquaculture	Base	8.7%	8.8%	8.4%	7.2%	8.4%	8.6%
Total GVP		3.0%	0.0%	0.3%	1.1%	1.0%	1.1%

Source: PC 2003 (ABARE), except commercial fisheries

Table D17: Additional base projections for Scenario B1

Industry	Estimated value added $million in 2000-01 prices			Employment Persons		
	2001	2010	2020	2001	2010	2020
Sugar	577	806	871	12,790	12,285	10,724
Beef	689	828	1,005	7,469	7,097	6,559
Horticulture	469	458	588	10,743	11,224	11,785
Mining	4,007	4,018	3,930	11,029	10,482	9,772
Mineral processing	991	1,204	1,344	4,069	4,272	5,945
Subtotal 1	6,733	7,314	7,738	46,100	45,360	44,785
Tourism	2,100	2,300	3,000	39,000	38,000	44,000
Fisheries (GRP)	115	121	132	3,374	3,374	3,374
Aquaculture	23	54	123	423	1,099	2,517
Subtotal 2	2,238	2,475	3,255	42,797	42,473	49,891
Grand total	8,971	9,789	10,993	88,897	87,833	94,676
Tourism proportion	23%	23%	27%	44%	43%	46%

Source: PC 2003 with additional estimates. Tourism employment based on OESR 2002, fisheries on Fenton and Marshall 2001a

Table D18: Gross value of base production projections for Scenario B2

$million in 2000-01 prices

Industry	Projection	Far North Queens-land	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total catch-ment
2001							
Sugar		183	177	150	-	107	617
Beef		139	131	154	544	285	1,253
Horticulture		291	224	19	35	225	794
Mining		271	755	2,871	2,840	173	6,910
Mineral processing		33	1,468	22	2,752	12	4,287
Subtotal		917	2,755	3,216	6,171	802	13,861
Tourism inbound		979	84	125	53	81	1,322
Tourism domestic		958	495	532	422	498	2,905
Commercial fisheries		55	34	37	30	53	208
Aquaculture		17	12	6	-	6	41
Total GVP		2,926	3,380	3,916	6,676	1,440	18,337
2010							
Sugar	Base	235	255	222	-	104	816
Beef	Base	155	146	172	609	319	1,401
Horticulture	Low	299	229	19	36	227	810
Mining	Base	271	757	2,879	2,847	173	6,927
Mineral processing	Base	38	2,109	26	3,022	13	5,208
Subtotal		998	3,496	3,318	6,514	836	15,162
Tourism inbound	Base	1,404	121	180	76	116	1,897
Tourism domestic	Low	914	472	508	403	475	2,772
Commercial fisheries	B2 prices	58	35	38	31	56	219
Aquaculture	Base	41	28	16	1	12	98
Total GVP		3,415	4,152	4,060	7,025	1,495	20,148
2020							
Sugar	Base	254	276	241	-	113	884
Beef	Base	174	164	193	683	358	1,572
Horticulture	Low	311	235	20	37	231	834
Mining	Base	266	741	2,816	2,785	170	6,778
Mineral processing	Base	43	1,936	29	3,791	15	5,814
Subtotal		1,048	3,352	3,299	7,296	887	15,882
Tourism inbound	Base	2,506	216	321	135	207	3,385
Tourism domestic	Low	914	461	497	394	465	2,731
Commercial fisheries	B2 prices	64	39	42	34	61	240
Aquaculture	Base	94	65	36	2	27	224
Total GVP		4,626	4,133	4,195	7,861	1,647	22,462

Source: PC 2003 (ABARE), except commercial fisheries

Table D19: Gross value of base production projections for Scenario B2: Annual change
$million in 2000-01 prices

Industry	Projection	Far North Queens-land	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total catch-ment
2001-2010							
Sugar	Base	2.8%	4.1%	4.5%		-0.3%	3.2%
Beef	Base	1.2%	1.2%	1.2%	1.3%	1.3%	1.2%
Horticulture	Low	0.3%	0.2%	0.0%	0.3%	0.1%	0.2%
Mining	Base	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mineral processing	Base	1.6%	4.1%	1.9%	1.0%	0.9%	2.2%
Subtotal		0.9%	2.7%	0.3%	0.6%	0.5%	1.0%
Tourism inbound	Base	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%
Tourism domestic	Low	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%
Commercial fisheries	B2 prices	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Aquaculture	Base	10.3%	9.9%	11.5%		8.0%	10.2%
Total GVP		1.7%	2.3%	0.4%	0.6%	0.4%	1.1%
2010-2020							
Sugar	Base	0.8%	0.8%	0.8%		0.8%	0.8%
Beef	Base	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
Horticulture	Low	0.4%	0.3%	0.5%	0.3%	0.2%	0.3%
Mining	Base	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%
Mineral processing	Base	1.2%	-0.9%	1.1%	2.3%	1.4%	1.1%
Subtotal		0.5%	-0.4%	-0.1%	1.1%	0.6%	0.5%
Tourism inbound	Base	6.0%	6.0%	6.0%	5.9%	6.0%	6.0%
Tourism domestic	Low	0.0%	-0.2%	-0.2%	-0.2%	-0.2%	-0.1%
Commercial fisheries	B2 prices	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%
Aquaculture	Base	8.7%	8.8%	8.4%	7.2%	8.4%	8.6%
Total GVP		3.1%	0.0%	0.3%	1.1%	1.0%	1.1%

Source: PC 2003 (ABARE), except commercial fisheries

Table D20: Additional base projections for Scenario B2

Industry	Estimated value added $million in 2000-01 prices			Employment Persons		
	2001	2010	2020	2001	2010	2020
Sugar	577	568	582	12,790	10,680	8,937
Beef	689	823	988	7,469	7,097	6,559
Horticulture	469	458	588	10,743	11,224	11,785
Mining	4,007	3,952	3,707	11,029	10,307	9,219
Mineral processing	991	908	952	4,069	3,816	4,205
Subtotal 1	6,733	6,709	6,817	46,100	43,124	40,705
Tourism	2,100	2,300	3,000	39,000	38,000	44,000
Fisheries (GRP)	115	121	132	3,374	3,374	3,374
Aquaculture	23	54	123	423	1,099	2,517
Subtotal 2	2,238	2,475	3,255	42,797	42,473	49,891
Grand total	8,971	9,184	10,072	88,897	85,597	90,596
Tourism proportion	23%	25%	30%	44%	44%	49%

Source: PC 2003 with additional estimates. Tourism employment based on OESR 2002, fisheries on Fenton and Marshall 2001a

