The Impacts and Management Implications of Climate Change for the Australian Government's Protected Areas

Discussion Paper

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Disclaimer

The views and opinions expressed in this publication are those of the authors and do not necessarily reflect those of the Australian Government or the Minister for Climate Change and Water and the Minister for the Environment, Heritage and the Arts.

Note on the names of Departments referred to in this report

Name changes to the Australian Government's environment department have occurred over the past several years. This report refers to:

- The Department of the Environment and Heritage (DEH);
- The Department of the Environment and Water Resources (DEW);
- The Department of the Environment, Water, Heritage and the Arts (DEWHA) – current name; and
- The Department of Climate Change – current name (formerly the Australian Greenhouse Office in DEW)

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Acronyms Used

AAD	Australian Antarctic Division
AGO	Australian Greenhouse Office (formerly in the Department of the Environment and Water Resources); now the Department of Climate Change
AIMS	Australian Institute of Marine Sciences
AMSA	Australian Maritime Safety Authority
ANBG	Australian National Botanic Gardens
ANZECC	Australian and New Zealand Environment Conservation Council
BOM	Bureau of Meteorology
CAMBA	China-Australia Migratory Birds Agreement
CAR	Comprehensive Adequate Representative
CITES	Convention on International Trade in Endangered Species
CPBR	Centre of Plant Biodiversity Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCC	Department of Climate Change (formerly known as the Australian Greenhouse Office in the Department of the Environment and Water Resources)
DEH	Department of Environment and Heritage (now the Department of the Environment, Water, Heritage and the Arts)
DEW	Department of the Environment and Water Resources (now the Department of the Environment, Water, Heritage and the Arts)
DEWHA	Department of the Environment, Water, Heritage and the Arts
EAC	East Australian Current
EEZ	Exclusive Economic Zone
ENSO	El Niño Southern Oscillation
EPBC	Environmental Protection and Biodiversity Conservation
ERISS	Environment Research Institute of the Supervising Scientist
FACE	Free Air CO2 Enrichment
GBRMP	Great Barrier Reef Marine Park
GIS	Geographic Information Systems
HIMI	Heard Island and McDonald Islands
IBRA	Interim Biogeographical Regionalisation for Australia

IMCRA	Interim Marine and Coastal Regionalisation for Australia
IPO	Interdecadal Pacific Oscillation
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature and Natural Resources (World Conservation Union)
JAMBA	Japan-Australia Migratory Birds Agreement
MPA	Marine Protected Area
NLWRA	National Land and Water Resource Audit
NNR	National Nature Reserve
NOAA	National Oceanic and Atmospheric Administration
NPWC	National Parks and Wildlife Conservation
NRSMPA	National Representative System of Marine Protected Areas
OHS	Occupational Health and Safety
PA	Protected Area
SRES	Special Report on Emission Scenarios
TSC	Threatened Species and Conservation
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WHA	World Heritage Area
WMO	World Meteorological Organisation

Executive Summary

Introduction

The Australian Government, represented by the Department of Climate Change (DCC) (formerly the Department of Environment and Water Resources), commissioned Hyder Consulting to assess the impacts and management implications of climate change for the Australian Government's protected areas.

The report examined twenty protected areas managed by the Department of Environment, Water, Heritage and the Arts, and declared under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), comprising:

- Six National Parks;
- The Australian National Botanic Gardens; and
- Thirteen Marine Protected Areas.

A number of additional marine protected areas are in the process of being declared – these are not included within this report. This report forms a component of the of the Australian Government's National Climate Change Adaptation Programme which aims to initiate actions towards preparing Australia for the impacts of climate change. The importance of managing Australia's biodiversity in the face of climate change is recognised in the commitments made in the *National Biodiversity and Climate Change Action Plan 2004-2007* (http://www.climatechange.gov.au/impacts).

Purpose of Report

The specific requirements of the report were to:

- Review the existing research and key information to identify the potential impacts of climate change on the Australian Government's protected areas (other than the Great Barrier Reef Marine Park);
- Identify major gaps in knowledge of how climate change will affect the management of each of the protected areas;
- Identify the implications of these changes for management of each protected area; and
- Identify the priorities for further attention and provide an assessment and key findings on the likely impacts and implications of climate change on the protected areas in a manner consistent with the management planning framework for each protected area.

Methodology

The baseline information on protected area values, including pressures and current management approaches, has been gathered through review of existing literature and through consultation with protected area managers including on-ground staff. Under guidance from DEWHA and DCC, the values have been categorised as follows:

- National Parks – natural, cultural and recreational and visitation;
- Botanic Gardens – natural, cultural, recreational and scientific; and
- Marine Protected Areas – natural, socio-cultural and economic.

The assessment is based on existing climate change research information, including projections and scenarios for 2030 and 2070 developed by CSIRO using scenario mapping that covers mainland Australia in distinct geographic regions, and present climate change data relative to the Intergovernmental Panel on Climate Change (IPCC) reference year 1990 (CSIRO 2006). The report does not use the CSIRO climate change projections released in October 2007 as these were only available after much of the analysis for this study was finalised.

Some of the more remote protected areas fall outside the currently available climate modelling. For these sites the most relevant terrestrial data has been adopted together with regional CSIRO projections for sea level rise and changes in atmospheric CO_2 concentrations. Other projections pertinent to marine areas, including changes to sea surface temperature, mixed layer depth and pH, have been sourced from a CSIRO Mk 3.5 model as presented in Hobday *et al*, 2006 (Part A) which describes changes in the physical and chemical characteristics of Australia's marine realm by 2070.

Due to the uncertainties involved in climate change scenarios, as well as the dynamic changes expected in protected areas, a qualitative, expert-led interpretation of climate change impacts on values and management implications was used. The projected impacts and implications were substantiated further through specific consultation with protected area managers to gain an understanding of on-ground issues and concerns.

Observed and Projected Climate Change for Australia

Observed

Warming of the climate system globally is now generally recognised, with observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC, 2007a). Average global temperatures have increased 0.74^{o}C (1906-2005), with eleven of the twelve years between 1993-2000 ranking among the twelve warmest years since 1850 (IPCC, 2007b).

Consistent with global trends, the average maximum temperature across Australia has increased 0.6^{o}C and the minimum temperature 1.2^{o}C, over the period 1910-2004, with most of the warming occurring since 1950 (Nicholls and Collins, 2006). There has been an increase in hot days (35^{o}C or more) of 0.10 days/year, and hot nights (20^{o}C or more) of 0.18 nights/year, and a decrease in cold days (15^{o}C or less) of 0.14 days/year and cold nights (5°C or less) of 0.15 nights/year (1957-2004) (Nicholls and Collins, 2006).

Sea surface temperatures in many tropical regions have increased by almost 1°C over the past one hundred years (some tropical seas up to 2°C) and are currently increasing ~1–2°C per century (Hoegh-Guldberg, 1999). Although not seen before 1979, recent warming has led to repeated coral bleaching events in 1983, 1987, 1991, 1998, 2002 and 2006 (pers comm, O. Hoegh-Guldberg, 2006).

Projected

Future projections for Australia generally indicate an increased incidence of hot days, fewer frosts, increased wind speeds and storm events, increased incidence of intense rainfall events and changes to seasonal rainfall (Pittock, 2003; Preston and Jones, 2006). When rainfall changes are combined with increases in potential evaporation, a general decrease in available soil moisture is projected across Australia, with droughts likely to become more severe.

Projected changes will be superimposed on natural variability including El Niño Southern Oscillation (ENSO) and the Inter-decadal Pacific Oscillation (IPO), and a move towards more El Niño-like conditions with a corresponding mean eastward shift of precipitation over the tropical Pacific and the weakening of the inter-annual ENSO-Asian-Australian monsoon connection (IPCC, 2007a). An increase in westerly winds is likely south of latitude 45°S, with a strengthening of the East Australian Current and southern mid-latitude ocean circulation (Cai *et al.*, 2005).

Implications for Natural Systems and their management

Climate change will have profound effects on biodiversity and on the structure and function of many Australian ecosystems, though the nature and timing of impacts will vary. Climate change will affect terrestrial species directly, by affecting their physiology and timing of life cycles, and indirectly, by affecting their interactions with other species. Together, this will lead to changes in the distribution, structure and composition of terrestrial species and communities.

Like terrestrial species, marine species will be affected directly and indirectly by climate change. Of particular concern are keystone species such as kelp, mangroves and corals, as well as dominant producer groups such as phytoplankton and zooplankton; with cascading effects throughout marine food webs (Hobday *et al.* 2006, Part A).

Australian flora and fauna and associated ecological processes have adapted to changing climatic conditions over time. However, species and ecosystems are anticipated to come under unprecedented pressure due to the to the rapid rate of the current warming cycle coupled with the range of additional external pressures that previously did not affect the resilience of species and ecosystems. These pressures include, but are not limited to, land use change, tourism, illegal fishing or overfishing, pollution and competition from invasive species. In some instances, these pressures can be exacerbated by climate change. The ranges and population sizes of many pest species for example, are projected to increase with warming and concomitant changes in fire regimes.

Key Findings for National Parks

The six National Parks included in the report represent a diversity of ecosystems from dry sclerophyll heathland and woodland (Booderee National Park) to vast savanna and wetland systems (Kakadu National Park) and arid and semi-arid habitats (Uluru-Kata Tjuta National Park). Some of these areas are very small (e.g. Norfolk Island National Park covers only 650 ha), while others cover some of the largest, and least disturbed areas of the continent (e.g. Kakadu National Park covers 1,980,400 ha). The National Parks provides habitat for a variety of rare, threatened or endemic species, and contain significant cultural values.

The National Parks are major attractions for the Australian tourism industry with around 1.4 million people visiting in 2005-2006, including approximately 193,000 at Kakadu and more than 350,000 at Uluru-Kata Tjuta (Director of National Parks, 2006).

Potential climate change impacts

There is now clear evidence that the relatively modest climatic changes over the past century have already had significant impacts on the distribution, abundance, life cycles and physiology of a wide range of species globally. Recent reviews have documented many instances of shifts in species distribution towards the poles or upward in elevation, and progressively earlier life cycle events such as flowering, reproduction and migration (Hughes 2000, Parmesan and Yohe, 2003, Root *et al.* 2003, 2005). Projected future impacts are consistent with these trends. The following potential impacts were found to be common to all National Parks:

- Changes to habitat availability with flow on effects to dependant species including threatened and endemic species;
- Changes to abundance, distribution and composition of species within parks including movement of species in and out of parks through expansion of range; and
- Increased pressure from weeds and introduced pest animals.

Climate change may also negatively affect the cultural and recreational values of National Parks, such as:

- An increase in temperatures and the incidence of hot days (over 35^{o}C), negatively affecting visitor comfort, including increased incidence of heat stress in visitors and staff;
- An increase in park closures in response to increases in temperature, fire risk and extreme events, with implications for visitor satisfaction and safety, and revenue;
- An increase in expenditure through increased maintenance and infrastructure requirements;
- An increase in extreme rainfall, temperatures and extreme events may exacerbate natural erosive processes on cultural values such as rock art and non-Indigenous heritage; and

- Changes to flora and fauna distribution and abundance may interrupt traditional practices, including fishing, hunting and gathering.

Management implications

Building resilience

Under changing climatic conditions, management activities may be limited to building the resilience of park values to climate change, by managing non climate related pressures such as human disturbance, fire, weeds, and introduced pest animals. A core management implication for park managers is therefore to minimise these pressures. In addition, existing management strategies may no longer be appropriate under changed climatic conditions and may therefore require review. This may include, for example, access protocols for visitors, risk assessments, erosion controls and maintenance regimes. A review of the effectiveness of existing rehabilitation plans and monitoring strategies may also be necessary. Resilience may also be strengthened by expanding park boundaries, improving connectivity and adopting bioregional approaches to conservation.

