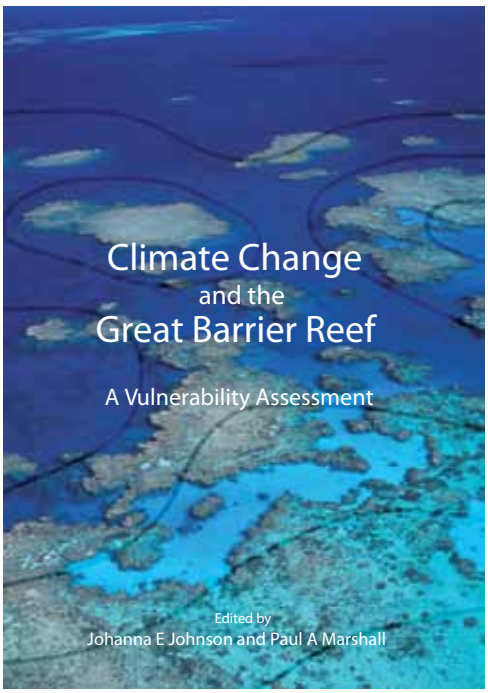

Climate Change and the Great Barrier Reef

A Vulnerability Assessment

Edited by Johanna E Johnson and Paul A Marshall

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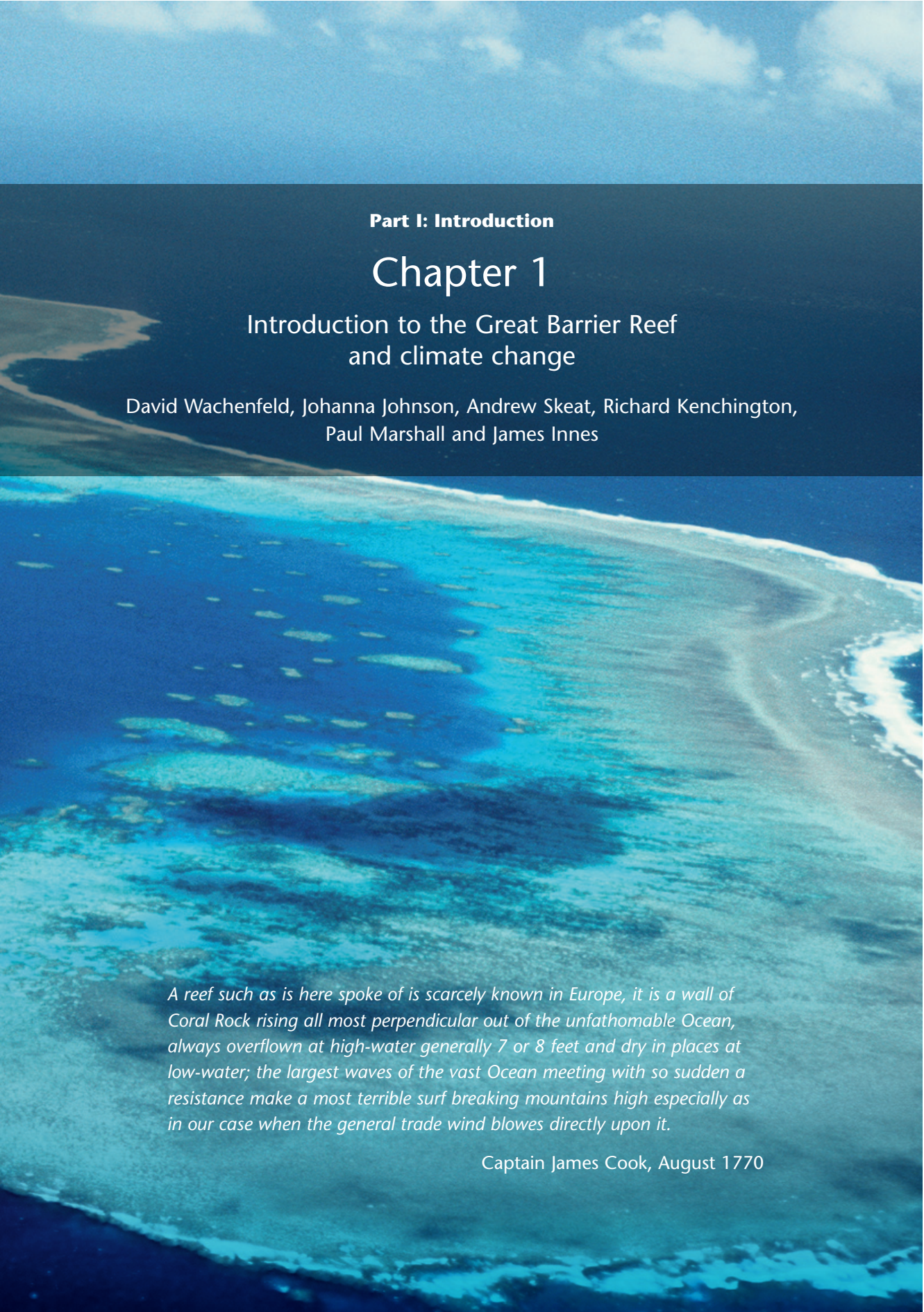