Table D21: Official population projections to 2021

LGA/SD	1991	1996	2001	2006	2011	2016	2021	1991-2001	2001-2021	1991-2021
Cook	7,489	8,014	8,464	9,089	9,394	9,661	9,892	1.2%	0.8%	0.9%
Douglas	7,716	9,698	10,688	12,607	14,206	15,866	17,528	3.3%	2.5%	2.8%
Cairns	92,630	113,507	120,433	140,346	155,872	171,591	187,565	2.7%	2.2%	2.4%
Cardwell	8,352	9,114	10,774	11,570	12,844	14,104	15,355	2.6%	1.8%	2.1%
Johnstone	18,196	19,780	19,383	21,558	22,458	23,312	24,126	0.6%	1.1%	0.9%
Rest of Far North	47,016	50,653	53,126	57,110	60,147	63,012	65,746	1.2%	1.1%	1.1%
Far North	181,399	210,766	222,868	252,280	274,921	297,546	320,212	2.1%	2.0%	2.1%
Hinchinbrook	15,501	15,495	14,700	15,655	15,668	15,656	15,638	-0.5%	0.3%	0.0%
Townsville-Thuringow	121,576	132,125	145,372	157,188	170,839	184,458	198,110	1.8%	1.6%	1.6%
Burdekin	19,248	18,955	18,466	18,387	18,120	17,857	17,593	-0.4%	-0.2%	-0.3%
Rest of Northern	12,764	12,462	12,246	12,030	11,772	11,503	11,237	-0.4%	-0.4%	-0.4%
Northern	169,089	179,037	190,784	203,260	216,399	229,474	242,578	1.2%	1.2%	1.2%
Bowen	13,492	13,142	12,423	12,143	11,812	11,584	11,471	-0.8%	-0.4%	-0.5%
Whitsunday	11,429	13,935	15,496	17,708	19,684	21,662	23,661	3.1%	2.1%	2.5%
Mackay	63,557	71,448	75,977	85,227	91,767	97,933	104,045	1.8%	1.6%	1.7%
Sarina	8,145	9,354	9,822	11,166	12,001	10,051	10,079	1.9%	0.1%	0.7%
Broadsound	8,571	7,552	6,235	6,433	5,970	7,032	6,952	-3.1%	0.5%	-0.7%
Rest of Mackay	18,599	18,035	17,320	18,207	18,173	19,345	19,631	-0.7%	0.6%	0.2%
Mackay	123,793	133,466	137,273	150,884	159,407	167,607	175,839	1.0%	1.2%	1.2%
Livingstone	18,042	23,156	26,369	30,770	35,306	40,000	44,333	3.9%	2.6%	3.0%
Fitzroy	8,281	9,820	9,951	11,378	12,772	14,143	15,476	1.9%	2.2%	2.1%
Rockhampton	60,067	59,857	58,775	59,314	59,349	59,390	59,451	-0.2%	0.1%	0.0%
Gladstone/Calliope	36,113	40,149	41,988	49,529	55,631	61,528	66,999	1.5%	2.4%	2.1%
Rest of Fitzroy	45,865	45,046	44,499	43,840	43,489	43,266	42,985	-0.3%	-0.2%	-0.2%
Fitzroy	168,368	178,028	181,582	194,831	206,547	218,327	229,244	0.8%	1.2%	1.0%
Miriam Vale	2,861	3,975	4,481	5,939	6,916	7,855	8,714	4.6%	3.4%	3.8%
Burnett	15,619	20,952	23,962	28,454	33,023	37,159	41,678	4.4%	2.8%	3.3%
Bundaberg	41,790	43,562	44,670	47,252	49,813	52,333	54,627	0.7%	1.0%	0.9%
Isis	4,730	5,795	5,882	6,540	7,057	7,595	8,140	2.2%	1.6%	1.8%
Hervey Bay	27,787	38,809	43,419	51,769	59,635	67,440	75,284	4.6%	2.8%	3.4%
Maryborough	24,587	24,841	25,145	25,591	26,140	26,710	27,269	0.2%	0.4%	0.3%
Rest of Wide Bay-Burn	78,192	86,351	89,315	94,412	100,082	105,663	111,057	1.3%	1.1%	1.2%
Wide Bay-Burnett	195,566	224,285	236,874	259,957	282,666	304,755	326,769	1.9%	1.6%	1.7%
Total GBR regions	838,215	925,582	969,381	1,061,212	1,139,940	1,217,709	1,294,642	1.5%	1.5%	1.5%
of which:										
Coastal areas[1]	610,373	684,652	721,806	798,553	863,710	927,043	991,221	1.7%	1.6%	1.6%
Inland areas	227,842	240,930	247,575	262,659	276,230	290,666	303,421	0.8%	1.0%	1.0%

[1] Though actually landlocked, Rockhampton and Bundaberg are included in coastal areas

Source: Planning & Forecasting Unit, Department of Local Government & Planning, shown in OESR 2002b

Table D22: Key components of A1 tourism projection

	Tropical North	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total GBR
Total tourist GRP, including business and other ($million)						
2001	870	290	314	246	304	2,024
2010	1,040	347	375	294	363	2,419
2020	1,267	422	457	358	443	2,947
Domestic visitor reef-interested GRP ($million)						
2001	309	97	103	81	40	630
2010	308	90	103	81	40	622
2020	317	92	106	83	41	639
Annual growth before adjustment of -1.2% pa						
2001-2010	0.0%	-0.8%	0.0%	0.0%	0.0%	-0.1%
2010-2020	0.3%	0.2%	0.3%	0.2%	0.2%	0.3%
Inbound visitor reef-interested GRP ($million)						
2001	345	22	35	16	13	431
2010	486	48	68	34	28	664
2020	654	47	97	39	40	877
Annual growth before adjustment of -1.2% pa						
2001-2010	3.9%	9.1%	7.7%	8.7%	8.9%	4.9%
2010-2020	3.0%	-0.2%	3.6%	1.4%	3.6%	2.8%
Domestic visitor reef-interested GRP, adjusted ($million)						
2001	309	97	103	81	40	630
2010	275	79	94	72	40	560
2020	254	69	84	62	40	509
Inbound visitor reef-interested GRP, adjusted ($million)						
2001	345	22	35	16	13	431
2010	437	44	61	30	24	596
2020	540	34	81	30	34	719
Total reduction in GRP ($million)						
2010	82	15	16	13	4	130
2020	177	36	38	30	7	288
Reduction compared with reef-interested GRP						
2010	-10%	-11%	-9%	-11%	-6%	-10%
2020	-18%	-26%	-19%	-25%	-9%	-19%
Reduction compared with total tourism GRP						
2010	-8%	-4%	-4%	-4%	-1%	-5%
2020	-14%	-9%	-8%	-8%	-2%	-10%