Managing for uncertainty

There are several common gaps in the knowledge and understanding of the six National Parks:

- The extent to which the geographic ranges of both native and introduced species will shift in response to changed climatic conditions;
- The endemic and threatened species which are most likely to be at risk under climate change, including those at risk as a result of associated changes to habitat. The capacity for ex-situ conservation of these species is also currently unknown;
- The implications of climate change on life cycle events of specific species, including, for example, the interaction between the timing of invertebrate distribution and abundance and migratory birds;
- Understanding the vulnerability of refuge-dependant species such as amphibians;
- The effectiveness of different strategies for managing invasive species and introduced pests, particularly with regard to interactions with changing fire regimes;
- The inter-relationships between the terrestrial and the marine environments, and the significance of ongoing sea level rise;
- Future constraints on resources such as water availability and financial resources, and implications for accommodating future tourist numbers; and
- The potential impacts of climate change on cultural practice and cultural values, including cultural expression.

Further research in these areas, will provide park managers with a greater understanding of the resilience of park ecosystems and species and the ability to protect or conserve existing values.

Maintaining infrastructure and protocols to ensure visitor safety

Changing climatic conditions such as increased temperatures, increased fire risk and increased intensity of storm events may require review of existing strategies, infrastructure and expenditure to ensure visitor safety, comfort and satisfaction.

Key Findings for Botanic Gardens

The Australian National Botanic Garden in Canberra is the premier national organisation devoted to growing, studying and promoting Australian native plants. A smaller Botanic Garden is located on Norfolk Island and an area within Booderee National Park also functions as a Botanic Garden.

Potential climate change impacts

The potential climate change impacts on the values of the three Botanic Gardens will to a large extent mirror those of natural systems; with overall impacts dependant on the ability of managers to intervene or actively manage these areas. Potential impacts include:

- Plant heat and water stress through increased temperatures, extreme temperature days and increased potential evaporation;
- Increased risk of fire;
- Increased photosynthetic activity as a consequence of increased CO_2;
- Increased growth of some species, through increased photosynthetic activity
- Increased variability in rainfall and impacts on security of water supplies; and,
- Increase in invasive species and pests through expansion of species range.
- Fundamentally the Australian continent is faced with the increased pressure and risk of extinction of flora species as a direct consequence of changes and rates of change in climatic conditions. The Australian Government's Botanic Gardens are ideally placed to respond to this challenge and may play an increasingly important role in ex-situ conservation. As their role increases however, additional constraints will be placed on existing resources including finance, space, water and staff.

Management implications

Building resilience

Under changing climatic conditions (such as increased carbon dioxide concentrations and temperature), existing management strategies may no longer be appropriate or effective. This may include watering and fertiliser application regimes, pest and pathogen control and fire management strategies. Management effort may also need to be increased as a consequence of maintaining plant collections under increasingly stressed conditions. As a result, climate change may exacerbate existing pressures on resources such as water, finance and staffing.

Managing for uncertainty

There are several common gaps in knowledge that may prevent managers from adequately answering questions regarding resilience, climate change impacts and sustainable use of the Gardens. Gaps in knowledge include:

- How individual species within the Gardens will respond to climate change;
- The type of species (and their individual water requirements) that should be grown in the Gardens in the long term; and
- The role the three Botanic Gardens will be expected to play in the national effort to preserve and conserve native flora and the implications for resources including water, land, finance and staff.

Maintaining infrastructure and protocols to ensure visitor safety

Changing climatic conditions such as increased temperatures, increased fire risk and increased intensity of storm events may require review of existing strategies, infrastructure and expenditure to ensure visitor safety, comfort and satisfaction.

Key Findings for Marine Protected Areas

As of June 2007, there were thirteen marine protected areas (MPAs) in the Commonwealth component of the National Representative System of Marine Protected Areas (NRSMPA) that is administered under the EPBC Act. These sites range across a diversity of ecosystems from the tropics to the sub-Antarctic, and from the Indian Ocean to the Coral and Tasman Seas.

Potential climate change impacts

A number of common potential impacts on MPAs may occur as a result of climate change. The impacts on marine life are many and varied but may include:

- Reduced ocean productivity with cascading effects through marine webs;
- Changes to habitat availability with flow-on effects to dependant species;
- Changes to abundance and distribution of species within marine reserves; and
- Movement of species in and out of reserves as a response to changing climatic and oceanic conditions including expansion of range.

Negative effects on coral reef systems was a common finding across many of the MPAs. Increases in sea temperature may result in more frequent and severe coral bleaching and increases in atmospheric CO_2 to above 500ppm will severely compromise the ability of warm and cold water coral reefs to maintain the reef structures and communities that they build against the forces of physical and biological erosion (pers comm. Hoegh-Guldberg, 2006). This could have major impacts on both limestone reef structures and on deep, cold-water reef communities with an estimated 70% of the world's cold-water coral reefs expected to be affected by the end of the century (Hobday *et al*, 2006 (Part A)). The subsequent impacts on marine biodiversity, global fisheries and coastal protection are largely unknown but potentially catastrophic.

Climate change may also negatively affect the socio-cultural and economic values of MPAs, such as:

- Changes to the abundance of marine species and corals may have flow on effects to nature based recreational activities, such as fishing, snorkeling and diving;
- Changes in abundance, distribution and composition of marine species in MPAs may have flow-on effects to existing research and monitoring programs;
- Climate change may result in the loss of species currently unknown to science (deep water environments in particular); and
- An increase in extreme rainfall, temperatures and extreme events may exacerbate natural erosive processes on cultural values such as shipwrecks.

Management implications

Building resilience

For many MPAs, management activities may be limited to building the resilience of values to climate change by managing non climate related pressures such as human disturbance, invasive species and pollution. A core management implication for MPAs is therefore to minimise these pressures. Existing strategies may no longer be appropriate and may therefore require review; such as access protocols for visitors, controls on commercial activities. A review of the effectiveness of existing rehabilitation plans and monitoring strategies under worst case projections may also be necessary. Resilience may also be strengthened by expanding protected area boundaries and improving connectivity between MPAs.

Managing for uncertainty

There is considerable uncertainty associated with the management of MPAs. Firstly, there is limited understanding of complex ocean systems, deep water environments in particular, and of marine ecosystem species interactions at a local level. This is further compounded by a limited but growing understanding of marine ecosystem response to climate change and difficulties in measuring these responses. In addition, there is currently no projection data available for remote or offshore MPAs; other than regional marine projections.

Further research in these areas will provide MPA managers with a greater understanding of the resilience of marine ecosystems and species and the actual and potential connectivity between MPAs. This will further enhance the ability to manage invasive species which will be a significant challenge going forward.

Maintaining infrastructure and protocols to ensure visitor safety

An increase in the intensity of cyclones and storms or destabilisation of coral reefs may present issues for visitor safety, including MPA managers and research personnel. Current management strategies to ensure visitor safety may no longer be appropriate and may therefore require review.

Other Key Findings

Under rapid climate change, protected area values may change, as species expand their range, migrate into or out of existing areas, or in some cases become extinct. Where endemic or threatened species are concerned however, there may be an increasing future demand for ex-situ conservation and preservation, including the use of botanic gardens and oceanariums for this purpose.

1 Introduction

This report, commissioned by the Australian Government, represented by the Department of Climate Change (DCC), assesses the impacts and management implications of climate change on the Australian Government's protected areas[1]. The commissioning of this report is a component of the *National Climate Change Adaptation Programme* (AGO 2007), which aims to commence preparing Australia for the unavoidable impacts of climate change.

The ultimate objective of the report is to provide policy makers, protected area managers, and other stakeholders including the public, with an indication of the likely impacts of climate change on the values of protected areas and the implications for management of these reserves. The findings of the report are intended to inform future management planning processes.

1.1 Report Scope

The scope of this report is to:

a Review existing research and key information sources to identify the potential impacts of climate change on the Australian Government's parks and reserves;

b Identify major gaps in knowledge of how climate change will affect the management of each of the reserves;

c Identify the implications of these changes for management of each reserve; and

d Identify the priorities for further attention and provide an assessment and key findings on the impact and implications of climate change on the protected areas in a manner consistent with the management planning framework for each protected area.

The twenty Commonwealth reserves that are included within the scope of this report are as follows:

6 National Parks (Booderee National Park, including Booderee Botanic Gardens); Christmas Island National Park and Conservancy; Kakadu National Park; Norfolk Island National Park (including Norfolk Island Botanic Gardens); Pulu Keeling National Park and Cocos (Keeling) Islands Conservancy and Uluru-Kata Tjuta National Park).

13 Marine Protected Areas (Ashmore Reef National Nature Reserve; Cartier Island Marine Reserve; Coringa-Herald National Nature Reserve; Elizabeth and Middleton Reefs Marine National Nature Reserve; Great Australian Bight Marine Park (Commonwealth Waters); Heard and

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1 The Great Barrier Reef Marine Park is managed through a separate agency and is not included in this report. Considerable work is being undertaken on climate change impacts and management actions for this reserve – further information on this and the reserve in general can be found at http://www.gbrmpa.gov.au/

McDonald Islands Marine Reserve; Lihou Reef National Nature Reserve (Coral Sea and Island Territory); Lord Howe Island Marine Park (Commonwealth Waters); Macquarie Island Marine Park; Mermaid Reef National Nature Reserve; Ningaloo Marine Park (Commonwealth Waters); Solitary Islands Marine Reserve (Commonwealth Waters) and Tasmanian Seamounts Marine Reserve).

Australian National Botanic Gardens

The report provides an analysis of the natural, cultural and recreational values of the protected areas, as a means to identify their vulnerabilities to increased stress from climate change. For the purpose of this report values were defined for the terrestrial areas and marine areas as follows:

Terrestrial Areas

- Natural values, including consideration of species and ecosystems particularly vulnerable to climate change;
- Cultural values and;
- Recreational and visitational values.

Marine Areas

- Natural values, including consideration of species and ecosystems particularly vulnerable to climate change;
- Socio-cultural values and;
- Economic values.

The values and baseline information (i.e. current condition) of each protected area considered within this report has been collated from existing management plans, bioregional information and from consultation with protected area managers. All values stated within this report have local importance; however, some are also of regional, national, international or global importance such as IUCN listed species, Ramsar wetlands and World Heritage Sites.

The report makes use of climate change information available, prior to release of new climate change projections by CSIRO in October 2007, including scenarios for 2030 and 2070 developed by the Commonwealth Scientific and Industrial Research Organisation No new data[2] has been generated, nor has an attempt to critically review existing climate scenarios been undertaken as part of this report.

The approach to this report was carefully tailored to allow for significant review and input from experts including protected area managers. Based on discussions with DCC and DEWHA at a workshop held in Canberra in October 2006, emphasis was placed on the worst case climate scenario for protected areas i.e. the use of the high global warming scenario. In addition, it was agreed to consider impacts on, and therefore the implications for, management of the values that represent the basis for the establishment of the particular protected area.

2 The exception to this is the general assumptions applied to those protected areas that fall outside the analyses already performed by CSIRO. Information has been provided by CSIRO via personal communication, using qualitative professional judgement, based on existing regional models and application of generic trends relating to warming and precipitation.

1.2 Methodology

The process of determining climate change impacts within the study and the implications for management of protected areas was primarily based on a literature review of available data and consultation with park managers.

Due to the uncertainties involved in climate change scenarios, as well as the dynamic changes expected in protected areas, a qualitative, expert-led interpretation of impacts and management implications was used.

The potential impacts on protected area values described in this report include, but are not limited to, the loss of biodiversity, damage to infrastructure, loss of tourism opportunities and loss of ability to undertake traditional activities. These types of impacts are described further in Chapter 4.

As seen in this report, the resilience of protected area values and systems to climate change can also be influenced, in some cases significantly, by the exertion of external pressures or stresses. These stresses include, but are not limited to land use change, illegal fishing or over fishing, pollution and competition from invasive species. In some instances, these pressures can be exacerbated by climate change. The ranges and population sizes of many pest species, for example, are projected to increase with warming, increases in atmospheric carbon dioxide concentrations and nitrogen deposits (Pittock 2003).

1.3 Uncertainty Surrounding Climate Change

Scientific understanding of climate change and accuracy of climate change models has increased dramatically within the last 15 years – as seen by the increase in certainty displayed by successive IPCC reports over that time. This is backed by a growing catalogue of observed changes in species and ecosystems in response to climate change that are consistent with the scenarios (Chapter 4 provides further detail).