Part I: Introduction

Chapter 1

Introduction to the Great Barrier Reef and climate change

David Wachenfeld, Johanna Johnson, Andrew Skeat, Richard Kenchington, Paul Marshall and James Innes

A reef such as is here spoke of is scarcely known in Europe, it is a wall of Coral Rock rising all most perpendicular out of the unfathomable Ocean, always overflown at high-water generally 7 or 8 feet and dry in places at low-water; the largest waves of the vast Ocean meeting with so sudden a resistance make a most terrible surf breaking mountains high especially as in our case when the general trade wind blowes directly upon it.

Captain James Cook, August 1770

1.1 Why do a vulnerability assessment?

The Great Barrier Reef owes its genesis to a change in climate approximately twelve thousand years ago. As the last ice age ended, glaciers melted and sea level started to rise and stabilised at present levels about six thousand years ago, which is when the reef formed. It may seem ironic then, that climate change is now regarded as the single biggest threat to the future of the Great Barrier Reef. Yet, human influences on the global climate system are causing changes that have not been seen for hundreds of thousands of years, at a pace that is likely to exceed anything experienced for many millions of years.

Worldwide, landscapes and ecological systems, together with the social and economic structures that depend on them, are facing a new challenge that is truly global in scale. While few systems are likely to benefit from climate change, coral reefs are particularly vulnerable. Mass coral bleaching events, resulting when sea temperatures become unusually hot, have already caused serious damage to over 16 percent of the world's coral reefs[22]. Although the Great Barrier Reef has not suffered the levels of damage seen in many other regions, up to 5 percent of reefs were severely degraded in each of the 1998 and 2002 bleaching events. Projections of future sea temperatures suggest that coral bleaching could become an annual phenomenon in the course of this century, threatening to undermine the physical and ecological foundations of this diverse and productive ecosystem.

While we have been working to understand the implications of increased sea temperatures for corals, other vulnerabilities are also coming to light. Temperature-sensitivities of other species, such as microbes, plankton, fishes, marine turtles and seabirds indicate the potential for impacts throughout the trophic system. Changes to other environmental variables suggest other impacts on species and habitats, possibly more subtle but also less reversible. The implications of ocean acidification for calcifying organisms such as corals and some plankton, for example, could be profound.

As our awareness of the immediacy and significance of climate change has increased, so, too, has our need to understand the threat. Knowledge of the vulnerability of the Great Barrier Reef to climate change is essential to inform and underpin actions to meaningfully respond to this challenge. While climate change cannot be fully averted, there is much that can, and must, be done to reduce its impacts and to prepare for the changes that are inevitable. This book was conceived to provide the scientific basis for an informed, targeted and effective plan of action to mitigate and adapt to the effects of climate change. While its focus is on the Great Barrier Reef, it is designed to be of interest and value to all who seek to understand the vulnerability of typical marine ecosystems to climate change, wherever they are.

1.2 Introducing the Great Barrier Reef

The Great Barrier Reef is renowned internationally for its ecological importance and the beauty of its seascapes and landscapes. These natural values also provide important ecosystem services, which underpin Australian $6.9 billion worth of economic activity[1] and incalculable social values. In combination, the social-ecological system centred on the reef is extraordinary in its importance, and in its complexity. Understanding the vulnerability of such a large and intricate system to climate change is a particularly difficult challenge. A first step in meeting this challenge is to describe the general characteristics of the system and the environment in which they interact. Toward this end, this chapter introduces the Great Barrier Reef and the human systems that interact with it, providing a context for the detailed chapters that follow.

1.2.1 The ecosystem

The Great Barrier Reef Marine Park is almost 350,000 square kilometres in area. This makes it larger than the combined area of the Australian states of Victoria and Tasmania. It is also larger than the United Kingdom, Malaysia and many other countries. It spans 14 degrees of latitude and is located along 2100 kilometres of the coastline of Queensland in northeast Australia.