Table D23: Key components of A2 tourism projection

	Tropical North	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total GBR
Total tourist GRP, including business and other ($million)						
2001	870	290	314	246	304	2,024
2010	995	332	359	281	348	2,314
2020	1,154	385	417	326	403	2,686
Domestic visitor reef-interested GRP ($million)						
2001	309	97	103	81	40	630
2010	281	84	94	74	36	569
2020	255	82	92	72	36	537
Annual growth before adjustment of -2% pa						
2001-2010	-1.0%	-1.6%	-1.0%	-1.0%	-1.2%	-1.1%
2010-2020	-1.0%	-0.2%	-0.2%	-0.3%	0.0%	-0.6%
Inbound visitor reef-interested GRP ($million)						
2001	345	22	35	16	13	431
2010	463	44	67	34	28	636
2020	583	36	85	37	37	778
Annual growth before adjustment of -2% pa						
2001-2010	3.3%	8.0%	7.5%	8.7%	8.9%	4.4%
2010-2020	2.3%	-2.0%	2.4%	0.8%	2.8%	2.0%
Domestic visitor reef-interested GRP, adjusted ($million)						
2001	309	97	103	81	40	630
2010	248	79	87	64	31	509
2020	183	57	67	51	28	386
Inbound visitor reef-interested GRP, adjusted ($million)						
2001	345	22	35	16	13	431
2010	390	27	56	27	22	522
2020	410	26	56	27	22	541
Total reduction in GRP ($million)						
2010	120	31	27	18	11	207
2020	255	34	59	29	26	403
Reduction compared with reef-interested GRP						
2010	-16%	-24%	-17%	-17%	-17%	-17%
2020	-30%	-29%	-33%	-27%	-36%	-31%
Reduction compared with total tourism GRP						
2010	-12%	-9%	-8%	-6%	-3%	-9%
2020	-22%	-9%	-14%	-9%	-6%	-15%

Table D24: Key components of B1 tourism projection

	Tropical North	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total GBR
Total tourist GRP, including business and other ($million)						
2001	870	290	314	246	304	2,024
2010	1,040	347	375	294	363	2,419
2020	1,267	422	457	358	443	2,949
Domestic visitor reef-interested GRP ($million)						
2001	309	97	103	81	40	630
2010	273	79	94	72	36	554
2020	243	73	85	67	31	499
Annual growth before adjustment of -0.8% pa						
2001-2010	-1.4%	-2.3%	-1.0%	-1.3%	-1.2%	-1.4%
2010-2020	-1.2%	-0.8%	-1.0%	-0.7%	-1.5%	-1.0%
Inbound visitor reef-interested GRP ($million)						
2001	345	22	35	16	13	431
2010	494	48	72	36	30	680
2020	681	47	106	42	45	921
Annual growth before adjustment of -0.8% pa						
2001-2010	4.1%	9.1%	8.3%	9.4%	9.7%	5.2%
2010-2020	3.3%	-0.2%	3.9%	1.6%	4.1%	3.1%
Domestic visitor reef-interested GRP, adjusted ($million)						
2001	309	97	103	81	40	630
2010	253	73	85	67	31	509
2020	208	63	74	57	21	423
Inbound visitor reef-interested GRP, adjusted ($million)						
2001	345	22	35	16	13	431
2010	461	44	68	33	27	633
2020	609	44	97	33	37	820
Total reduction in GRP ($million)						
2010	53	10	13	8	8	92
2020	107	13	20	19	18	177
Reduction compared with reef-interested GRP						
2010	-7%	-8%	-8%	-7%	-12%	-7%
2020	-12%	-11%	-10%	-17%	-24%	-12%
Reduction compared with total tourism GRP						
2010	-5%	-3%	-3%	-3%	-2%	-4%
2020	-8%	-3%	-4%	-5%	-4%	-6%

Table D25: Key components of B2 tourism projection

	Tropical North	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total GBR
Total tourist GRP, including business and other ($million)						
2001	870	290	314	246	304	2,024
2010	1,040	347	375	294	363	2,419
2020	1,267	422	457	358	443	2,949
Domestic visitor reef-interested GRP ($million)						
2001	309	97	103	81	40	630
2010	295	86	99	77	38	595
2020	288	85	97	76	37	583
Annual growth before adjustment of -0.6% pa						
2001-2010	-0.5%	-1.3%	-0.4%	-0.6%	-0.6%	-0.6%
2010-2020	-0.2%	-0.1%	-0.2%	-0.1%	-0.3%	-0.2%
Inbound visitor reef-interested GRP ($million)						
2001	345	22	35	16	13	431
2010	494	48	72	36	30	680
2020	681	46	106	42	45	920
Annual growth before adjustment of -0.6% pa						
2001-2010	4.1%	9.1%	8.3%	9.4%	9.7%	5.2%
2010-2020	3.3%	-0.4%	3.9%	1.6%	4.1%	3.1%
Domestic visitor reef-interested GRP, adjusted ($million)						
2001	309	97	103	81	40	630
2010	282	79	94	72	40	567
2020	262	69	84	68	40	523
Inbound visitor reef-interested GRP, adjusted ($million)						
2001	345	22	35	16	13	431
2010	469	46	69	35	27	646
2020	634	46	101	35	37	853
Total reduction in GRP ($million)						
2010	38	9	8	6	1	62
2020	73	16	18	15	5	127
Reduction compared with reef-interested GRP						
2010	-5%	-7%	-5%	-5%	-1%	-5%
2020	-8%	-12%	-9%	-13%	-6%	-8%
Reduction compared with total tourism GRP						
2010	-4%	-3%	-2%	-2%	0%	-3%
2020	-6%	-4%	-4%	-4%	-1%	-4%

Table D26: Projections for commercial fisheries (wild)

Basic weights: Benthic 35%, Pelagic 25%, Trawling 40% (after 2001 restructure)

Scenario	Tonnage caught				Average price	Change in GRP
	Benthic	Pelagic	Trawl	Total		
A: Change from base projection of no change in quantity						
Scenario A1						
2010	-20.0%	-10.0%	-10.0%	-13.5%	10.0%	-4.9%
2020	-55.0%	-35.0%	-35.0%	-42.0%	20.0%	-30.4%
Scenario A2						
2010	-15.0%	-7.5%	-7.5%	-10.1%	5.0%	-5.6%
2020	-50.0%	-30.0%	-30.0%	-37.0%	5.0%	-33.9%
Scenario B1						
2010	-5.0%	0.0%	-50.0%	-21.8%	5.0%	-17.8%
2020	-15.0%	-5.0%	-100.0%	-46.5%	15.0%	-38.5%
Scenario B2						
2010	0.0%	0.0%	-100.0%	-40.0%	5.0%	-37.0%
2020	-10.0%	-5.0%	-100.0%	-44.8%	15.0%	-36.5%

	Far North	Northern	Mackay	Fitzroy	WBB	Total GBR
B: Estimated gross regional product ($million at 2000-01 prices)						
2001	**30.5**	**18.6**	**20.1**	**16.3**	**29.2**	**114.6**
Scenario A1						
2010	32.1	19.6	21.2	17.2	30.8	120.8
2020	25.5	15.5	16.8	13.7	24.5	96.0
Scenario A2						
2010	30.4	18.5	20.0	16.2	29.1	114.2
2020	21.3	13.0	14.0	11.4	20.4	80.0
Scenario B1						
2010	26.4	16.1	17.4	14.1	25.3	99.4
2020	21.6	13.1	14.2	11.6	20.7	81.2
Scenario B2						
2010	20.3	12.3	13.4	10.8	19.4	76.2
2020	22.3	13.6	14.7	11.9	21.4	83.9
C: Estimated employment						
2001	**627**	**427**	**674**	**472**	**1,175**	**3,374**
Scenario A1						
2010	596	406	641	449	1,118	3,210
2020	436	297	469	328	818	2,348
Scenario A2						
2010	591	403	636	445	1,109	3,184
2020	415	282	446	312	777	2,232
Scenario B1						
2010	515	350	554	387	965	2,772
2020	386	262	415	290	723	2,076
Scenario B2						
2010	395	269	425	297	740	2,125
2020	398	271	428	300	746	2,144