Despite this growing body of knowledge, there remains uncertainty around climate change scenarios and about the rate and magnitude of species and ecosystem response. Relevant to the topic of this report, some of these uncertainties include, but may not be limited to:

- Future global and regional climate outcomes;
- Difficulties in identifying and measuring system–specific responses to climate change; and
- . Limited knowledge of the detailed interactions between species and responses at a local level.

(Allen Consulting Group, 2005).

There is also uncertainty surrounding specific protected areas, namely the deep water environments and the processes and species that exist in these areas.

In response to the difficulties described above, this report also identifies knowledge gaps (on an individual protected area basis) as well as suggestions for further research and investment in resources.

Despite these uncertainties, there are a range of actions that may increase opportunities for adaptation and also reduce the impacts of climate change and the vulnerability of values to those impacts. These actions include managing external stresses, increasing resilience of values to potential change, as well as knowledge improvement and monitoring of values.

1.4 Report Structure

The remainder of this report is divided into two parts:

Part 1 provides background and context to the report as follows:

- **Chapter 2** describes the Australian government's approach to protected area management;
- **Chapter 3** presents Australian climate trends including both observed and projected changes;
- **Chapter 4** describes climate change impacts on the values of protected areas including both observed and projected; and
- **Chapter 5** provides an introduction to Part 2 of the report

Part 2 provides analysis and discussion of the impacts and implications of climate change on protected areas as follows[3]:

- **Chapters 6-11** analyse the potential impacts of climate change and implications for management for the National Parks included in this report;
- **Chapters 12-14** analyse the potential impacts of climate change and implications for management for the Botanic Gardens included in this report;
- **Chapters 15-25** analyse the potential impacts of climate change and implications for management for the Marine Protected Areas included in this report; and
- **Chapter 26** provides conclusions including a discussion of the range of actions that may help reduce the impact of climate change and the vulnerability of values to those impacts.

3 The protected areas in this report are analysed on an individual basis with the exception of Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve, and Coringa Herald National Nature Reserve and Lihou Reef National Nature Reserve which are analysed collectively due to their geographical proximity and corresponding management arrangements.

2 Protected Area Management

2.1 Background

Australia is a signatory to the Convention on Biological Diversity, which requires all member nations to, among other things, establish a system of protected areas and to develop guidelines for the selection, establishment and management of those areas.

The Australian Government, through the Director of National Parks, manages Commonwealth parks and reserves including areas located on external island territories and within Australian waters (the Australian waters extending from the State boundary at three nautical miles from the coastal baseline to the outer edge of Exclusive Economic Zone (EEZ).

The majority of Commonwealth Marine Protected Areas declared under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* are managed by the Marine and Biodiversity Division of DEWHA. The Heard Island and McDonald Islands Marine Reserve is managed by the Australian Antarctic Division.

The Great Barrier Reef Marine Park is managed by the Great Barrier Reef Marine Park Authority under separate legislation and is not included in this study.

2.1.1 Environment Protection and Biodiversity and Conservation Act 1999

Under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) EPBC Act and amendments there of, all Commonwealth reserves (terrestrial and marine) must have a management plan. Management goals are determined at the establishment of the protected area through the consideration of key values. A management plan for a Commonwealth reserve has effect for up to 10 years, subject to being revoked or amended earlier by another management plan for the reserve. The management plans for most of these reserves identify climate change as a risk and the need to better understand the implications of climate change for the management of these reserves.

2.1.2 Australia's biogeographical regions

The Interim Biogeographic Regionalisation for Australia (IBRA) divides the Australian continent into 85 bioregions. Four hundred and four sub-regions have now also been defined Australia-wide, based on major geomorphic features in each bioregion (DEW, 2007a).

The bioregions and sub-regions are the reporting unit for assessing the status of native ecosystems, their protection in the national reserve system and for use in the monitoring and evaluation framework in the Australian Government's current Natural Resource Management initiatives.

The National Marine Bioregionalisation provides a picture of the spatial distribution of the broad scale physical and biological components of Australia's marine jurisdiction, including only the offshore island territories of Norfolk, Cocos (Keeling), Christmas and Macquarie Islands. It complements the IMCRA v3.3 management framework by extending regionalisations beyond the continental shelf to cover all of Australia's Exclusive Economic Zone (EEZ).The National Marine Bioregionalisation consists of two parts, the Benthic Regionalisation and Pelagic Regionalisation (DEW 2007b).

A biogeographic approach to conservation and protected area management is increasingly relevant as the range of species adjusts in response to changing climatic conditions. This is particularly important for attempts to manage the pole ward migration of species and the inter-connectivity between established habitat and protected areas.

2.2 Terrestrial Protected Areas

The Commonwealth terrestrial protected areas comprise six National Parks; Booderee National Park; Christmas Island National Park and Conservancy; Kakadu National Park; Norfolk Island National Park; Pulu Keeling National Park and Cocos (Keeling) Islands Conservancy and Uluru-Kata Tjuta National Park, and the Australian National Botanic Gardens. Three of the six National Parks, namely Kakadu National Park and Uluru - Kata Tjuta National Park in the Northern Territory and Booderee National Park in the Jervis Bay Territory are managed jointly with their Aboriginal Traditional Owners. The other three national parks protect unique island ecosystems within Cocos (Keeling) Islands and Christmas Island (located in the Indian Ocean) and the Norfolk Island Territory (in the South Pacific). Kakadu and Uluru-Kata Tjuta are included on the World Heritage List and are probably Australia's best known parks.

These sites include a diversity of ecosystems from dry sclerophyll heathland/woodland (Booderee) to vast savanna and wetland systems (Kakadu) and arid and semi-arid habitats (Uluru- Kata Tjuta). Some of these areas are very small (e.g. Norfolk Island National Park covers only 650 ha), while others such as Uluru-Kata Tjuta and Kakadu cover some of the largest, and least disturbed areas of the continent (further detail about these parks is provided in the respective chapters). Each protected area provides habitat for a variety of rare, threatened or endemic species.

These protected areas are major attractions for the Australian tourism industry with around 1.4 million people visiting in 2005-2006, including approximately 193,000 at Kakadu and more than 350,000 at Uluru-Kata Tjuta (Director of National Parks, 2006).

2.2.1 Goals of Commonwealth Terrestrial Reserves

The Australian Government's terrestrial protected areas, excluding Botanic Gardens, are all national parks. Goals for terrestrial national parks are:

- To protect and manage the reserve in its natural condition;

- To protect the reserve for spiritual, scientific, educational, recreational and tourist purposes
- To perpetuate in as natural a state as possible representative examples of physiographic regions, biotic communities, genetic resources, and native species to provide ecological stability and diversity;
- To manage visitor use for inspirational, educational, cultural and recreational purposes at a level that will maintain the reserve or zone in a natural or near natural state;
- To ensure that exploitation or occupation inconsistent with the above does not occur;
- To maintain respect for the ecological, geomorphologic, sacred and aesthetic attributes of the reserve;
- To take into account the needs of indigenous people, including subsistence resource use, to the extent that they do not conflict with the above; and
- To recognise and take into account the aspirations of traditional owners of land within the reserve, their continuing land management practices, the protection and maintenance of cultural heritage, and the benefit the traditional owners derive from enterprises established in the reserve, consistent with the above.

2.3 Marine Protected Areas

Australia's ocean territory includes some of the most spectacular examples of marine ecosystems seen anywhere on the planet. Covering 40 degrees of latitude, from tropical to Antarctic, Australian marine ecosystems include coastal, shelf and oceanic salt marsh and coral reef ecosystems. Within this area, Australia has established a number of marine protected areas, some of which are among the largest, least disturbed and best managed globally (Pandolfi *et al*. 2003).

At the time this project was commissioned there were 13 marine protected areas (MPAs) in the Commonwealth component of the National Representative System of Marine Protected Areas (NRSMPA) that are administered under the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*). These sites range across a diversity of ecosystems from the tropics to the sub Antarctic, and from the Indian Ocean to the Coral and Tasman Seas.

In addition to the existing estate of Commonwealth MPAs, DEWHA is pursuing the identification and selection of new areas for declaration and management in the context of Bioregional Marine Planning under Section 176 of the *EPBC Act*.

2.3.1 Goals of the Commonwealth Marine Reserves

The primary goals of the Commonwealth's National Representative System of Marine Protected Areas are to contribute to the comprehensiveness, adequacy and representativeness of the national system; to contribute to the long-term ecological viability of ecological systems; to maintain ecological processes; and to protect Australia's biological diversity at all levels (ANZECC, 1999).

In order to achieve these goals, Commonwealth protected areas aim, specifically:

- To promote the development of protected areas within the framework of integrated ecosystem management;
- To provide a formal management framework for a broad spectrum of human activities, including recreation, tourism, and the use or extraction of resources, the impacts of which are compatible with the primary goals;
- To provide scientific reference sites;
- To provide for the special needs of rare, threatened or depleted species and threatened ecological communities;
- To provide for the conservation of special groups of organisms – for example, species with complex habitat requirements or mobile or migratory species, or species vulnerable to disturbance and which may depend on reservation for their conservation;
- To protect areas of high conservation value including those containing high species diversity, natural refugia for flora and fauna and centres of endemism; and
- To provide for the recreational, aesthetic and cultural needs of Indigenous and non-Indigenous people.

Each protected area is managed according to a specific set of management objectives that relate to the site and the values. Each protected area is also assigned to an IUCN category as per the *EPBC Act* (1999) and managed according to the Australian IUCN Reserve Management Principles, set out in Section 8 of the EPBC Regulations.

2.4 Botanic Gardens

The only legal definition of a botanic garden in Commonwealth legislation occurs in the *National Parks and Wildlife Conservation Act 1975*. This definition is carried forward into the replacement *Environment Protection and Biodiversity Conservation Act 1999* by bridging legislation.

“Botanic garden" means a scientific and educational institution the purpose of which is the advancement and dissemination of knowledge and appreciation of plants by:

(a) Growing them in a horticultural setting;

(b) Establishing herbarium collections;

(c) Conducting research; and

(d) Providing displays and interpretative services.

Botanic gardens have played a significant role in the preservation of species and genetic material over time. With climate change changing ecosystems and species, it is anticipated that botanic gardens including living collections and herbariums will have an increasingly important role to play.

2.4.1 Goals of Botanic Gardens

The primary goal of Botanic Gardens is to:

- Grow, study and promote Australia's flora.

There are a number of objectives which may be considered in achieving this goal. As an example, below are the objectives outlined in the management plan for the Australian National Botanic Gardens (CHABG 2006)

- Achieve excellence in the presentation of the Gardens to enable people of all ages, abilities and backgrounds to enjoy and appreciate the values of Australian plants and botanic gardens;
- Maintain and enhance integrated living, herbarium and photographic collections of Australian plants, supported by the library collection;
- Provide high quality information and an educational resource for government, industry, scientific institutions and the community;
- Conduct and encourage research using the Gardens' living and herbarium collections;
- Foster understanding of the origins and values[4] of Australia's plant biodiversity, while promoting its protection, conservation and wise use;
- Provide a national focus for, and work in effective partnership with, other organisations in matters concerning botanic gardens, herbaria and Australian plant biodiversity; and
- Maintain an accountable, innovative and receptive organisation that is responsive to clients and new circumstances and which values staff contributions.

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4 'values' should be read as including environmental, cultural, economic, heritage and aesthetic values.

3 Global and Australian Climate Trends

This chapter provides a brief overview of climate change, emission scenarios on global and regional levels, changes in the Australian climate applicable to the management of the Commonwealth protected areas, and projected regional climate change for 2030 and 2070 (CSIRO 2001, 2006). The climate information presented in this chapter provides the baseline data for considering the impacts of climate change on a regional basis and hence the implications for managers of the Commonwealth protected areas.

3.1 An Introduction to Climate Change

The Framework Convention on Climate Change (UNFCCC), in its Article 1, defines ‘climate change’ as: ‘*a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*’. The UNFCCC thus makes a distinction between ‘climate change‘, attributable to human activities altering the atmospheric composition, and ‘climate variability’, attributable to natural causes (United Nations 1992).