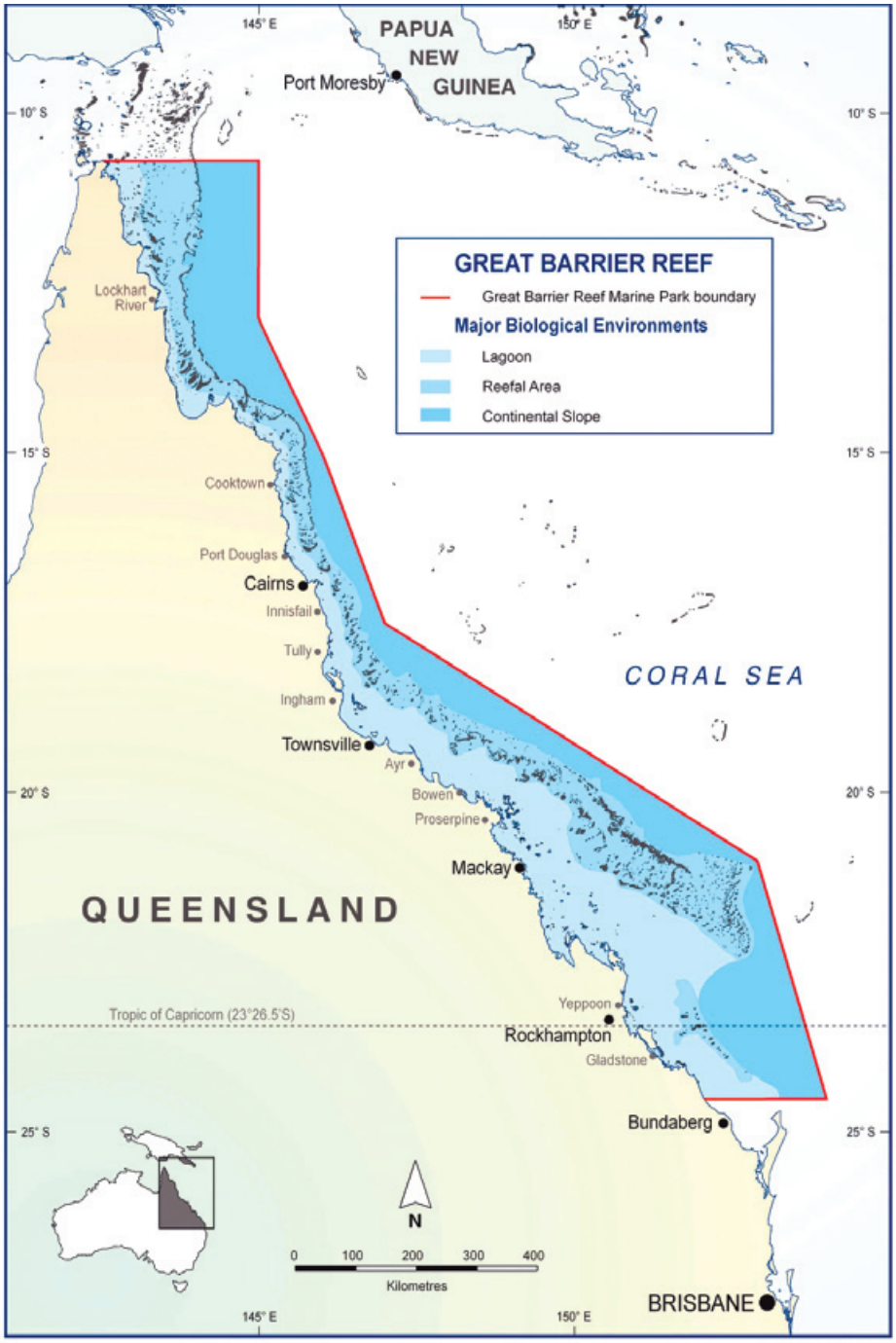
Most people think of the Great Barrier Reef as an enormous single coral reef. In truth, there is a complex maze of about 2900 separate coral reefs. However, these reefs account for only about 6 percent of the area of the Great Barrier Reef Marine Park. About 36 percent of the Great Barrier Reef Marine Park is continental slope, where the water is between 150 and 2000 metres deep. The remaining 64 percent is continental shelf, including the coral reefs, which is anywhere from 1 to 150 metres deep. The other main geographical components of the continental shelf are the inter-reef areas (25% of the Marine Park) and the lagoon (33%). The vast majority of the coral reefs are found relatively far offshore with the inshore lagoon having few reefs (Figure 1.1).

Within these major geographic divisions of the Great Barrier Reef are many different types of habitat and biological community. The best known of these are the coral reefs, but there are also seagrass beds, algal meadows, sponge and soft coral gardens, sandy and muddy areas, mangrove forests and islands. This array of habitats supports an amazing biodiversity. The Great Barrier Reef is home to about 1500 species of fish, 350 species of hard coral, more than 4000 species of mollusc, 500 species of algae, 6 of the world's 7 species of marine turtle, 24 species of seabird, more than 30 species of whale and dolphin and the dugong. And these are just the species that have been recorded so far. As biodiversity surveys continue, more species new to the Great Barrier Reef and sometimes even new to science are being discovered.