Table D27: Estimated impact on total regional economy: Scenario A1

	Far North Queensland	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total GBR
Base projection						
Gross value of production, eight industries ($million in 2000-01 prices) - from Table D9						
2001	2,926	3,380	3,916	6,676	1,440	18,337
2010	3,609	4,636	4,270	8,072	1,566	22,153
2020	4,810	4,546	4,613	9,056	1,757	24,781
Estimated gross regional product, eight industries ($million in 2000-01 prices)						
2001	1,491	1,722	1,995	3,402	734	9,344
2010	1,839	2,362	2,176	4,113	798	11,288
2020	2,451	2,317	2,350	4,614	895	12,627
Annual rate of growth, base projection						
2001-10	2.36%	3.57%	0.97%	2.13%	0.94%	2.12%
2010-20	2.91%	-0.20%	0.77%	1.16%	1.15%	1.13%
Adjustment for Great Barrier Reef						
Reduction in tourism GRP						
2010	82	15	16	13	4	130
2020	177	36	38	30	7	288
Reduction in wild fisheries GRP						
2010	1	1	1	1	1	5
2020	11	7	7	6	11	42
Regional multiplier effect (80% of primary impact)						
2010	67	13	14	11	4	108
2020	150	34	36	29	14	264
Total change in GRP including 1.8 regional multiplier effect						
2010	150	29	30	25	10	243
2020	338	77	81	65	32	593
Adjusted GRP, eight industries						
2010	1,689	2,334	2,145	4,088	789	11,045
2020	2,112	2,240	2,269	4,550	864	12,034
Annual rate of growth, A1 projection (driving industries one-third of total regional economy)						
2001-10	2.04%	3.53%	0.92%	2.11%	0.89%	2.04%
2010-20	2.71%	-0.27%	0.70%	1.13%	1.07%	1.04%

Table D28: Estimated impact on total regional economy: Scenario A2

	Far North Queensland	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total GBR
Base projection						
Gross value of production, eight industries ($million in 2000-01 prices) - from Table D12						
2001	2,926	3,380	3,916	6,676	1,440	18,337
2010	2,981	3,142	3,767	5,674	1,255	16,820
2020	3,267	3,257	3,490	5,211	1,301	16,527
Estimated gross regional product, eight industries ($million in 2000-01 prices)						
2001	1,491	1,722	1,995	3,402	734	9,344
2010	1,519	1,601	1,920	2,891	639	8,571
2020	1,665	1,660	1,779	2,655	663	8,421
Annual rate of growth, base projection						
2001-10	0.21%	-0.81%	-0.43%	-1.79%	-1.52%	-0.96%
2010-20	0.92%	0.36%	-0.76%	-0.85%	0.36%	-0.18%
Adjustment for Great Barrier Reef						
Change in tourism GRP						
2010	120	31	27	18	11	207
2020	255	34	59	29	26	403
Change in wild fisheries GRP						
2010	2	1	1	1	2	6
2020	11	7	7	6	10	40
Regional multiplier effect (80% of primary impact)						
2010	97	26	22	15	10	171
2020	213	32	53	28	29	355
Total change in GRP including 1.8 regional multiplier effect						
2010	219	58	51	34	23	384
2020	478	73	119	63	65	798
Adjusted GRP, eight industries						
2010	1,300	1,544	1,869	2,857	617	8,187
2020	1,187	1,587	1,660	2,593	598	7,623
Annual rate of growth, A1 projection (driving industries one-third of total regional economy)						
2001-10	-0.34%	-0.94%	-0.53%	-1.83%	-1.65%	-1.12%
2010-20	0.40%	0.33%	-0.90%	-0.89%	0.14%	-0.35%

Table D29: Estimated impact on total regional economy: Scenario B1

	Far North Queensland	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total GBR
Base projection						
Gross value of production, eight industries ($million in 2000-01 prices) - from Table D15						
2001	2,926	3,380	3,916	6,676	1,440	18,337
2010	3,415	4,152	4,060	7,025	1,495	20,148
2020	4,606	4,133	4,195	7,861	1,647	22,442
Estimated gross regional product, eight industries ($million in 2000-01 prices)						
2001	1,491	1,722	1,995	3,402	734	9,344
2010	1,740	2,116	2,069	3,580	762	10,266
2020	2,347	2,106	2,138	4,006	839	11,435
Annual rate of growth, base projection						
2001-10	1.7%	2.3%	0.4%	0.6%	0.4%	1.05%
2010-20	3.0%	0.0%	0.3%	1.1%	1.0%	1.08%
Adjustment for Great Barrier Reef						
Change in tourism GRP						
2010	53	10	13	8	8	92
2020	107	13	20	19	18	177
Change in wild fisheries GRP						
2010	6	3	4	3	5	21
2020	13	8	9	7	13	51
Adjustment for delayed aquaculture development						
2010	6	2	1	-	1	10
2020	21	15	8	-	6	50
Regional multiplier effect (80% of primary impact)						
2010	52	12	14	9	11	98
2020	113	29	29	21	30	222
Total change in GRP including 1.8 regional multiplier effect						
2010	110	26	31	20	25	211
2020	234	50	58	47	60	450
Adjusted GRP, eight industries						
2010	1,630	2,090	2,038	3,560	737	10,055
2020	2,113	2,056	2,079	3,958	779	10,986
Annual rate of growth, A1 projection (driving industries one-third of total regional economy)						
2001-10	1.49%	2.27%	0.35%	0.55%	0.29%	0.97%
2010-20	2.91%	-0.09%	0.28%	1.11%	0.84%	1.02%

Table D30: Estimated impact on total regional economy: Scenario B2

	Far North Queensland	Northern	Mackay	Fitzroy	Wide Bay-Burnett	Total GBR
Base projection						
Gross value of production, eight industries ($million in 2000-01 prices) - from Table D18						
2001	2,926	3,380	3,916	6,676	1,440	18,337
2010	3,415	4,152	4,060	7,025	1,495	20,148
2020	4,626	4,133	4,195	7,861	1,647	22,462
Estimated gross regional product, eight industries ($million in 2000-01 prices)						
2001	1,491	1,722	1,995	3,402	734	9,344
2010	1,740	2,116	2,069	3,580	762	10,266
2020	2,357	2,106	2,138	4,006	839	11,445
Annual rate of growth, base projection						
2001-10	1.73%	2.31%	0.40%	0.57%	0.41%	1.05%
2010-20	3.08%	-0.05%	0.33%	1.13%	0.98%	1.09%
Adjustment for Great Barrier Reef						
Change in tourism GRP						
2010	38	9	8	6	1	62
2020	73	16	18	15	5	127
Change in wild fisheries GRP						
2010	12	7	8	6	11	44
2020	13	8	8	7	12	48
Regional multiplier effect (80% of primary impact)						
2010	40	13	13	10	10	85
2020	69	19	21	17	14	140
Total change in GRP including 1.8 regional multiplier effect						
2010	90	29	28	22	22	191
2020	154	43	48	39	31	315
Adjusted GRP, eight industries						
2010	1,651	2,087	2,041	3,558	740	10,075
2020	2,203	2,063	2,090	3,966	808	11,131
Annual rate of growth, A1 projection (driving industries one-third of total regional economy)						
2001-10	1.54%	2.26%	0.35%	0.55%	0.31%	0.98%
2010-20	3.03%	-0.07%	0.30%	1.12%	0.95%	1.06%