The greenhouse effect is a natural warming process of the earth. When the sun's energy reaches the earth some of it is reflected back to space and the rest is absorbed. The absorbed energy warms the earth's surface which then emits heat energy back toward space as longwave radiation. This outgoing longwave radiation is partially trapped by greenhouse gases such as carbon dioxide, methane and water vapour which then radiate the energy in all directions, warming the earth's surface and atmosphere. Without these greenhouse gases the earth's average surface temperature would be about 33^{o}C cooler. (Australian Bureau of Meteorology, 2003)

Emission Scenarios

The Intergovernmental Panel on Climate Change (IPCC) has developed global emission scenarios ranging from ‘business as usual’ scenarios that project current emission trends, to a range of emission reduction scenarios that consider slow to rapid transitions to a low carbon economy. The scenarios are based upon a range of assumptions relating to population growth, economic development and technological change, without explicit policies to reduce greenhouse gas emissions. Some 40 anthropogenic scenarios have been developed by the IPCC which map out plausible future emission pathways of greenhouse gases and include CO_2, CH_4, N_20, sulphate aerosols and other aerosols from biomass burning.

Since carbon dioxide is the most important anthropogenic greenhouse gas it is generally used as a barometer of atmospheric change. According to the 2007 IPCC report (IPCC 2007a), the global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280ppm to 379ppm in 2005 and the atmospheric concentration of carbon dioxide in 2005 exceeded by far the natural range over the last

650,000 years (180 to 300ppm) as determined from ice cores (IPCC, 2007a).

There is a strong consensus amongst leading scientists that increased emissions are resulting in rising global temperatures. On a regional level the rate and magnitude of climate change is difficult to project, although greater confidence is ascribed to temperature, compared to rainfall projections. In Australia, the CSIRO has pioneered assessment work to project the impacts and implications of climate change at a regional level. For this study CSIRO regional climate change scenarios for both 2030 and 2070 timelines have been adopted. In some circumstances regional climate change scenarios for areas of mainland Australia have been extrapolated and applied to adjacent marine protected area locations for which there is no specific projected data.

Vulnerability

The extent to which a natural system or human society is unable to cope with the negative impacts of climate change, variability and extremes. It depends on changes in climate as well as the sensitivity and adaptive capacity of the system or society (Pittock 2003).

3.2 Observed Changes in Climate

3.2.1 Summary of global trends

Warming of the climate system globally is now considered unequivocal, with observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC, 2007a). Average global temperatures have increased 0.74°C over the last century (1906-2005), with 11 of the last 12 years (1993-2000) ranking among the 12 warmest years since 1850. According to a preliminary estimate released by the World Meteorological Organisation (WMO, 2006), the global mean temperature for 2006 was about 0.42°C above average, making it the sixth-warmest year globally since records commenced in 1861(BOM, 2007).

Warming is accelerating, with the average rate over the past 50 years twice that of the previous 50 (IPCC, 2007a). Changes in extreme temperatures have also been observed over the last 50 years, with fewer cold days, cold nights and frosts, and more hot days, hot nights and heat waves. The average temperature of the oceans has increased to depths of at least 3000m. Such warming causes seawater to expand, contributing to sea level rise. Mountain glaciers and snow cover have decreased in both hemispheres. Melting of glaciers and polar ice sheets have also contributed to sea level rise. Global average sea levels have risen 1.8 mm per annum from 1961-2003; this increase is accelerating, with a rate of 3.1 mm per annum estimated over 1993-2003 (IPCC, 2007a).

Long term trends in precipitation over large regions have been observed from 1900-2003, although these trends are highly variable both spatially and temporally. More intense and longer droughts have also been observed since the 1970s over wide areas, particularly in the tropics and subtropics. The frequency of heavy rainfall events has increased over most land areas but there is no clear trend as yet in the annual number of tropical cyclones (IPCC, 2007a).

3.2.2 Australian climate trends

Consistent with global trends, average maximum temperature across Australia has increased 0.6^{o}C and the minimum temperature 1.2^{o}C, over the period 1910-2004, with most of the warming occurring since 1950 (Nicholls and Collins, 2006). There has been an increase in hot days (35^{o}C or more) of 0.10 days/year, and hot nights (20^{o}C or more) of 0.18 nights/year, and a decrease in cold days (15^{o}C or less) of 0.14 days/year and cold nights (5^{o}C or less) of 0.15 nights/year (1957-2004) (Nicholls and Collins, 2006).

Southern and eastern Australia have become drier since the 1950s, while the north-western two-thirds of the continent has experienced an increase in summer monsoon rainfall (Smith, 2004b). Droughts have become more extreme since about 1973 because temperatures are higher for a given rainfall deficiency (Nicholls, 2004).

In New South Wales, extreme daily rainfall since 1950 has increased in the north-western and central regions and over the western tablelands of NSW, but decreased in the southeast, southwest and central east-coast (Gallant *et al.*, 2006). South-east Australian snow depths at the start of October have declined 40% in the past 40 years (Alexander *et al*, in press; Nicholls, 2005). There is no trend in the frequency of tropical cyclones in the Australian region from 1981-2003, but an increase in intense systems (very low central pressure) has been observed (Kuleshov, 2003; Hennessy, 2004). Relative sea-level rise around Australia averaged 1.2 mm/year from 1920 to 2000 (Church *et al.* 2004).

Since 1950 the Northern Territory's average annual maximum temperature has increased by about 0.12°C per decade and the minimum has increased 0.17°C per decade, with greater warming in May-Oct than Nov-April (Hennessy *et al*, 2004). The territory has also become wetter. From 1900-2002 Territory average rainfall rose 14.2 mm per decade during Nov-Apr and 2.5 mm per decade during May-Oct. However since 1950, the Territory average has risen 35.7 mm per decade during Nov-Apr and fallen 0.4 mm per decade in May-Oct. This was mainly due to extremely wet conditions in the mid-1970s and 1999-2000. Since 1910 the intensity of heavy daily rainfall events has risen 10% (Hennessy *et al.* 2004).

Sea surface temperatures in many tropical regions have increased by almost 1^{o}C over the past 100 years (some tropical seas up to 2^{o}C) and are currently increasing ~1–2^{o}C per century (Hoegh-Guldberg, 1999). In the Great Barrier Reef, sea surface temperatures have increased 0.46^{o}C per century in the north to 2.59^{o}C per century in the waters off Townsville. Sea surface temperatures on the Great Barrier Reef in early 1998 were the warmest in the past 95 years of instrumental record (Lough 2000) and were associated with significant coral bleaching.

Figure 3-1 below illustrates changes to the mean annual average temperatures for Australia (based on departures from 1961-90 data) for the period 1910 to 2010. The findings show that the period from 1961 to 1990 experienced significantly warmer annual mean temperatures (+0.5 °C) than the preceding time period from 1910 to 1961. The figure also illustrates that the period from 1980 to 2006 also experienced significantly warmer annual mean temperatures (+0.6°C) than 1961-1990.

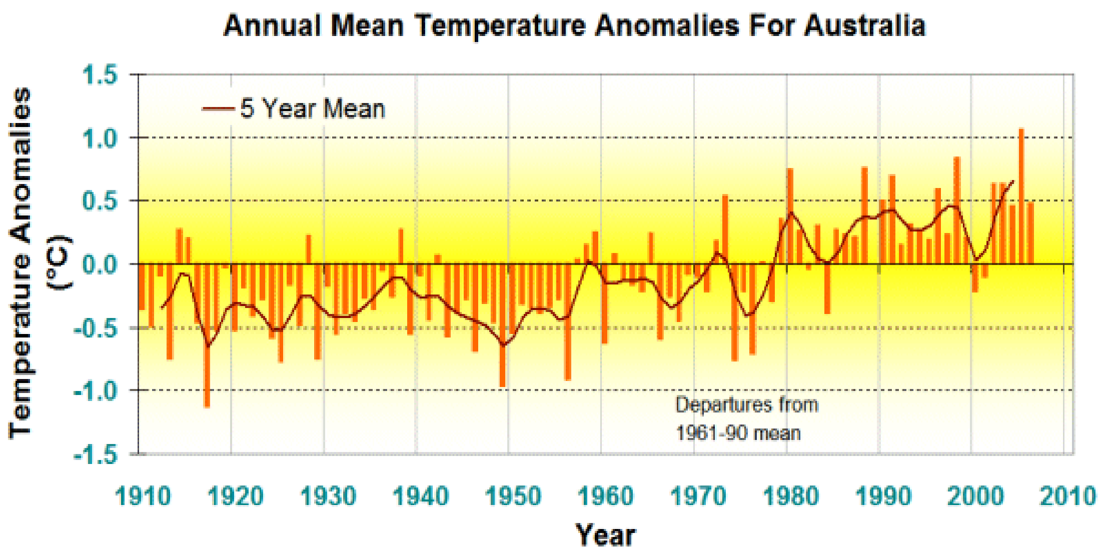

Figure **3-1** Australian annual mean temperature anomalies (compared to the 1961-90 average) since 1910
(Source: WMO 2007, BOM 2007)

3.3 Projected Changes in Australian Climate and Second Order Effects

Future projections for Australia generally indicate an increased incidence of hot days, fewer frosts, increased wind speeds and storm events, increased incidence of intense rainfall events and changes to seasonal rainfall (Pittock 2003, Preston and Jones 2006). When rainfall changes are combined with increases in potential evaporation, a general decrease in available soil moisture is projected across Australia, with droughts likely to become more severe.

Projected changes will be superimposed on natural variability including El Niño Southern Oscillation (ENSO) and the Inter-decadal Pacific Oscillation (IPO), and a move towards more El Niño-like conditions with a corresponding mean eastward shift of precipitation over the tropical Pacific and the weakening of the inter-annual ENSO-Asian-Australian monsoon connection (IPCC Working Group I, Chapter 10, 2007). An increase in westerly winds is likely south of latitude 45°S, with a strengthening of the East Australian Current and southern mid-latitude ocean circulation (Cai *et al.* 2005).

3.3.1 Temperature

Annual average temperatures in Australia are projected to increase by 0.4 to 2.0 °C by 2030, and 1.0 to 6.0 °C by 2070, relative to 1990 (CSIRO 2001). Warming is expected to be greater inland than near the coast. Increases in daily maximum and minimum temperate will be similar to changes in average temperature. The average number of summer days over 35°C is expected to increase (e.g. Sydney might be expected to have 2-4 days by 2030 and 3-11 days by 2070, compared to an average of 2 days at present). The average number of winter days below 0°C is expected to decline (e.g. in Canberra to 31-42 days by 2030, and to 6-38 days by 2070, compared to 44 days at present).

3.3.2 Precipitation and ENSO

A future trend towards more El Niño-like conditions with a corresponding mean eastward shift of precipitation over the tropical Pacific and the weakening of the interannual ENSO-Asian-Australian monsoon connection is expected (IPCC 2007a).

There is a wide range of uncertainty in scenarios of future rainfall trends. Overall, the CSIRO (2001) scenarios indicate annual average rainfall may decrease in the southwest (-20% to +5% by 2030 and -60% to +10% by 2070), and in parts of the southeast and Queensland (-10% to +5% by 2030 and -35% to +10% by 2070). In some other areas, including much of eastern Australia, projected ranges are -10% to +10% by 2030 and -35% to +35% by 2070.

The ranges for the tropical north are (-5% to +5% by 2030 and -10% to +10% by 2070). In winter and spring most locations tend towards decreased rainfall (or are seasonally dry) with typical ranges of -10% to +5% by 2030 and +5% to +10% by 2070.

For arid areas, scenarios projected under global warming by Global Circulation Models (GCMs) are especially variable (Hulme *et al* 1999, 2000). One reason for this may be the extreme natural variability of climate in these areas (both spatial and temporal). Even areas experiencing the same storm can receive very different amounts of rainfall. The rainfall pattern in arid areas is poorly represented not only in the GCMs but also in regional models (Lioubimtseva 2004). Projecting changes in precipitation in these areas is particularly problematic.