The Great Barrier Reef is often heralded as one of the world's best-studied tropical marine ecosystems. Indeed, the coral reefs have been intensively studied since the first formal scientific expedition to the Great Barrier Reef in 1928. Despite this, our understanding of even coral reefs is incomplete. This is unsurprising given that the 2900 coral reefs cover 21,000 square kilometres and are spread out through much of the Great Barrier Reef. Moreover, our understanding of the other major components of the Great Barrier Reef is even less developed. Recent research has begun to unlock the secrets of the inter-reef and lagoon areas by documenting and mapping their biodiversity. However, the continental slope remains an almost complete mystery. In 1990 a trawler brought up a species of crayfish from the continental slope that had never before been encountered in Australian waters. The continental slope is up to 2000 metres deep, presenting a logistical challenge that has discouraged serious research in the area.

Despite a great deal of research, the Great Barrier Reef ecosystem and its biodiversity are far from fully understood. We do not have a complete inventory of the species in the Great Barrier Reef, let alone maps of species distributions or complete accounts of their ecology. Nevertheless there is a great deal that is known and this book draws on that knowledge to assess the vulnerability of Great Barrier Reef species, habitats and processes to climate change.

Figure 1.1 *Major biological environments of the Great Barrier Reef*



1.2.2 The physical environment

The Great Barrier Reef extends along approximately 14 degrees of latitude, with marine realms spanning coastal to oceanic. This geographic diversity encompasses a range of physical conditions, including various regimes of temperature, current influence, water quality and weather.

The climate of the Great Barrier Reef is influenced by monsoonal wind and rainfall patterns. Strong south-easterly winds dominate during the dry season (April to October), while weaker variable winds are more common during the summer wet season when most of the annual rainfall occurs. Mean sea temperatures in offshore waters vary between 23°C in the coldest months of the dry season (July to August) and 28°C in the warmest months of the wet season (January to February). Inshore areas generally experience a higher seasonal range of between 21 and 30°C. Cyclones are most likely to occur between January and April. The high winds at the centre of a cyclone create large, powerful waves that can greatly affect coral reefs and other marine habitats. Any single cyclone only affects a small proportion of the area of the Great Barrier Reef, but over many decades, almost every part of the Great Barrier Reef will be affected by a cyclone at least once.

Currents are important physical driving factors that strongly affect the Great Barrier Reef's biodiversity and its ecosystem functions. There are three types of current: oceanic, wind-driven and tidal. All three interact in complex ways with the physical structure of the Great Barrier Reef's seabed to produce the current regime. The South Equatorial Current is an oceanic current that flows westward across the Pacific Ocean and Coral Sea. When it reaches the Australian continental shelf at about 14 degrees south, it divides into two currents. One of these flows north along the edge of the continental shelf, the Hiri Current, and the other flows south, the East Australian Current.

At a regional scale, these three currents are the most significant currents that influence the oceanography of the Great Barrier Reef. In some areas, these shelf-edge currents can cause upwelling of deep, cold, nutrient-rich water onto the continental shelf. This upwelled water has regional effects on biodiversity and can cause the formation of significant habitats, such as large algal mounds, only found in the far northern Great Barrier Reef. While oceanic currents have a strong influence on currents on the continental shelf, in shallow waters, currents are also driven by wind. In strong wind conditions, particularly those during the dry season with steady south-easterly winds, the effect of wind on current direction can be stronger than that of oceanic currents. Oceanic and wind-driven currents primarily drive water parallel to the coast, along the continental shelf. However, the tides, which operate on a 12-hour cycle, drive water across the continental shelf perpendicular to the coast. These two driving forces for currents, operating at 90 degrees to each other, create a complex pattern of water movement, especially in and around the intricate matrix of the coral reefs.

1.2.3 The human dimensions

The Great Barrier Reef is iconic. It has a central place in Australian culture and psyche, and a visit to the reef is reliably rated among the top three *must do* experiences in international surveys. The Great Barrier Reef has continued to evoke wonder and awe in visitors, from the earliest European explorers negotiating the *"monstrous labyrinth of coral"* by sailing ship, to the thousands of tourists who arrive annually to experience one of the natural wonders of the world. Long before these relatively recent visitors, however, it was Indigenous Australians who had established a strong relationship with the Great Barrier Reef.