Appendix E: IPCC projections

This appendix shows key projections for the four marker scenarios A1B, A2, B1 and B2, plus the two variants on A1: A1F1 and A1T. The marker scenarios were made by one of the six organisations listed below:

- Asian Pacific Integrated Model (AIM) from the National Institute of Environmental Studies in Japan.

- Atmospheric Stabilization Framework Model (ASF) from ICF Consulting in the USA.

- Integrated Model to Assess the Greenhouse Effect (IMAGE) from the National Institute for Public Health and Environmental Hygiene (RIVM), used in connection with the Dutch Bureau for Economic Policy Analysis (CPB).

- Multiregional Approach for Resource and Industry Allocation (MARIA) from the Science University of Tokyo in Japan.

- Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) from the International Institute of Applied Systems Analysis (IIASA) in Austria.

- Mini Climate Assessment Model (MiniCAM) from the Pacific Northwest National Laboratory (PNNL) in the USA.

Table E1: IPCC projections: A1 variants

	Scenario A1F1 (AIG MINICAM) Fossil fuels dominate					Scenario A1T (MESSAGE) Decarbonisation				
	1990	2000	2020	2050	2100	1990	2000	2020	2050	2100
Population (million)	5293	6117	7493	8704	7137	5262	6091	7617	8704	7056
GNP/GDP (trillion US$)[1]	20.7	26.6	56.6	183.4	525.0	20.9	26.8	57.0	187.1	550.0
Primary Energy (EJ)[2]										
Coal	88	115	193	475	607	91	106	151	119	25
Oil	131	136	173	283	248	128	155	193	250	77
Gas	70	85	203	398	578	71	87	166	324	196
Nuclear	24	26	51	137	233	7	8	17	115	114
Biomass	0	6	18	52	123	46	46	75	183	370
Other Renewables	24	24	32	86	284	8	15	48	222	1239
Total	336	392	669	1431	2073	352	416	649	1213	2021
Ratios										
Coal	26%	29%	29%	33%	29%	26%	25%	23%	10%	1%
Oil	39%	35%	26%	20%	12%	37%	37%	30%	21%	4%
Gas	21%	22%	30%	28%	28%	20%	21%	26%	27%	10%
Nuclear	7%	7%	8%	10%	11%	2%	2%	3%	9%	6%
Biomass	0%	2%	3%	4%	6%	13%	11%	12%	15%	18%
Other Renewables	7%	6%	5%	6%	14%	2%	4%	7%	18%	61%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Anthropogenic Emissions[3]										
Fossil Fuel CO_2 (GtC)[4]	5.99	6.90	11.19	23.10	30.32	5.99	6.90	12.12	16.01	4.31
Other CO_2 (GtC)	1.11	1.07	1.55	0.80	-2.08	1.11	1.07	0.52	0.37	0.00
Total CO_2 (GtC)	7.10	7.97	12.73	23.90	28.24	7.10	7.97	12.64	16.38	4.32
CH_4 (million tons)	310	323	416	630	735	310	323	421	452	274
N_2O (million tons)	6.7	7.0	9.3	14.5	16.6	6.7	7.0	7.2	7.4	5.4
SO_x (million tons)	70.9	69.0	86.9	80.5	40.1	70.9	69.0	100.2	64.1	20.2

[1] At constant 1990 values

[2] Exajoules (10^{18} J) - peaks in CO_2 emissions reached in 2080 (A1F1), 2050 (A1B), and 2040 (B1)

[3] Standardised (the selected greenhouse gases are carbon dioxide, methane, nitrous oxide, and sulphur emissions)

[4] Gigatons carbon

Source: IPCC 2000

Table E2: Scenarios for IPCC projections: Marker scenarios for A1 and A2 storylines

	Scenario A1B (AIM) Balanced fuel mix					Scenario A2 (ASF) Heterogeneous regionalism				
	1990	**2000**	**2020**	**2050**	**2100**	**1990**	**2000**	**2020**	**2050**	**2100**
Population (million)	5262	6117	7493	8704	7056	5282	6170	8206	11296	15068
GNP/GDP (trillion US$)[1]	20.9	26.7	56.5	181.3	528.5	20.1	25.2	40.5	81.6	242.8
Primary Energy (EJ)[2]										
Coal	93	99	163	186	84	92	90	129	294	904
Oil	143	167	238	214	125	134	172	291	228	0
Gas	73	91	196	465	576	71	74	126	275	331
Nuclear	6	8	30	123	78	8	13	17	62	234
Biomass	50	48	61	193	376	0	0	12	71	162
Other Renewables	10	12	23	167	987	8	11	20	42	86
Total	376	424	711	1347	2226	313	360	595	971	1717
Ratios										
Coal	25%	23%	23%	14%	4%	29%	25%	22%	30%	53%
Oil	38%	39%	33%	16%	6%	43%	48%	49%	23%	0%
Gas	19%	21%	27%	35%	26%	23%	21%	21%	28%	19%
Nuclear	2%	2%	4%	9%	3%	3%	3%	3%	6%	14%
Biomass	13%	11%	9%	14%	17%	0%	0%	2%	7%	9%
Other Renewables	3%	3%	3%	12%	44%	3%	3%	3%	4%	5%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Anthropogenic Emissions[3]										
Fossil Fuel CO_2 (GtC)[4]	5.99	6.90	12.12	16.01	13.10	5.99	6.90	11.01	16.49	28.91
Other CO_2 (GtC)	1.11	1.07	0.52	0.37	0.39	1.11	1.07	1.25	0.93	0.18
Total CO_2 (GtC)	7.10	7.97	12.64	16.38	13.49	7.10	7.97	12.25	17.43	29.09
CH_4 (million tons)	310	323	421	452	289	310	323	424	598	889
N_2O (million tons)	6.7	7.0	7.2	7.4	7.0	6.7	7.0	9.6	12.0	16.5
SO_x (million tons)	70.9	69.0	100.2	64.1	27.6	70.9	69.0	99.5	105.4	60.3

[1] At constant 1990 values

[2] Exajoules (10^{18} J) - peaks in CO_2 emissions reached in 2080 (A1F1), 2050 (A1B), and 2040 (B1)