Projected decreases are stronger in the southwest (-20% to +5% by 2030 and –60% to +10% by 2070). Tasmania tends toward increases in winter (-5% to +20% by 2030 and -10% to +60% by 2070). In summer and autumn, projected rainfall ranges from -10% to +10% by 2030 and -35% to +35% at most locations.

Most models simulate an increase in extreme daily rainfall, leading to more frequent heavy rainfall events, even in areas where average rainfall is projected to decline (CSIRO, 2001). For example, the intensity of the 1-in-20 year daily-rainfall event is likely to increase by up 25% in northern Queensland by 2050 (Walsh *et al.*, 2001) and up to 30% by the year 2040 in south-east Queensland (Abbs, 2004). In NSW, the intensity of the

1-in-40 year event increases by 5 to 15% by 2070 (Hennessy *et al.* 2004). Increases in extreme daily rainfall may result in increased risk of flooding.

The area of mainland Australia with at least 1 day of snow cover per year is likely to shrink 10-40% by 2020 and 22-85% by 2050 (Hennessy *et al.* 2003).

3.3.3 Evaporation, moisture balance and runoff

The CSIRO models indicate increases in potential evaporation of up to 8% per degree of global warming over most of Australia, and up to 12% over the eastern highlands and Tasmania with increases tending to be larger where there is a corresponding decrease in rainfall. The resulting scenario is a decrease in annual moisture balance over the continent averaging from ~40 to 120 mm per degree of global warming, depending on the model used. This represents decreases of 15 to 160 mm by 2030 and 40 to 500 mm by 2070 and indicates that much of the continent will be subject to reduced soil moisture and runoff in the future (CSIRO 2001). Up to 20% more droughts (defined as the 1-in-10 year soil moisture deficit from 1974-2003) are simulated over most of Australia by 2030 and up to 80% more droughts by 2070 in south-western Australia (Mpelasoka *et al.* 2007). Projected changes in the Palmer Drought Severity Index indicate drought increases over much of eastern Australia between 2000 and 2046 (Burke *et al.* 2006).

3.3.4 Storms and tropical cyclones

The behaviour of tropical cyclones under enhanced greenhouse conditions has been the subject of considerable speculation but projections are difficult because tropical cyclones are not well resolved by global or regional climate models (Pittock *et al*. 1996; Walsh and Pittock 1998). Present indications are that modest to moderate (0–20%) increases in average and maximum cyclone intensities are expected by the end of the century in some regions (Walsh and Ryan 2000). The frequency of severe tropical cyclones (Categories 3, 4 and 5) is projected to increase on the east coast (Leslie *et al.* 2007) and in the north-east (Walsh *et al*, 2004). A southerly shift in occurrence is also expected.

3.3.5 Changes in fire regimes

Warming temperatures and reductions in rainfall will increase the incidence and intensity of fire in many areas. Increases in atmospheric CO_2 may also increase fuel loads in some vegetation types due to the impacts of CO_2 fertilisation on plant growth (Tapper 2000; Williams *et al.* 2001; Cary 2002; Hughes 2003). The frequency of very high and extreme fire danger days in the south-east is simulated to rise 4-25% by 2020 and 15-70% by 2050 (Hennessy *et al.* 2006). The fire season length is therefore likely to be extended, with the window of opportunity for control burning shifting towards winter.

Williams et al. (2001) also looked at the distributions of fire danger rating days for a range of specific sites in southern and northern Australia and found a general trend towards a decreasing frequency of low and moderate fire danger rating days, but an increasing frequency of very high and in some cases extreme fire danger days.

3.3.6 Oceanic changes

By 2070, waters around Australia are expected to warm by 1-2ºC, with greatest warming in SE Australia/Tasman Sea due to a strengthening of the East Australia Current (Hobday *et al*. 2006a). At depths of 500m, warming of 0.5-1.0ºC is projected (Hobday *et al*. 2006a). Warming oceans will contribute to rises in sea level, in addition to input from melting glaciers and ice caps. The global-mean projected sea-level rise by 2100 is 0.18 to 0.59 m, relative to the year 2000; excluding uncertainties in carbon cycle feedbacks and the possibility of faster ice melt from Greenland and Antarctica (IPCC 2007a). These values would apply to Australia but may be modified by as much as +25% due to regional differences in thermal expansion rates and oceanic circulation changes and by local differences in relative sea-level changes due to vertical land movements.

There will generally be more incident solar radiation on the sea surface in Australian waters, with projections between 2 and 7 units Wm^{-2} by 2070 (Hobday *et al*, 2006a). Almost all areas of Australia will have greater stratification and a shallowing of the mixed layer by about 1m, reducing nutrient inputs from deep waters. There is also likely to be an increase of 0-1m/s in surface winds by 2070 (Hobday *et al*. 2006a).

3.4 Protected Areas outside Regions Covered by CSIRO Scenarios

Fifteen of the twenty protected areas included within the scope of the study are in remote locations, thus falling outside the scope of CSIRO climate change scenarios which are limited to the Australian mainland. Where feasible, scenarios for terrestrial areas have been treated as an indication of change only, for example for Christmas Island National Park and Pulu-Keeling National Park. Where terrestrial data cannot feasibly be applied, for example, for the sub-Antarctic Heard Island and McDonald Island Marine Reserve, the study team has endeavoured to develop variables from regional projections. This has been undertaken in close consultation with the Centre for Atmospheric Research at CSIRO, primarily Dr Penny Whetton.

This information has been generated so that some understanding of possible influence of climate change on those protected areas can be generated and considered. Further information relating to those derived variables is provided in the specific protected area chapters.

For the offshore marine areas listed below, CSIRO regional scenarios for sea level and atmospheric CO_2 concentrations have been applied. Other scenarios pertinent to marine areas, including changes to sea surface temperature, mixed layer depth and pH, have been sourced from a CSIRO Mk 3.5 model as presented in (Hobday *et al*. 2006a) which describes changes in physical and chemical characteristics of Australia's marine realm by 2070.

- Elizabeth and Middleton Reefs Marine National Nature Reserve;
- Great Australian Bight Marine Reserve;
- Heard Island and McDonald Island Marine Reserve;
- Lord Howe Island Marine Park (Commonwealth Waters);
- Macquarie Island Marine Park;
- Mermaid Reef Marine National Nature Reserve;
- Solitary Islands Marine Reserve (Commonwealth waters); and
- Tasmanian Seamounts Marine Reserve.

3.5 Regional Climate Scenarios (2030 and 2070)

Climate change projections[5] can be presented for any time in the future. The years 2030 and 2070 have commonly been chosen since they represent short and longer term planning horizons. The following projections are based on climate change scenarios which have been prepared for 2030 and 2070.

The climate change scenarios used for **2030** are drawn from the publications "Climate change scenarios for initial assessment of risk in accordance with risk management guidance" (CSIRO, 2006)

Scenarios for 2030 are provided for ten regions of Australia as seen in Figure 3-2 . The scenarios are presented as changes relative to 1990, since that is the year used by the IPCC.

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5 The term "climate projection" when used by the IPCC refers to model-derived estimates of future climate. On the other hand a scenario is "a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions)."(IPCC, http://www.ipcc-data.org/ddc_definitions.html)

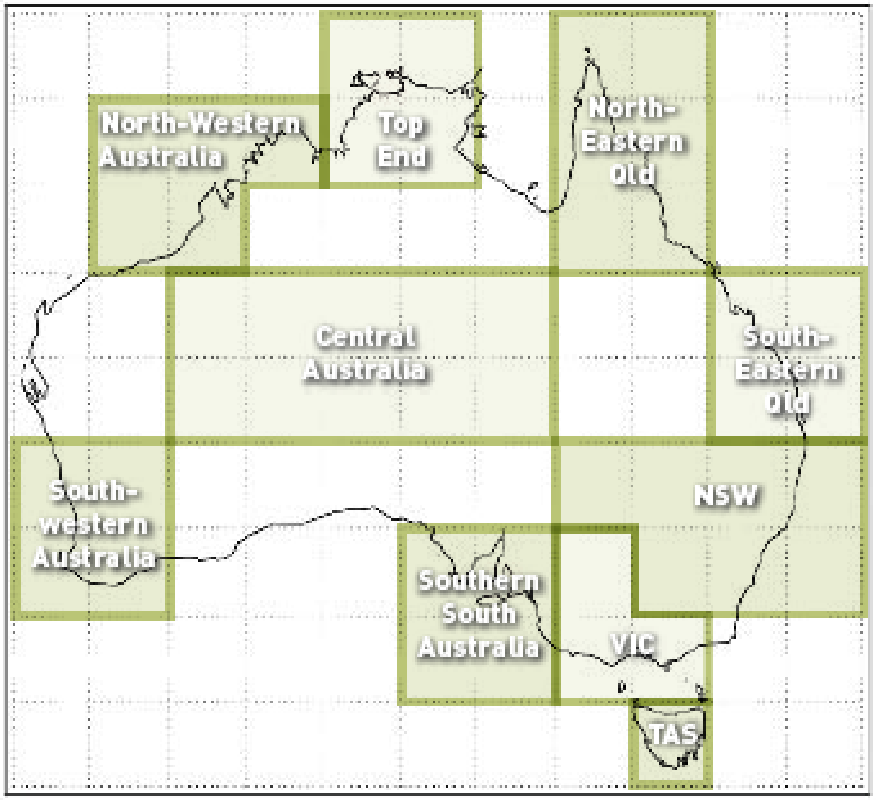

Figure 3-2 Climate change regions used for 2030 scenarios

(Source: CSIRO, 2006)

These scenarios include changes in the following variables:

- Average annual temperature, rainfall,
- Potential evaporation and sea-level rise;
- Average daily extremes of temperature, rainfall, cyclone intensity and fire danger; and
- Average solar radiation and humidity, and extreme daily wind-speed.

The scenarios for **2070** are internally consistent with those used for 2030 and have been provided by CSIRO, in particular Dr Penny Whetton. In addition to the 10 regions included for the 2030 scenarios, an additional five have been added for the 2070 scenarios, Mid Western Australia, Mid Northern Territory, Western Queensland, Mid South Australia and South Eastern Western Australia thus providing coverage of all of mainland Australia (in effect filling the gaps in Figure 3-2 above).

Scenarios for six of the fifteen regions are applicable to this study (not including marine offshore protected areas) and a summary of the worst case scenarios (i.e. high global warming scenario) for 2030 and 2070 is provided below.

3.5.1 North-Western Australia

The scenarios for north-western Australia are applied to the following protected areas:

- Ashmore Reef National Nature Reserve (due to the remote location, scenarios are treated as an indication of change only); and
- Cartier Island Marine Reserve (due to the remote location, scenarios are treated as an indication of change only).

Of particular note are the following scenarios for this region:

- By 2070, the region is anticipated to have a 4.0°C rise (with uncertainty of ±1.7°C) in annual average temperature;
- Regional average sea level is projected to increase by 17cm and 50cm by 2030 and 2070 respectively;
- Annual average rainfall is estimated to decline by 11% (with uncertainty of ±34%) with seasonal average summer rainfall declining by 11% (with uncertainty of ±34%). N.B. From the high degree of uncertainty it is plausible that annual and seasonal average rainfall may increase or decrease;
- Annual average potential evaporation is projected to increase by 4% (uncertainty of ±3%) and 13% (uncertainty of ±9%) by 2030 and 2070 respectively; and
- The annual average number of hot days (over 35°C) is projected to increase from 54 days (at Broome) at present to an additional 65 days by 2030 and 240 days by 2070, averaging a total of over 119 days a year and 304 days a year respectively.

3.5.2 Top End of the Northern Territory

The projections for the top end of the Northern Territory are applied to:

- Kakadu National Park

Of particular note are the following projections for this region:

- By 2070, the region is anticipated to have a 4.0°C rise (with uncertainty of ±1.7°C) in annual average temperature;
- Regional average sea level is projected to increase by 17cm and 50cm by 2030 and 2070 respectively;
- By 2070 annual average rainfall is projected to have no change i.e. 0% estimate (with uncertainty of ±23%); as are summer and autumn rainfall (with uncertainty of ±23% and ±45% respectively) but spring rainfall is projected to increase by 11% (uncertainty ±57%). N.B. From the high degree of uncertainty it is plausible that annual and seasonal average rainfall may increase or decrease; and
- The annual average number of hot days (over 35 °C) is projected to increase from 11 days (at Darwin) at present to an additional 62 days by 2030 and 295 days by 2070, averaging a total of over 73 and 306 days a year respectively.