Human associations with the Great Barrier Reef predate recorded history. Australia's Aboriginal people knew of and used the reef. Oral history and archaeological evidence shows that they regularly journeyed to the reef to make use of its rich and varied resources[11,20,3,13]. What the region meant spiritually and socially to these people can only be assumed from either early ethnographic accounts[18,20], or interpreted from contemporary reports of association and connection[7,16]. Statements made by contemporary Traditional Owners[23] can also assist understanding.

Aboriginal and Torres Strait Islander people continue to have a strong presence in the Great Barrier Reef. They continually champion their rights and interests in the region[10,6,5] and make use of resources such a fish, dugong and turtle. The majority of Aboriginal and Torres Strait Islander people organise themselves into Traditional Owner groups based on clan and language groups. This form of Traditional Ownership for specific sea country and adjacent lands is an effect of the recognition by the High Court of Australia of the existence of Native Title in the 1992 Mabo Case and subsequent passage into statute of the Native Title Act in 1993. The primary form of interaction Aboriginal and Torres Strait Islander people had and continue to have with the Great Barrier Reef is to support a subsistence lifestyle. Activities such as fishing, hunting and experiencing the Great Barrier Reef are critical to maintain cultural values and identity as the Traditional Owners of the region[17].

The earliest European contact with the Great Barrier Reef[a] was the result of expeditions of discovery. These early expeditions discovered the vastness, beauty and danger of the region. In the 18th century, reports by James Cook of the *"monstrous labyrinth of coral"* and the naturalist reports by Joseph Banks brought the existence of this vast reef area to British and European attention. Throughout the 19th century, the search for safe shipping lanes to the east coast of Australia brought survey vessels with naturalists. Since the 1890s, many more explorers came specifically to visit the Great Barrier Reef. The tradition of formal natural history research[9] and amateur naturalist accounts provided by Banfield's *Confessions of a Beachcomber*[2] revealed to the world aspects of the naturally diverse wonder that is Australia's Great Barrier Reef[9,24,19,4,8,21,14].

In 1893, Saville Kent reported on a scientific study of the fishery and natural resource potential of the Great Barrier Reef. The long-term field studies of the Royal Society of London and Great Barrier Reef Committee Expedition to Low Isles in 1927 to 1928 laid the foundation for the development of coral reef science. After the middle of the 20th century the development of field stations, university research programs and research institutes saw rapid growth in coral reef science. This was coupled with growing development on the adjacent coast and growing technological capacity to reach and exploit the Great Barrier Reef. The adventure of the expedition to the reef continues to draw people. The thrill of exploring its varied aspects and enjoying the many forms of nature entrances people and brings them back to the Great Barrier Reef[15].

There are significant social and economic benefits to Australia from the Great Barrier Reef. The major activities that occur on the Great Barrier Reef are tourism, recreation and commercial fishing. During 2005, 1.9 million people visited the Great Barrier Reef using tourism services and it is estimated that

a Torres and Prado in 1606, James Cook and the Endeavour in 1770, Matthew Flinders in the *Investigator, Cato* and *Porpoise* in 1801–03, King in the *Mermaid* and *Bathurst* in 1819–21, Stokes, Wickham, Bynoe in the *Beagle* 1839-41, Blackwood Jukes and MacGillivray in the *Fly* in 1843-45 and the *Rattlesnake* in 1847–49, Mosely in the *Challenger* in 1887; Coppinger and Miers in the *Alert* in 1881 and McFarlane in the *Constance* in 1887.

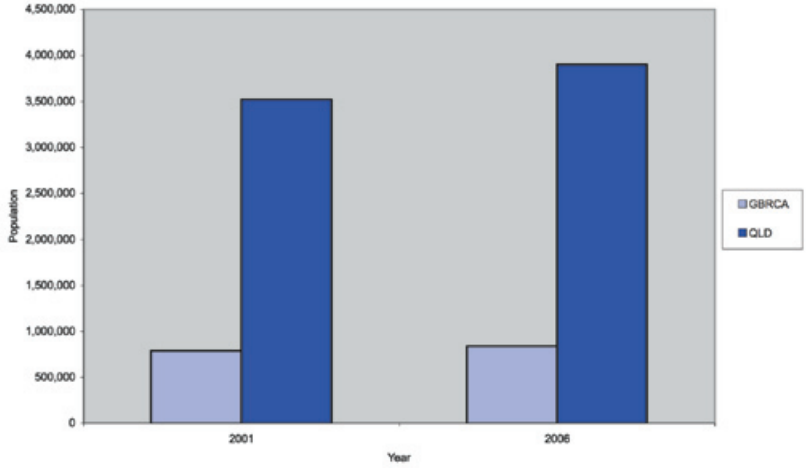
there are a further 6 million recreational visits to the Great Barrier Reef annually. Recreation includes activities such as fishing, snorkelling, diving, sightseeing, adventure sports and sailing. Tourism is a major activity on the Great Barrier Reef and is estimated to contribute as part of regional tourism $6.1 billion to the Australian economy annually[1]. The tourism industry also employs an estimated 63,000 people. Commercial fishing activity undertaken in the Great Barrier Reef has a gross value of production of $119 million annually and employs an estimated 3,600 people or 0.94 percent of the Great Barrier Reef coastal labour force. Recreational fishing and boating contribute $640 million annually to the region and comprise a major recreational activity for residents and visitors to the region.