[3] Standardised (the selected greenhouse gases are carbon dioxide, methane, nitrous oxide, and sulphur emissions)

[4] Gigatons carbon

Source: IPCC 2000

Table E3: Scenarios for IPCC projections: Marker scenarios for B1 and B2 storylines

	Scenario B1 (IMAGE) Global policy reform					Scenario B2 (MESSAGE) Regional & social sustainability				
	1990	**2000**	**2020**	**2050**	**2100**	**1990**	**2000**	**2020**	**2050**	**2100**
Population (million)	5280	6122	7618	8708	7047	5262	6091	7672	9367	10414
GNP/GDP (trillion US$)[1]	21.0	26.8	52.6	135.6	328.4	20.9	28.3	50.7	109.5	234.9
Primary Energy (EJ)[2]										
Coal	105	109	134	167	44	91	91	98	86	300
Oil	129	141	206	228	99	128	168	214	227	52
Gas	62	71	138	173	103	71	84	150	297	336
Nuclear	8	14	33	105	165	7	8	16	48	142
Biomass	3	4	29	95	67	46	43	53	105	315
Other Renewables	61	68	66	46	36	8	14	34	107	212
Total	368	407	606	813	514	352	408	566	869	1357
Ratios										
Coal	29%	27%	22%	21%	8%	26%	22%	17%	10%	22%
Oil	35%	35%	34%	28%	19%	37%	41%	38%	26%	4%
Gas	17%	17%	23%	21%	20%	20%	21%	27%	34%	25%
Nuclear	2%	3%	5%	13%	32%	2%	2%	3%	5%	10%
Biomass	1%	1%	5%	12%	13%	13%	11%	9%	12%	23%
Other Renewables	17%	17%	11%	6%	7%	2%	3%	6%	12%	16%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Anthropogenic Emissions[3]										
Fossil Fuel CO_2 (GtC)[4]	5.99	6.90	10.00	11.70	5.20	5.99	6.90	10.00	11.70	13.82
Other CO_2 (GtC)	1.11	1.07	0.63	-0.41	-0.97	1.11	1.07	0.63	-0.41	-0.50
Total CO_2 (GtC)	7.10	7.97	10.63	11.29	4.23	7.10	7.97	10.63	11.29	13.32
CH_4 (million tons)	310	323	377	359	236	310	323	377	359	597
N_2O (million tons)	6.7	7.0	8.1	8.3	5.7	6.7	7.0	8.1	8.3	6.9
SO_x (million tons)	70.9	69.0	74.6	68.9	24.9	70.9	69.0	74.6	68.9	47.9

[1] At constant 1990 values

[2] Exajoules (10^{18} J) - peaks in CO_2 emissions reached in 2080 (A1F1), 2050 (A1B), and 2040 (B1)

[3] Standardised (the selected greenhouse gases are carbon dioxide, methane, nitrous oxide, and sulphur emissions)

[4] Gigatons carbon

Source: IPCC 2000

Table E4: IPCC projections for world in three main regions: A1 Variants

Main region	Absolute levels 1990	2000	2020	2050	2100	Proportion of world 1990	2000	2020	2050	2100
Scenario A1F1 (AIG MiniCAM) - Fossil fuels dominate										
Population (million)										
OECD 90	838	908	1007	1081	1112	15.8%	14.9%	13.2%	12.4%	15.6%
Asia-Pacific	2790	3226	3937	4219	2919	52.7%	52.9%	51.7%	48.5%	40.9%
Rest of world	1665	1965	2674	3403	3106	31.4%	32.2%	35.1%	39.1%	43.5%
Total	5293	6100	7618	8703	7137	100.0%	100.0%	100.0%	100.0%	100.0%
GNP/GDP ($US trillion)										
OECD 90	16.3	20.5	31.5	53.5	117.7	79.0%	74.8%	59.7%	32.6%	22.4%
Asia-Pacific	1.4	3.1	11.7	61.0	192.6	6.8%	11.2%	22.2%	37.2%	36.7%
Rest of world	2.9	3.9	9.5	49.4	214.7	14.2%	14.1%	18.0%	30.1%	40.9%
Total	20.7	27.4	52.8	164.0	525.0	100.0%	100.0%	100.0%	100.0%	100.0%
GDP per head										
OECD 90	$19,505	$22,563	$31,319	$49,514	$105,767	499%	502%	452%	263%	144%
Asia-Pacific	$ 503	$ 951	$ 2,981	$14,465	$ 65,978	13%	21%	43%	77%	90%
Rest of world	$ 1,771	$ 1,961	$ 3,554	$14,527	$ 69,130	45%	44%	51%	77%	94%
Total	$ 3,911	$ 4,495	$ 6,927	$18,843	$ 73,551	100%	100%	100%	100%	100%
Total CO_2 emissions (GtC)										
OECD 90	2.83	3.20	4.19	5.07	7.55	39.8%	40.1%	32.9%	21.2%	26.7%
Asia-Pacific	1.53	2.03	4.54	10.30	9.59	21.5%	25.5%	35.6%	43.1%	33.9%
Rest of world	2.75	2.74	4.00	8.53	11.10	38.7%	34.3%	31.4%	35.7%	39.3%
Total	7.10	7.97	12.73	23.90	28.24	100.0%	100.0%	100.0%	100.0%	100.0%
Scenario A1T MESSAGE - Decarbonisation										
Population (million)										
OECD 90	859	919	1007	1081	1110	16.3%	15.0%	13.2%	12.4%	15.7%
Asia-Pacific	2798	3261	3937	4220	2882	53.2%	53.3%	51.7%	48.5%	40.8%
Rest of world	1605	1937	2673	3403	3064	30.5%	31.7%	35.1%	39.1%	43.4%
Total	5262	6117	7617	8704	7056	100.0%	100.0%	100.0%	100.0%	100.0%
GNP/GDP ($US trillion)										
OECD 90	16.4	20.6	31.6	55.7	124.3	63.7%	61.7%	47.0%	29.9%	23.2%
Asia-Pacific	1.5	2.7	13.5	65.3	218.2	5.8%	8.1%	20.1%	35.0%	40.8%
Rest of world	7.8	10.1	22.1	65.4	192.5	30.5%	30.2%	32.9%	35.1%	36.0%
Total	25.7	33.4	67.2	186.4	535.0	100.0%	100.0%	100.0%	100.0%	100.0%
GDP per head										
OECD 90	$19,092	$22,416	$31,380	$51,526	$111,982	488%	499%	453%	273%	152%
Asia-Pacific	$ 536	$ 828	$ 3,429	$15,474	$ 75,711	14%	18%	50%	82%	103%
Rest of world	$ 4,888	$ 5,214	$ 8,282	$19,232	$ 62,836	125%	116%	120%	102%	85%
Total	$ 4,893	$ 5,460	$ 8,827	$21,421	$ 75,826	125%	121%	127%	114%	103%
Total CO_2 emissions (GtC)										
OECD 90	2.83	3.20	3.20	1.96	0.67	39.8%	40.1%	31.2%	16.0%	15.4%
Asia-Pacific	1.53	2.03	3.77	5.22	1.53	21.5%	25.5%	36.7%	42.6%	35.4%
Rest of world	2.75	2.74	3.29	5.08	2.12	38.7%	34.3%	32.1%	41.5%	49.2%
Total	7.10	7.97	10.26	12.26	4.32	100.0%	100.0%	100.0%	100.0%	100.0%