3.5.3 North-eastern Queensland

The scenarios for north-eastern Queensland are applied to:

- Coringa Herald National Nature Reserve; and
- Lihou Reef National Nature Reserve.

Due to the remote locations of these reserves, scenarios are treated as an indication of change only.

Of particular note are the following scenarios for this region:

- By 2070, a 4.0°C rise (with uncertainty of ±1.7°C) in annual average temperature is projected;
- Regional average sea level is projected to increase by 17cm and 50cm by 2030 and 2070 respectively;
- By 2070, an 11% decrease in annual average rainfall (uncertainty of ±34%), an 11% decrease in average summer rainfall (uncertainty of ±34%), a 23% decrease in average autumn rainfall (uncertainty of ±45%), and no change in spring rainfall (uncertainty of ±68%). N.B. From the high degree of uncertainty it is plausible that annual and seasonal average rainfall may increase or decrease;
- Increase in daily extreme rainfall by 25% (1-in-20 year intensity for 2050); and
- The annual average number of hot days (over 35 °C) is projected to increase from 3 days (at Cairns) at present to an additional 116 days by 2070, averaging a total of over 119 days a year.

3.5.4 Central Australia

The scenarios for central Australia is applied to:

- Uluru-Kata Tjuta National Park.

Of particular note are the following scenarios for this region:

- By 2070, the region is anticipated to have a 5.1°C rise (with uncertainty of ±1.7°C) in annual average temperature;
- By 2070 annual average rainfall is projected to have no change i.e. 0% estimate (with uncertainty of ±45%); as are summer and autumn rainfall (both with uncertainties of ±45%). N.B. From the high degree of uncertainty it is plausible that annual and seasonal average rainfall may increase or decrease;
- Annual average potential evaporation is projected to increase by 6% (with uncertainty of ±3%) and 17% (with uncertainty of ±9%); by 2030 and 2070 respectively;
- The annual average number of hot days (over 35°C) is projected to increase from 89 days (at Alice Springs) at present to an additional 102 days by 2070, averaging a total of over 191 days a year; and
- The annual average number of cold nights (below 0°C) is projected to decrease from 16 days (at Alice Springs) at present to 11 days less by 2030 and 16 days less by 2070, totalling zero cold nights annually on average.

3.5.5 Mid-Western Australia

The scenarios for mid-Western Australia are applied to:

- Ningaloo Marine Park.

Of particular note are the following scenarios for this region:

- By 2070, the region is anticipated to have a 5.1°C rise (uncertainty of ±1.7°C) in annual average temperature;
- Regional average sea level is projected to increase by 17cm and 50cm by 2030 and 2070 respectively; and
- By 2070 a projected 23% decrease in annual average rainfall (with uncertainty of ±45%), an 11% decrease, in annual average summer and autumn rainfall (uncertainty of ±57% and ±34% respectively) and a 23% decrease in winter rainfall (uncertainty of ±45%). N.B. From the high degree of uncertainty it is plausible that annual and seasonal average rainfall may increase or decrease.

3.5.6 NSW

The scenarios for New South Wales are applied to the following protected areas:

- Booderee National Park;
- Booderee Botanic Gardens;
- Australian National Botanic Gardens;
- Norfolk Island National Park (due to the remote location, scenarios are treated as an indication of change only); and
- Norfolk Island Botanic Gardens (due to the remote location, scenarios are treated as an indication of change only).

Of particular note are the following scenarios for this region:

- By 2070, the region is anticipated to have a 4.0°C rise (uncertainty of ±1.7°C) in annual average temperature;
- Regional average sea level is projected to increase by 17cm and 50cm by 2030 and 2070 respectively;
- By 2070 a projected 11% increase (with uncertainty of ±34%) in annual average rainfall; with a projected 11% increase in summer and autumn rainfall (both with uncertainties of ±57%) and a 23% decrease in both average winter and spring rainfall (both with uncertainties of ±45%). N.B. From the high degree of uncertainty it is plausible that annual and seasonal average rainfall may increase or decrease;
- An increase in annual daily extreme rainfall by 10% (uncertainty of ±5%) by 2070 (based on 1-in-40 year intensity)[6];
- An increase in annual average potential evaporation by 17% (uncertainty of ±13%) by 2070;

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6 Based on two climate models (Hennessy *et al*. 2004)

- The annual average number of hot days (over 35°C) at Sydney is projected to increase from 3 days to an additional 15 days by 2070, totalling an average of 18 days a year;
- The annual average number of hot days (over 35°C) at Canberra is projected to increase from 5 days at present to an additional 30 days by 2070, totalling an average of 35 days a year;
- The annual average number of very high and extreme forest fire danger days will increase from 11 days (at Richmond) at present to an additional 8 days by 2050; and
- The annual average number of cold nights (below 0°C) is projected to decrease from 62 days (at Canberra) at present to 52 days less by 2070 – totalling ten cold nights annually on average.

4 Climate Change Impacts on the Values of Protected Areas

4.1 Factors Influencing the Australian Biota

4.1.1 Terrestrial Biota

The terrestrial biota of the Australian continent has been shaped by a range of forces, of which the most notable are climate variability, topography, the long period of isolation from other continents, fire and humans.

The Australian flora and fauna is a composite of Gondwanan[7] elements, evolutionary lines shared with South America, post-Miocene[8] arrivals from Asia, colonists from New Guinea and endemic species (Augee and Fox 2000). Approximately 85% of the flora is endemic and many species are restricted in geographic and climatic range.

Australia has a diverse range of climate zones varying from the tropical regions in the north through to the arid expanses of the interior to temperate regions in the south. Seasonal fluctuations can be great with temperatures ranging from above 50°C to well below zero. Australia is the driest of the world's inhabited continents, with 80% of the land having a rainfall less than 600 millimetres per year and 50% having less than 300 millimetres (BoM 2007). Australia also has the lowest percentage of rainfall as runoff, the lowest amount of runoff, the least amount of water in rivers, and the smallest area of permanent wetland (Augee and Fox 2000). This aridity is a consequence of both variable and low precipitation, coupled with a high radiation load leading to high rates of evapo-transpiration over much the continent's interior.

The continent is relatively flat and has no strong rain barrier to intercept rainfall from moist air. The mountains of New Guinea to the north also act as an orographic barrier to tropical circulation of rain-bearing air. Rainfall is highest in the east and north, but there is marked seasonal differentiation between north and south. The northern parts of the continent receive intense summer rainfall from tropical depressions or monsoons. In the south, winter depressions bring rain. Between these two seasonal rainfall zones the arid areas receive little rain. The arid zone (<250 mm pa) is also characterised by unpredictability of both the amount and seasonality of this meagre rainfall. In the southeast, both rainfall patterns coincide and this region receives sufficiently high and reliable rain to support woodlands and forests. The strongest regional driver of climate variability is the powerful El Niño - Southern Oscillation (ENSO)

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7 The break up of Gondwana occurred about 180 million years ago (NPWS 2004)
8 The Miocene epoch is part of Tertiary period which took place between 23.8 to 5.3 million years ago (University of California 2007)

phenomenon. In inland Australia especially, this phenomenon means that the climate can rapidly swing from cyclonic or monsoonal depressions causing flooding, to prolonged drought (Power *et al.* 1998).

Approximately 5% of the continent burns each year, and in some areas (such as the northern savannas) fire is an annual event. The impacts of fire can be complex and exert both positive and negative impacts on terrestrial biota. Fire is however, critical to the maintenance of biodiversity and ecological processes and contributes to the distinctive nature of Australian forests and woodlands. Aboriginal communities have used fire as a management tool on the land for more than 40,000 years. European colonisation and introduction of species have further transformed large tracts of land for settlement and agricultural purposes with direct impacts on local habitat and biota. .

4.1.2 Marine Biota

Marine biota within Australia's coastal waters are sustained and influenced by significant ocean currents that act as conveyor belts. The East Australian Current brings warm, low-nutrient tropical waters down the eastern coast of Australia. It is the dominant influence on the composition of marine biota including fisheries, along the eastern seaboard. To the north, the Indonesian Through flow transports large amounts of warm water from the Pacific into the Indian Ocean resulting in a warming of the sea surface of the Indian Ocean and increases in rainfall over Western Australia (CSIRO 2002). This in turn provides a mass of warm water to the Leeuwin current off Western Australia as it sweeps south along the west coast and east along the south coast.

Because of these currents, waters surrounding Australia are largely of tropical and subtropical origin and are mostly nutrient poor (oligotrophic), particularly with respect to nitrate and phosphate. The impact of changing productivity on marine oligotrophic systems is largely unknown; they may not be as resilient to stress and disturbance, including climate change, as more productive systems that commonly experience considerable interannual variability (Hobday *et al* 2006a).

Other significant ocean systems that influence biota and are being extensively studied to understand their influence on the Australian environment include:

- The Southern Ocean which is a major component of oceanic heat transport, overturning circulation and carbon sink;
- The Antarctic coastal region, where deep ocean water – Antarctic Bottom Water – is formed as a result of the formation of cold and saline water;
- The Antarctic Circumpolar Current that connects all of the major ocean basins to the south of Australia; and
- The ocean-atmosphere linkage that causes the El Niño Southern Oscillation annual variations that so greatly affect Australian climate variability.

With the exception of the Murray-Darling river system, Australian rivers are short. Because of the small size of most catchments, flood events are usually of short duration, often lasting only a few days. These high flow periods are closely coupled to local rainfall patterns. In the monsoonal climate of northern Australia, significant flow into and nutrient discharge from rivers is restricted to the summer wet season and is highly variable between and within years (Isdale 1984). Major flood events are related to the activity of monsoonal depressions or tropical cyclones. Relative to overall size of Australia's continental shelf environment, river runoff is a small and at most, a regional contributor to shelf nutrient processes and fluxes (Zann 1995)

Recent climate trends over the Southern Hemisphere summer indicate a strengthening of the circumpolar westerly and a weakening of the mid-latitude westerly extending from the stratosphere to the earth's surface. Much of this change is currently attributable to the depletion of the ozone layer over Antarctica. The results of a recent study (Cai, 2006) demonstrate that changes in atmospheric surface flows over the past decades have induced a southward intensification of the Southern Ocean super gyre circulation, including a strengthening of the East Australian Current flow through the Tasman Sea (Cai 2006).

4.2 Climate Change Influences on Biota

Climate change will have profound effects on biodiversity and on the structure and function of many Australian ecosystems. Climate change will affect species directly, by affecting their physiology and timing of life cycles, and indirectly, by affecting their interactions with other species. Together, these changes will alter species distributions and lead to changes in the structure and composition of communities.

4.2.1 Impacts on terrestrial biodiversity

Changes in temperature, water availability and CO_2 concentration will directly affect the physiology of most terrestrial species in some way. In animals, temperature can affect metabolic rate, fecundity, egg development, survivorship, sex ratio, length of oestrus, hormone release and parasitic infection rates. In plants, a 1^{o}C increase in temperature corresponds to an increase in respiration of approximately 10-30%. Increased CO_2 concentration enhances photosynthesis, water use efficiency and growth in many plant species, and alters the chemical composition of plant tissues. The effects of enhanced CO_2 on yield may, however, be offset to some extent by the deleterious effects of increased UV-B radiation and changes in the soil moisture balance. Enhanced CO_2 may also affect the nitrogen fixation, decomposition, and respiration rate in micro-organisms and fungi (Hughes 2003).

The life cycles of many organisms are also strongly influenced by temperature and precipitation. Warmer conditions may advance flowering and fruiting in some plants, and hasten development time in many animal species. Decoupling of relationships between some species, such as plants and pollinators, may also occur, especially where one partner is cued by day length, which will not change, and the other by climate (Hughes 2003).