At the 2006 census, there were approximately 836,000 people living in the Great Barrier Reef Catchment with an average annual growth rate of 1.23 percent. This is 21 percent of Queensland's resident population of almost 4 million (Figure 1.2). The region is economically dependent on agriculture, manufacturing and mining except in Cairns city, Douglas and Whitsunday Shires that have tourism as their major industry. Sugar cane is the main crop grown on the Queensland coast.

The value of agricultural production from Great Barrier Reef coastal communities is in the order of Australian $1.7 billion annually. The resources sector contributes Australian $14.5 billion annually in exports from the 11 ports located in the Great Barrier Reef region[b]. Of these exports, 94 percent are for mineral products, primarily coal and metal ores, and the remaining 6 percent agricultural and manufactured products.

The key regional centres of Cairns, Townsville, Mackay, Rockhampton and Gladstone provide services to inland mining and agricultural industries. Townsville is the largest major centre in the Great Barrier Reef region with considerable government, education and defence activities servicing state and national interests.

Figure 1.2 *Residential population in the Great Barrier Reef Catchment Area and Queensland for 2001 and 2006. (Source: Australian Bureau of Statistics 2007)*



b http://www.oesr.qld.gov.au/

Limiting the effects of people, within and adjacent to the Great Barrier Reef is the challenge presented to marine managers, communities, industries and governments when considering how best to manage the Great Barrier Reef. The nature of the interactions people have with the Great Barrier Reef are shaped by the demands they have to meet. For each ecosystem the type of management applied to maintain its functional status, as a 'healthy' ecosystem is directly dependent on the social, economic and institutional context of the society that interacts directly and indirectly with the ecosystem.

The length of time that humans have interacted with the Great Barrier Reef provides an appropriate historical context for understanding current social, economic, institutional and political issues involved in the management of the Great Barrier Reef. Unlike many other tropical marine ecosystems[c], the Great Barrier Reef exists in close proximity to a region that has experienced intensive farming and pastoral activities as well as substantial urban development for close to one hundred and fifty years. Apart from the Cape York region, which has experienced much less land based development; coastal and catchment regions bordering the Great Barrier Reef bear witness to the progressive development of the region's ocean, land and mineral resources.

The infrastructure for supporting the growing regional population of approximately 836,000 people with associated manufacturing, agricultural and urban services from Bundaberg in the south to Cairns in the north represents a substantial modification of the Great Barrier Reef's coastal and catchment landscape. The effect of 68,000 personal watercraft, active commercial fisheries, 1.9 million tourist visits annually, defence activities and development of infrastructure to support visitors and residents accessing and enjoying the Great Barrier Reef combines to make an extensive ecological footprint. This will affect the Great Barrier Reef in far more complex forms than tropical marine ecosystems that are more isolated.

1.2.4 Management and conservation

In recognition of its diverse, unique and universal values, the Great Barrier Reef is listed as a World Heritage Area, and protected within the Great Barrier Reef Marine Park. The enactment of the Great Barrier Reef Marine Park Act in 1975 by the Commonwealth established the legal framework for protecting these values for conservation and wise use into the future. Further recognition of the importance of the outstanding universal values of the Great Barrier Reef occurred in 1981 when the area was listed as a World Heritage site.

The Great Barrier Reef Marine Park Act establishes a Great Barrier Reef Marine Park Authority with responsibility for managing the Marine Park. The goal of the Authority is the long-term protection, ecologically sustainable use, understanding and enjoyment of the Marine Park. A range of management tools are used including zoning plans, management plans, site plans, environmental impact assessment, permits and programs providing information, education and compliance. The Marine Park is managed in association with the Queensland Government, which undertakes day-to-day management through several agencies. For example, the Queensland Government is responsible for the management of commercial fisheries in the Marine Park.

c The Florida Keys is another exception as it too lies adjacent to a heavily developed coastal area

Community input into Marine Park management is actively sought through a range of committees including Reef Advisory Committees and Local Marine Advisory Committees, which deal with key issues such as water quality, and 11 Local Marine Advisory Committees.