Source: IPCC 2000

Table E5: IPCC projections for world in three main regions: A1 and A2 markers

	Absolute levels					Proportion of world				
Main region	1990	2000	2020	2050	2100	1990	2000	2020	2050	2100
Scenario A1B AIM - Balanced fuel growth										
Population (million)										
OECD 90	859	919	1002	1081	1110	16.3%	15.0%	13.4%	12.4%	15.7%
Asia-Pacific	2798	3261	3851	4220	2882	53.2%	53.3%	51.4%	48.5%	40.8%
Rest of world	1605	1938	2640	3403	3065	30.5%	31.7%	35.2%	39.1%	43.4%
Total	5262	6117	7493	8704	7056	100.0%	100.0%	100.0%	100.0%	100.0%
GNP/GDP ($US trillion)										
OECD 90	16.4	20.5	31.0	54.1	121.1	78.4%	76.8%	54.9%	29.9%	22.9%
Asia-Pacific	1.5	2.7	12.3	62.7	207.3	7.2%	10.1%	21.8%	34.6%	39.2%
Rest of world	3.0	3.5	13.1	64.4	200.1	14.4%	13.1%	23.3%	35.5%	37.9%
Total	20.9	26.7	56.5	181.3	528.5	100.0%	100.0%	100.0%	100.0%	100.0%
GDP per head										
OECD 90	$ 19,051	$ 22,325	$ 30,974	$ 50,094	$ 109,191	480%	511%	411%	240%	146%
Asia-Pacific	$ 539	$ 831	$ 3,197	$ 14,869	$ 71,926	14%	19%	42%	71%	96%
Rest of world	$ 1,872	$ 1,804	$ 4,976	$ 18,933	$ 65,285	47%	41%	66%	91%	87%
Total	$ 3,966	$ 4,369	$ 7,537	$ 20,832	$ 74,901	100%	100%	100%	100%	100%
Total CO_2 emissions (GtC)										
OECD 90	2.83	3.20	3.54	3.35	2.31	39.8%	40.1%	28.0%	20.5%	17.1%
Asia-Pacific	1.53	2.03	4.16	5.98	5.46	21.5%	25.5%	32.9%	36.5%	40.5%
Rest of world	2.75	2.74	4.94	7.05	5.71	38.7%	34.3%	39.1%	43.0%	42.4%
Total	7.10	7.97	12.64	16.38	13.49	100.0%	100.0%	100.0%	100.0%	100.0%
Scenario A2 ASF - Heterogeneous regionalism										
Population (million)										
OECD 90	851	923	1027	1151	1496	16.1%	15.0%	12.5%	10.2%	9.9%
Asia-Pacific	2791	3295	4308	5764	7340	52.8%	53.4%	52.5%	51.0%	48.7%
Rest of world	1640	1952	2871	4381	6232	31.0%	31.6%	35.0%	38.8%	41.4%
Total	5282	6170	8206	11296	15068	100.0%	100.0%	100.0%	100.0%	100.0%
GNP/GDP ($US trillion)										
OECD 90	15.3	18.7	26.0	39.9	87.6	76.2%	74.1%	64.1%	48.9%	36.1%
Asia-Pacific	1.4	2.3	5.3	15.0	57.1	7.2%	9.1%	13.1%	18.3%	23.5%
Rest of world	3.3	4.2	9.2	26.7	98.1	16.6%	16.8%	22.8%	32.8%	40.4%
Total	20.1	25.2	40.5	81.6	242.8	100.0%	100.0%	100.0%	100.0%	100.0%
GDP per head										
OECD 90	$ 17,993	$ 20,254	$ 25,280	$ 34,646	$ 58,529	473%	495%	512%	480%	363%
Asia-Pacific	$ 515	$ 693	$ 1,234	$ 2,595	$ 7,785	14%	17%	25%	36%	48%
Rest of world	$ 2,034	$ 2,173	$ 3,213	$ 6,100	$ 15,737	54%	53%	65%	84%	98%
Total	$ 3,802	$ 4,088	$ 4,936	$ 7,221	$ 16,113	100%	100%	100%	100%	100%
Total CO_2 emissions (GtC)										
OECD 90	2.83	3.20	3.96	4.74	6.91	39.8%	40.1%	32.3%	27.2%	23.8%
Asia-Pacific	1.53	2.03	3.92	6.48	10.74	21.5%	25.5%	32.0%	37.2%	36.9%
Rest of world	2.75	2.74	4.38	6.20	11.44	38.7%	34.3%	35.7%	35.6%	39.3%
Total	7.10	7.97	12.25	17.43	29.09	100.0%	100.0%	100.0%	100.0%	100.0%