While these direct physiological effects of changes in temperature, precipitation and CO_2 concentration may be dramatic for many species, in natural assemblages it is likely that changed competitive relationships will be even more important. Any change that favours a particular species in a community will indirectly disadvantage its competitors and in every community there will be winners and losers. For example, C3 plants (which include more than 95 percent of the plant species on earth) may be advantaged over C4 plants (the second most prevalent photosynthetic type including crop plants such as sugar cane and corn) because C3 species continue to increase photosynthesis with rising CO2 , while C4 species do not. Therefore, C3 plants can respond readily to higher CO2 levels, and C4 plants can make only limited responses. Species that are early-successional, highly-dispersible, or good colonisers, may be strongly advantaged; leading to the possibility that many landscapes will become increasingly dominated by a few opportunistic species (Table 4-1). Species with high reproductive rates and short generation times will also be advantaged, including many parasites and pathogens (Hughes 2003).

Other indirect effects of climate change will include changes in relationships between plants and their herbivores. Elevated CO_2 reduces the amount of nitrogen relative to carbon in plant foliage, as well as changing the concentrations of some defensive chemicals, making plants less nutritious. Many herbivorous insects, for example, have been found to increase consumption when fed plants grown at high CO_2, in order to satisfy their nutritional requirements (Hughes 2003).

4.2.2 Impacts on marine biodiversity

Like terrestrial species, marine species will be affected directly and indirectly by climate change. Habitats occupied by keystone species such as kelp, mangroves and corals will be particularly affected. Climate change impacts on dominant producer groups such as phytoplankton and zooplankton will have cascading effects throughout marine food webs (Hobday *et al*. 2006a). The relatively productive south-eastern temperate phytoplankton province, for example, is likely to retreat west of Tasmania by the 2070s, with associated reductions in food web productivity including fisheries yields (Hobday *et al*. 2006a). Among species most at risk are the coastal species endemic to south-east Tasmania (Edgar *et al* 1997).

Ocean currents

Currents play a major role in determining local conditions and the flow of propagules between reefs and coastal areas. They are believed to be largely stable over thousands of years, being determined by factors such as global drivers (Coriolis Effect), land masses and the temperature differences between regions of the planet. As a result, they drive genetic connectivity, biogeographical patterns and may be critical to whether a population, community or reef is maintained over time.

Australia is exceptional in that its western and eastern coastal areas are washed by warm poleward flowing currents. The East Australian Current (EAC) flows down the east coast while the Leeuwin current flows down the west coast of Australia. These currents have a large influence on the ecosystems that exist along the two coasts. There is now growing evidence that global patterns of water movement are changing, largely due to the rapid heating of polar areas relative to the rest of the planet. Changes to the strength of the Gulf Stream, for example, is dependent on the vigour of the thermohaline circulation of water around the planet. Similar changes are expected in the drivers of currents in Australia, although there is little information available on the detail of the changes that might occur. These changes are likely to be important and to affect the distribution and abundance of marine life around the Australian coastline (Hobday *et al* 2006a). Monitoring of rapid warming of the ocean off Maria Island in Tasmania since the 1970's, reveals a warming trend three times greater than the global warming rate. This warming is mainly driven by Antarctic ozone depletion, which is causing circulation changes in the stratosphere, which is in turn causing the strengthening of the circumpolar westerlies and weakening of the mid-latitude westerly winds. These wind changes are causing a strengthening of the East Australian current, which is shifting more warm water south, thus causing a warming of the Tasman Sea (Cai and Cowan 2007).

Ocean temperatures

The CSIRO climate model projects waters around Australia to warm by 1-2 °C by the 2070's, with the greatest warming off south east Australia in the Tasman Sea (Hobday *et al* 2006b). Many species, especially strong swimmers or those with highly dispersible planktonic larvae, may adapt to temperature changes by shifting distributions, most likely to the south.

Coral reefs will be particularly vulnerable because rising temperatures will increase the frequency and intensity of mass coral bleaching events. Corals bleach in response to a range of stresses including reduced salinity (Kerswell and Jones 2003), high or low irradiance (Yonge and Nichols 1931; Hoegh-Guldberg and Smith 1989; Gleason and Wellington 1993; Lesser *et al*. 1990), the presence of some toxins e.g. cyanide, (Jones and Hoegh-Guldberg 1999); and copper ions (Jones 1997), microbial infection e.g. Vibrio, (Kushmaro *et al*. 1996) and elevated or reduced temperatures (Jokiel and Coles 1990; Coles and Jokiel 1978; Hoegh-Guldberg and Smith 1989; Glynn and D'Croz 1990; Saxby *et al*. 2003; Hoegh-Guldberg and Fine 2004). When temperatures exceed a critical level, for example, the symbiosis between the corals and their dinoflagellate symbionts disintegrates and the coral bleaches. Mass coral bleaching events have affected coral communities all over the world and are only known in the scientific literature over the last 30 years. Events stretch over hundreds to thousands of square kilometres of coral reefs and are triggered by warmer than normal conditions. These events can be predicted from sea surface temperature anomalies measured from satellites. The response of thermal stress in corals is enhanced under strong light and by still water conditions (Hoegh-Guldberg 1999, 2005). Corals may recover from coral bleaching if conditions are mild, but will experience major mortalities if conditions are warm enough for long enough. A major global disturbance in 1998, for example resulted in 16% of corals in surveys across 30 different nations dying. In some cases, such as the Western Indian Ocean, up to 46% of corals died by the end of the global bleaching event (GCRMN 2000).

If bleaching begins to occur annually, or near-annually, reef communities are likely to change markedly in structure and composition, moving away from coral dominated communities to those dominated by macroalgae (Hoegh-Guldberg 1999).

The potential impacts of increasing sea temperatures on deep water habitats are less well understood, but likely to be substantial given that these communities (as with any ecosystems) have adapted to and existed at ambient temperatures (between 4 and 12^{o}C) for thousands of years. Climate change impacts on species and habitats may escalate in coming decades given that deep waters are rising in temperature at rates that are faster than that of surface waters.

Ocean acidification

The effects of thermal stress on marine organisms such as corals are likely to be exacerbated in the future by the gradual acidification of the world's oceans. In the past 200 years, the oceans have absorbed about half of the CO_2 produced by fossil fuel burning and cement production. Calculations based on measurements of the surface oceans and knowledge of ocean chemistry indicate that this uptake of CO_2 has led to a reduction of the pH of surface seawater of 0.1 units, equivalent to a 30% increase in the concentration of hydrogen ions. (Raven *et al*. 2005).

The calcification rate of a range of marine organisms as diverse as microalgae (coccolithophores), molluscs (pteropods) and corals is strongly dependent on the concentration of carbonate ions in seawater (Raven *et al*. 2005). Calcification declines with decreasing carbonate ion concentrations, becoming zero at a carbonate ion concentration of approximately 200 µmol/kg (Langdon *et al.* 2000; Langdon 2002). This occurs at atmospheric CO_2 concentrations of approximately 500 ppm. Tropical species are not the only ones potentially affected because acidification may also decrease the depth of the aragonite saturation horizon, the point below which corals have difficulty laying down skeletons in deep water and cold water-communities (Guinotte *et al.* 2006, Hobday *et al* 2006c). Reduced growth due to acidic conditions may hinder reef recovery after bleaching events and will reduce resilience of reefs to other stressors such as deposition of sediment and eutrophication.

Once atmospheric CO_2 concentrations exceed 500ppm, the ability of warm and cold water coral reefs to maintain the reef structures and communities that they build against the forces of physical and biological erosion will be severely compromised (Hobday *et al* 2006c). This could have major impacts on both limestone reef structures and on deep, cold-water reef communities with an estimated 70% of the world's cold-water coral reefs expected to be affected by the end of the century. Seamount habitats off South Australia, for example, could become inhospitable for cold water corals below a few hundred metres. The combined changes in both warm and cold water communities (given the biodiversity in warm water reef systems, and endemism in cold water communities) are likely to result in substantial losses of Australian marine biodiversity.

Sea level rise

Coral reefs will also be affected by sea level rise. Recent and even projected sea level rise is slow relative to the rate at which corals grow (Pittock 1999, Done 1999) and hence are not seen as a threat for healthy growing coral reefs if rates remain in the vicinity of 25-50 cm per century. The problem however, as described above, is that rates of coral growth are likely to be reduced by the effects of temperature and acidification (Hobday *et al* 2006c). Furthermore, sea level rise may accelerate in the future, especially if non-linear effects apply to the melting of large bodies of terrestrial ice sheets such as that in Greenland or the Western Antarctic Ice sheet. In these cases, there is potential for coral growth to lag behind that of sea level rise.

Storms and cyclones

Storms and cyclones can have large-scale effects on shallow marine habitats and coastal infrastructure. Hurricane Andrew[9] had major impacts on coral reefs in the Caribbean through the breakage and disruption of coral communities via wave impacts (Porter and Meier 1992). Any increase in storm intensity in Australia, like that of the 2005 season in the Caribbean, would have large effects on the structure and integrity of coral reefs in northern Australia. This would be heightened if reef recovery was inhibited by reduced coral growth and calcification as discussed above. Intense, sporadic cyclones may also change river flows and lead to increases in the amount of sediment running off coastal areas.

In contrast to the negative effects often associated with cyclonic activity, Cyclone Larry in 2006 is thought to have had a positive impact on the Great Barrier Reef. It is possible that while the sheer speed of cyclone Larry across the coast left the Great Barrier Reef relatively undamaged it also prevented coral bleaching events later that year. It has been suggested that cyclones turn the water column over and remove the warmer surface layers that are about 10 - 20 metres thick, which affect corals and coral bleaching. It has been suggested that this cyclonic activity may have prevented coral bleaching events later that year (University of Queensland, 2006).

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9 Cyclones are referred to as hurricanes in the northern hemisphere

While uncertainty exists as to how important changes to the frequency and intensity of major storms in Australia are, their interaction with other factors, like increased ocean temperatures and acidity, may further contribute to reducing the viability of coral populations and incline warm shallow coral reefs towards net erosion and dissolution (Puotinen 2006).

4.3 Potential Responses of biota to Climate Change

The responses of individual species to climate change will depend on their life history, genetic and phenotypic variability, and current geographic range. Some species may be able to tolerate the changes in their current location, others may adapt by migrating to more suitable sites. Species that cannot respond in these ways will go extinct (see Chapter 4.3.4). Individualistic responses by species will result in changes to the structure and composition of virtually all communities and ecosystems (pers comm, L Hughes 2007).

4.3.1 Tolerance

For species that use the environment at a fine spatial scale (e.g. insects and small plants), tolerating future climate change may simply involve changing behaviour to exploit a suitable microclimate. Some species may also have enough phenotypic plasticity and/or genetic variability to readily withstand the predicted changes. Species that currently have a broad geographic range and therefore broad climatic tolerance may undergo some contractions or expansions at the edges of their range, but remain largely unaffected, at least over the next few decades. However, some species with broad geographic ranges will consist of several ecotypes, each adapted to local climate. These species may be just as vulnerable to rapid climatic changes as those with restricted ranges (pers comm, L Hughes 2007).

4.3.2 Genetic Adaptation

Species with short generation times and rapid population growth rates may undergo micro evolutionary change to the changing environmental conditions *in situ*. However, the speed with which environmental change is predicted to occur requires that adequate response through adaptive evolution is unlikely for most species. Micro-organisms, some invertebrates, and early successional plant species may be the exceptions, by virtue of their broader range of tolerance as well as their potential to evolve faster. These species may spread at the expense of others that are slower to mature (pers comm, L Hughes 2007).

4.3.3 Change in Geographic Distribution

The ability of species to track changing environments will depend on the rate of climatic change, the migratory potential of the species, changes in local disturbance regimes, and physical obstacles in the path of migrating individuals. During warming events in the past, species colonised new habitats toward the poles, often while their ranges contracted away from the equator as conditions there became unsuitable. Equatorial organisms expanded into the temperate zone and temperate ones into the boreal zone. Fossil pollen records of Northern Hemisphere deciduous trees, for example, indicate that some species migrated in response to climatic changes at average rates of 1-20 km per decade. Simple extrapolations of these rates have been used to predict future migration rates. The general consensus has been that because future warming rates may be 10-60 times greater than any since the last glaciation, most species will be unable to migrate fast enough to keep up with shifting climate zones (Hughes and Westoby 1994).