Despite national and international frameworks designed to conserve the Great Barrier Reef, it is under pressure from a range of local, regional and global stresses. Local and regional issues, such as water quality and fishing, are managed through a range of plans, regulations and agreements. Recent key management actions aimed at increasing the resilience of the Great Barrier Reef include the *Reef Water Quality Protection Plan* and the rezoning of the Marine Park in 2003.

The *Reef Water Quality Protection Plan* is a multi-stakeholder agreement to 'halt and reverse the decline in water quality entering the Reef within ten years'. The *Reef Water Quality Protection Plan* contains nine strategies including education and extension, economic incentives and regulatory changes. Major investment in the *Reef Water Quality Protection Plan* is flowing through programs such as the Natural Heritage Trust. A comprehensive water quality and ecosystem health monitoring program has been put in place under this initiative.

The Marine Park was rezoned in 2003 to increase the level of protection afforded to the Great Barrier Reef. The overall proportion of the Marine Park included in highly protected no-take zones increased from less than 5 percent to more than 33 percent. Most importantly, at least 20 percent of each of 70 bioregions was included in no-take zones. The rezoning is accepted internationally as a world leading initiative with regard to protecting ecosystem health and maximising the resilience of a tropical marine ecosystem.

Considerable management effort is also invested in ensuring ecologically sustainable outcomes for tourism and fishing industries in the Great Barrier Reef. All tourism activity is subject to environmental impact assessment and requires permits to operate. The impacts of fishing are minimised through negotiation between the Great Barrier Reef Marine Park Authority and the Queensland Government with outcomes including management plans for trawling and coral reef line fishing, which include a total allowable catch and spawning closures.

Despite these landmark initiatives, the ecological integrity of the Great Barrier Reef and its ability to sustain provision of goods and services to society are under increasing threat from climate change. While some level of change is inevitable, it is now imperative that action is taken to reduce the magnitude of human related impacts on the Great Barrier Reef ecosystem, and the industries and communities that depend on it.

1.3 Understanding vulnerability and uncertainty

Global stresses associated with climate change pose new challenges for natural resource management. Efforts to understand the threat are often hampered by substantial gaps in knowledge about natural systems, as well as by uncertainty in climate scenarios and in ecosystem responses. Approaches and frameworks to assist with assessments of vulnerability and their uncertainty are emerging as efforts to understand the implications of climate change intensify.

The Great Barrier Reef is not immune to the threat of climate change. Climate change, together with other human pressures is having synergistic effects on the Great Barrier Reef. Although environmental managers cannot directly control climate, there is an urgent need to identify possibilities for reducing climate-induced stresses on the Great Barrier Reef ecosystem, and to develop strategies to support natural resilience and adaptation in the face of uncertainty. An important part of this response to the threat of climate change is investigation of the vulnerabilities and risks of climate change effects on all components of the Great Barrier Reef ecosystem.

Climate vulnerability refers to ecosystem's potential to suffer damage or ill effects as a result of climate change. There is an increasing likelihood that climate change will create a need for adjustments of established ecosystems on spatial and temporal scales that are unprecedented in human history. Further, such changes are unplanned with an ever-increasing risk that, as the concentration of greenhouse gases in the atmosphere grows so too does the prospect of irretrievable damage. Vulnerability assessments of ecosystems to climate change provide a structure for examining the potential impacts of climate change and adaptation options.

1.3.1 Assessing vulnerability

Vulnerability assessments are a form of integrated assessment that aim to integrate social, ecological and economic information. This technique has been applied extensively in other domains, such as hazard risk and human health, however it is a relatively new method in the climate change arena.

Initiatives in other domains appear to be adopting similar conceptual frameworks, generally deriving from well-developed thinking in climate policy and science. Knowledge of vulnerability is generally derived from an integrated assessment approach that includes scientific information (published and unpublished), professional and community knowledge and expert opinion. Assessments of vulnerability or risk are social processes linking public knowledge to policy and governance frameworks[12].

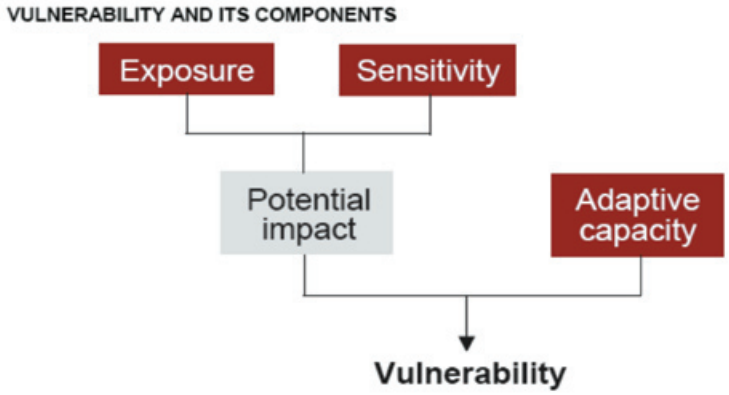
The Intergovernmental Panel on Climate Change (IPCC) has described climate change vulnerability as: *The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity*[d].