Source: IPCC 2000

Table E6: IPCC projections for world in three main regions: B1 and B2 markers

Main region	Absolute levels					Proportion of world				
	1990	2000	2020	2050	2100	1990	2000	2020	2050	2100
Scenario B1 IMAGE - Global policy reform										
Population (million)										
OECD 90	799	849	932	1001	1032	15.1%	13.9%	12.2%	11.5%	14.6%
Asia-Pacific	2781	3246	3929	4220	2886	52.7%	53.0%	51.6%	48.5%	41.0%
Rest of world	1700	2027	2757	3487	3129	32.2%	33.1%	36.2%	40.0%	44.4%
Total	5280	6122	7618	8708	7047	100.0%	100.0%	100.0%	100.0%	100.0%
GNP/GDP ($US trillion)										
OECD 90	16.5	20.2	32.4	49.9	82.3	78.7%	75.6%	61.6%	36.8%	25.1%
Asia-Pacific	1.4	2.7	8.7	37.9	103.1	6.7%	10.2%	16.5%	28.0%	31.4%
Rest of world	3.1	3.8	11.5	47.8	143.0	14.6%	14.2%	21.9%	35.3%	43.5%
Total	21.0	26.8	52.6	135.6	328.4	100.0%	100.0%	100.0%	100.0%	100.0%
GDP per head										
OECD 90	$20,638	$23,840	$34,732	$49,820	$79,738	520%	545%	503%	320%	171%
Asia-Pacific	$ 503	$ 838	$ 2,207	$ 8,983	$35,724	13%	19%	32%	58%	77%
Rest of world	$ 1,806	$ 1,880	$ 4,178	$13,705	$45,695	45%	43%	61%	88%	98%
Total	$ 3,970	$ 4,373	$ 6,899	$15,568	$46,597	100%	100%	100%	100%	100%
Total CO_2 emissions (GtC)										
OECD 90	2.83	3.20	3.26	1.90	0.99	39.8%	40.1%	30.7%	16.9%	23.4%
Asia-Pacific	1.53	2.03	3.40	3.85	0.93	21.5%	25.5%	32.0%	34.1%	22.0%
Rest of world	2.75	2.74	3.97	5.53	2.31	38.7%	34.3%	37.4%	49.0%	54.6%
Total	7.10	7.97	10.63	11.29	4.23	100.0%	100.0%	100.0%	100.0%	100.0%
Scenario B2 MESSAGE - Regional and social sustainability										
Population (million)										
OECD 90	859	916	982	976	928	16.3%	15.0%	12.8%	10.4%	8.9%
Asia-Pacific	2798	3248	4008	4696	4968	53.2%	53.3%	52.2%	50.1%	47.7%
Rest of world	1605	1927	2682	3695	4518	30.5%	31.6%	35.0%	39.4%	43.4%
Total	5262	6091	7672	9367	10414	100.0%	100.0%	100.0%	100.0%	100.0%
GNP/GDP ($US trillion)										
OECD 90	16.4	21.1	30.3	38.3	56.6	78.5%	74.6%	59.8%	35.0%	24.1%
Asia-Pacific	1.5	3.5	13.2	41.8	97.1	7.2%	12.4%	26.0%	38.2%	41.3%
Rest of world	3.0	3.7	7.2	29.4	81.2	14.4%	13.1%	14.2%	26.8%	34.6%
Total	20.9	28.3	50.7	109.5	234.9	100.0%	100.0%	100.0%	100.0%	100.0%
GDP per head										
OECD 90	$19,092	$23,035	$30,855	$39,242	$60,991	481%	496%	467%	336%	270%
Asia-Pacific	$ 536	$ 1,078	$ 3,293	$ 8,901	$19,545	13%	23%	50%	76%	87%
Rest of world	$ 1,869	$ 1,920	$ 2,685	$ 7,957	$17,973	47%	41%	41%	68%	80%
Total	$ 3,972	$ 4,646	$ 6,608	$11,690	$22,556	100%	100%	100%	100%	100%
Total CO_2 emissions (GtC)										
OECD 90	2.83	3.20	3.64	3.22	2.91	39.8%	40.1%	40.3%	29.2%	21.8%
Asia-Pacific	1.53	2.03	2.87	4.10	5.63	21.5%	25.5%	31.7%	37.2%	42.3%
Rest of world	2.75	2.74	2.53	3.69	4.78	38.7%	34.3%	28.0%	33.5%	35.9%
Total	7.10	7.97	9.05	11.01	13.32	100.0%	100.0%	100.0%	100.0%	100.0%

Source: IPCC 2000

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Hans Hoegh-Guldberg graduated from the University of Copenhagen with a First Class Degree in Economics. Up to 1984 he worked with three leading economic and management consulting companies in Sydney and eight years as a strategist and new business planner with a major Australian manufacturing company. These years gave him a solid grounding in areas including macroeconomic forecasting, industry economics, Australian regional studies, tourism, cost-benefit analysis and strategic planning. He was admitted as a Member of the Institute of Management Consultants in 1979 and is a Certified Management Consultant.

In 1984 he founded Economic Strategies Pty Ltd with a focus on medium and long-term change. He first established a niche in the cultural economics area with a major pioneering study for the Australia Council, The Australian Music Industry (published in 1987). Over the years more than 30 other published studies of the cultural and arts sector followed, including A Study of Cultural Tourism in Australia for the Commonwealth Government with Peter Brokensha (1992) and The Arts Economy 1968-98: Three decades of growth in Australia (2000) for the Australia Council, which is regarded as the definitive presentation of the growth of the arts industries in this country.

Hans's interest in scenario planning started in 1998 when he published four futures for Indonesia, following the collapse of the Soeharto regime (Indonesia Outlook: Four Scenarios to 2008). His first major venture into ecological economics was Pacific in Peril: Biological, Economic and Social Impacts of Climate Change on Pacific Coral Reefs for Greenpeace with Ove Hoegh-Guldberg and others (2000). Other studies of the socioeconomic impact of climate change followed.

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Professor Ove Hoegh-Guldberg (44) has dedicated over twenty years of his life to the study and protection of one of the world's most unique habitats, coral reefs. Ove began his career at the University of Sydney, going on to complete his PhD at the University of California. Since completing his PhD in 1989 Ove has made a significant contribution to the disciplines of research and teaching in the groundbreaking area of coral bleaching and its connection to global warming. Over the past decade Ove has produced over seventy peer reviewed research publications in internationally renowned publications, received awards in Australia and the USA for research and teaching, and served on numerous societies at both national and international levels for the protection of coral habitats.

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Before joining the World Bank in 1990, John Dixon was a researcher at the East-West Centre in Honolulu, and also worked with the Ford Foundation in Indonesia. His recent work has focussed on the economics of parks and protected areas, especially marine parks, tourism and the environment interactions, the economics of cultural heritage, and the development of indicators to measure sustainable development. Recent professional work includes activities in China and East Asia, Latin America and the Caribbean, and Russia.

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Dr Lara Hansen is the Chief Scientist for WWF's Climate Change Program. She studies the effects of anthropogenic change on marine and freshwater ecosystems. Her current focus is on developing conservation strategies in response to climate change. She earned her Ph.D. in Ecology from the University of California.

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In 1988 Michael became a member of the tenured academic staff where he remained until 2001 when he accepted a Professorial Position at James Cook University. His scientific background is in reef ecology, with an emphasis on fishes, and biological oceanography. His projects have encompassed a range of latitudes. In addition to research, he teaches undergraduate and postgraduate students and supervises many postgraduate students.

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Prof David Stout was New South Wales' Rhodes Scholar in 1954. He studied Economics and Philosophy at Magdalen College, Oxford, and stayed on to become an economics don at Oxford until the mid 1970s. He resigned his fellowship to head up economics at the UK tripartite National Economic Development Council. Following this, he was appointed Professor of Economics at Leicester University. In the 1980s, he was recruited by Unilever to head its corporate development and economics function in London employing a team of over 50 economists.

Recently, he has been the Director of the Centre for Business Strategy at the London Business School. He has returned to Australia a number of times as an advisor on inflation and incomes policy. In the mid 1960s, he wrote a report, published by the UK Ministry of Overseas Development, on the New Hebrides economy and its taxation policy. Between 1998 and 2000 he published a number of papers on the strategic use of scenarios.

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Prof Jeff Wilks is currently Professor of Tourism and Director, Centre for Tourism & Risk Management at The University of Queensland, Australia. A qualified Psychologist and Lawyer, he has a particular interest in the health and safety of tourists. In the area of marine tourism Jeff has published extensively in industry magazines and academic journals, including production of the book Scuba Safety in Australia.

As a marine tourism consultant Jeff has worked with government departments and tourism industry groups along the Great Barrier Reef. He is currently a member of the Risk Management Advisory Committee for Surf Life Saving Queensland, and a Consultant in Safety and Security for the World Tourism Organization in Madrid.

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