This publication draws on this approach, where the vulnerability of a system to climate change is a function of three elements: exposure (to climate change effects), sensitivity, and adaptive capacity (Figure 1.3).

This approach to assessing of vulnerability is important because it highlights the key elements that combine to amplify (or alleviate) the costs and risks that climate change can impose on a system. Understanding these elements can help identify the climate change threat, highly vulnerable elements and action in each of these areas that can help reduce or deal with that threat.

d IPCC 2001, Third Assessment Report

Figure 1.3 *Framework for assessing vulnerability of the Great Barrier Reef to climate change*



Source: Adapted from D. Schroter and the ATEAM consortium 2004, *Global change vulnerability — assessing the European human–environment system*, Potsdam Institute for Climate Impact Research.

The success of incorporating the findings of vulnerability assessments into policy depends on whether they are perceived to be salient, credible and legitimate. That is, that stakeholders respect the source of the information, understand the assessment process and have participated in the assessment. This vulnerability assessment engaged expert scientists who integrated all current knowledge to assess the vulnerability of the different components of the ecosystem. The assessment of social vulnerability engaged with communities and industries that depend on the Great Barrier Reef, are regular users of the reef or reside in the reef catchment. In this way, the information used for the assessment was sourced from a representative population that participated in the process.

1.3.2 Dealing with uncertainty

Uncertainty, in the context of assessing vulnerability to climate change, comes from a range of sources, such as unpredictability, structural uncertainty and value uncertainty. Unpredictability usually refers to uncertainty about projections of human behaviour, ie how human society will change in the future and the resultant effect on greenhouse gas emissions. Structural uncertainty comes from inadequate or incomplete models, ambiguous system boundaries or definitions, or poorly considered processes or relationships. Value uncertainty comes from missing or inaccurate data, inappropriate spatial or temporal resolution or poorly known or changing model parameters. All forms of uncertainty can be addressed by clearly defining the scope of the assessment, using plausible scenarios, setting specific assumptions and parameters, estimating the degree of uncertainty and the probable range of predictions based on that uncertainty.

Expert judgements are a mechanism for dealing with uncertainty by providing a traceable account of the steps taken to reach key findings, and to estimate uncertainty or confidence in those findings. Where knowledge is extensive, expert judgements will have less uncertainty and greater confidence and will be quantitative in nature. However, a lack of data does not prohibit making expert judgements, and should instead draw on the available information to make judgements on the

direction of change, degree of change, expected trend, range of change or threshold or a likelihood or probability of occurrence. This guidance on uncertainty[e] was used by authors when making assessments of the vulnerability of the Great Barrier Reef to climate change.

1.4 How to use this book

This publication is intended as a resource for scientists, managers and anyone with an interest in the future of coral reefs. In order to assess the vulnerability of a complex ecosystem such as the Great Barrier Reef, divisions of the ecosystem need to be made. There are many ways to group the various components of the Great Barrier Reef, however, for ease of reading and undertaking effective assessments the following pragmatic organisation has been used. The book has been divided into sections that deal with species and species groups, habitats, processes and management of the Great Barrier Reef.

An **Introductory** section provides background information on the Great Barrier Reef, current and future climate scenarios for the Great Barrier Reef, climate change implications for physical oceanography and the concept of resilience as it relates to the Great Barrier Reef and climate change.

A **Species and Species Group** section assesses the vulnerability of species in the Great Barrier Reef to climate change, from tropical marine microbes and plankton to fish, corals, seagrass and whales.

A **Habitat** section assesses the vulnerability of the major habitats within the Great Barrier Reef to climate change, including coral reefs, pelagic environments, coasts and estuaries and islands and cays. This section also provides an assessment of how climate change will affect the geomorphology of coral reefs, reef islands, beaches and coasts, and a historical perspective of coral reefs and climate change over geological time.

Finally, a **Concluding** section that provides a synthesis of the implications of climate change for Great Barrier Reef communities and industries and a summary of the key vulnerabilities and management implications for the Great Barrier Reef.

Chapters within this book are comprehensive, however, as the Great Barrier Reef ecosystem is interlinked, so too are the chapters that deal with the different components of the ecosystem. Therefore, chapters frequently draw on each other and reference the assessments of other chapters.

e Intergovernmental Panel on Climate Change, Guidance Notes on Uncertainty for Fourth Assessment Report (2005)

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