Apart from dispersibility, the main factor that will limit the ability of species to keep up with the moving climate will be the availability of suitable establishment sites. Human land use patterns and the increasing fragmentation of natural landscapes now present formidable barriers to natural migration. Community disruption and inter-specific competition, particularly with weedy species and aliens, will play a major part in migration success. The availability of suitable substrate is also a requirement for successful establishment and in the case of many plant species, suitable mycorrhizal fungi will need to be present in newly colonised soils (pers comm, L Hughes 2007).

Most research in Australia addressing the potential for species ranges to shift or change in size has used bioclimatic mapping programs such as CLIMEX (Sutherst *et al.* 1998) and BIOCLIM (Busby 1991). Taxa that have been studied in this way include butterflies (Beaumont and Hughes 2002), vertebrates (Brereton *et al.* 1995, Dexter *et al.* 1995, Hilbert *et al.* 2001, Williams *et al.* 2003, Shoo *et al.* 2005, Chapman and Milne 1998, Pouliquen-Young and Newman 2000), native plants (Chapman and Milne 1998, Pouliquen-Young and Newman 2000), and invasive species (Kriticos *et al.* 2003 a, b). In general, while species are expected to respond individualistically to future climate change, the consistent message from these modelling exercises is that the distributions of most native species will contract and/or become increasingly fragmented. Climate change may also increase the potential distribution and abundance of exotic weeds (e.g. *Acacia nilotica* and *Cryptostegia grandiflora*, Kriticos *et al.* 2003 a, b) and native woody species (e.g. *A. aneura,* Moore *et al*. 2001).

While correlative bioclimatic models provide a relatively rapid tool for assessing potential changes in future species distributions they have several, well-reviewed limitations (e.g. Baker *et al.* 2000). One such limitation is that they assume that climate is the only factor affecting a species distribution and therefore do not take into account other potentially important influences such as elevated CO_2, availability of suitable soil types, competition and dispersal ability.

Climate change may also result in the potential shift in abundance and distribution of marine species and communities. For example, changes in ocean chemistry and temperature may influence the survival of organisms with calcium carbonate structures and changes to ocean circulation, which drives larval transport and influences productivity, will have important consequences for population dynamics. Further climatic impacts on a few leverage species, such as foundation species like corals or kelp may result in sweeping community level-changes. Hobday *et al* (2006a) identified the following potential distribution changes to marine life groups:

- Southwards shift in seagrasses distribution as temperatures warm;
- Shift in mangrove distribution with rising temperatures and sea levels, dependant on habitat availability and dispersal; and
- Shift in distributions of kelp and other temperate reef species southward with increasing temperatures and decreases in nutrients. Movement will be limited by the southern coastline boundary.

4.3.4 Extinction

It seems likely that there will be many species unable to tolerate the changing environmental conditions within their current range, and also be limited in their ability to move to more suitable habitat. Unfortunately, many species that are already endangered may be the biggest losers (Table 4-1). The most vulnerable species will be those with long generation times, low mobility, highly specific host relationships, small or isolated ranges, and/or low genetic variation, for example corals. Species such as vertebrates with large home range requirements, and those dependent on precise climatic triggers that determine aspects of their life cycle will also be at risk. Populations within reserves, which are typically remnants of larger original populations reduced through habitat loss or over-harvesting, may be particularly vulnerable (Hughes and Westoby 1994).

Table 4-1: Winners and losers under climate change

Winners	Losers
Generalist, adaptable species Colonizers of disturbed habitats, opportunists, weeds Species already advantaged by human settlement Mobile species Species with short generation times, rapid development and high fecundity (r strategists) Plants that are strongly responsive to CO_2 fertilization e.g. C3 annuals	Relic and rare species Isolated species, especially those in remnant habitats in reserves Genetically impoverished species Slow-growing, slow-reproducing, or poor-dispersing species Species with precise ecological niches, those dependent on precise climatic triggers and those with highly specific host relationships Migratory species that rely on a framework of similar habitats spread over large distances Species at the edge of their range Species with large home ranges Species in ecosystems likely to undergo major changes e.g. polar,

Winners	Losers
	coral reef and alpine species

4.3.5 Community and Ecosystem Responses

The global distribution of ecosystem types is primarily controlled by climate, and modification of climatic regimes must eventually result in adjustments in zonation. Major changes in vegetation composition will come through shifts in rainfall patterns and changes in runoff with establishment of woody vegetation at the expense of some herbaceous communities. Increasing incidence of drought conditions will have many impacts especially on freshwater and wetland communities, in turn affecting species such as migratory birds which rely on wetland habitat for breeding and foraging (Kingsford 2000). Drought conditions are also associated with extreme fire danger, as woody fuel and undergrowth dry.

But ecosystems will not move wholesale in response to climate change and predicting their response is extremely difficult for a number of reasons. First, each species within a community or ecosystem will respond individualistically. This means that existing species associations will be broken up and new assemblages of plants and animals will form in their place. Second, most current climate change models predict changes at regional scales, encompassing several climate zones, and are thus too coarse in scale to predict changes in local communities. Third, although there is some certainty about future temperature changes, other variables such as rainfall, seasonality of rainfall and soil moisture remain very uncertain. Finally, while predicting the direct physiological effects of climate on individual species is possible, predicting changes in interactions between species is much more complex (pers comm, L. Hughes 2007).

4.4 Constraints on Adaptation by Australian Biota

Adaptation options for many terrestrial species will be limited due to a number of characteristics of the Australian environment and taxa, both physical and biotic, including topography, habitat fragmentation, low fertility soils, low capacity for dispersal and the restricted geographic ranges of many species.

Australia’s average elevation is only 440 m (Augee and Fox 2000). Only 13.2% of the Australian continent is over 500 m above sea level and only 0.01% is over 2000 m (the tallest peak, Mt Kosciuszko is a modest 2200 m) (Augee and Fox 2000). This low relief will constrain opportunities for species shifts to higher altitudes in response to warming. In addition human occupation of the continent for the past 50-60,000 years and particularly during European settlement over the past 200 years has resulted in large areas of land clearing for agriculture. This has resulted in much of the remaining natural habitat being highly fragmented (Burgman and Lindenmayer 1998).

While enhanced CO_2 may mitigate some of the potential negative impacts of warmer, drier conditions in some areas (Farquhar 1997, Howden *et al.* 1999b), responses of vegetation to CO_2-fertilisation may be limited by the infertility of the soils in most regions. Soils across the continent are generally infertile as a result of deep weathering during the Late Cretaceous and Tertiary, the long period of relative stability, and small extent of recent (Quaternary)[10] glacial activity (Augee and Fox 2000). About one third of the continent is sand, and a high proportion of soils cannot support introduced agriculture without the addition of nutrients. The fine-scale mosaic of soil types in many areas, together with this general level of degradation, has a number of implications for the capacity of species to adapt to climate change. In particular, species with particular soil requirements, especially those that now live on small patches of more fertile soils surrounded by poorer substrates, may be unable to find new sites suitable for establishment, even if they are capable of migration as climate zones shift.

Finally, many species in Australia, both terrestrial and marine, are endemic, with narrow geographic and climatic ranges. The genus *Eucalyptus*, for example, which dominates over 90% of Australian forests and woodlands (Pryor and Johnson 1981) has over 800 species, many of which have sharply defined ranges that are closely associated with local environmental conditions such as soil and drainage. Over 50% of the species have current climatic ranges spanning less than 3^{o}C of mean annual temperature, with 41% having a range less than 2^{o}C and 25% spanning less than 1^{o}C (Hughes *et al.* 1996). In addition, 23% of species have ranges of mean annual rainfall that span less than 20% variation (Hughes *et al.* 1996). While the actual climatic tolerances of many of these species may be wider than the climatic envelope they currently occupy, if even a modest proportion of present day boundaries reflect thermal or rainfall tolerances, substantial changes in the abundance and distribution of Australian tree flora (and other species) may be expected in the future.

4.5 How Biodiversity is Responding to Climate Change

There is now clear evidence that the relatively modest climatic changes over the past century have already had significant impacts on the distribution, abundance, life cycles and physiology of a wide range of species globally. Recent reviews have documented many instances of shifts in species distributions toward the poles or upward in elevation, and progressively earlier life cycle events such as flowering, reproduction and migration (Hughes 2000, Parmesan and Yohe, 2000, Root *et al.* 2003, 2005). These reviews, however, largely focus on Northern Hemisphere species because published evidence of changes occurring in Australia and elsewhere in the Southern Hemisphere is scarce, except for the more mobile taxa such as birds (Hughes 2003, Chambers 2005, Chambers *et al.* 2005, Beaumont *et al.* 2006). This scarcity is largely due

10 Cretaceous -144 to 65 million years ago; Tertiary period (65 to 1.8 million years ago), Quaternary period (1.8 million years ago to today (University of California 2007).

to the lack of long-term datasets in which such trends can be detected (Chambers 2005).

4.5.1 Terrestrial vegetation

Australian vegetation has been profoundly altered during the last 200 years of European colonisation. While most changes in composition and age structure have been attributed to grazing or to changes in fire regimes following European settlement, some have been specifically attributed to changes in climate and atmospheric CO_2 (summarised in Hughes 2003). These include:

- Increases in woody biomass in a wide variety of arid and semi-arid environments, as well as tropical savannas and open woodlands ("vegetation thickening"), at least partially attributed to the fertilising effect of CO_2;
- Expansion of rainforest at expense of eucalypt forest and grasslands in Northern Territory, Queensland and New South Wales, linked to changes in rainfall and fire regimes (Bowman *et al*. 2001); and
- Encroachment by snow gums into sub-alpine grasslands at higher elevations (Wearne and Morgan 2001).

4.5.2 Wetlands

The landward transgression of mangroves into salt marsh environments in the estuaries of QLD, NSW, VIC and SA over the past five decades has been a widespread phenomenon with salt marsh losses ranging up to 80% (Saintilan and Williams 1999). While direct human disturbance is undoubtedly a factor in these trends, increases in rainfall and altered tidal regimes have also been implicated (Saintilan and Williams 1999). Saltwater intrusion into freshwater swamps has also been occurring since the 1950s in Northern Territory, accelerating since 1980s (Woodroffe and Mulrennan 1993; Bayliss *et al.* 1997, Mulrennan and Woodroffe 1998). There is most likely a multitude of causes, including the impacts of water buffalo, possibly associated with sea level and precipitation changes. Colonisation by mangroves has had dramatic effects on the vegetation of formerly freshwater wetlands with more than 17,000 ha adversely affected and a further 35-40% of the plains immediately affected (Mulrennan and Woodroffe 1998).

4.5.3 Terrestrial fauna

Many species of the more mobile terrestrial taxa such as birds and bats are exhibiting significant range shifts and expansions to the south, consistent with warming over the past few decades (Tidemann 1999, Hughes 2003, Chambers *et al*. 2005). Phenological changes are also evident with earlier arrival of migratory birds (Green and Pickering 2002, Chambers *et al* 2005, Beaumont *et al*. 2006) and behavioural changes in reptiles (Bull and Burzacott 2001). Increased penetration of feral mammals into alpine and high sub-alpine areas and prolonged winter presence of macropods has also been associated with warming and reductions in snow cover (Green and Pickering 2002)

4.5.4 Marine biota

Major changes in the distribution of seabird colonies off the coast of Western Australia have occurred over the past few decades, with at least eight species establishing colonies well to the south of known historical distributions (Dunlop 2001). Some of the shifts began as early as the 1920s (bridled tern), others in the 1950s and 60s (roseate tern, red-tailed tropicbird) while others did not begin until the last decade of the 20th century (Brown noddy, sooty tern). The rate of establishment and/or growth of new colonies seems to have accelerated since the early 1980s. It is likely that changes in the behaviour of the Leeuwin current, affecting marine food chains, is the ultimate cause of the shifts in the seabird fisheries and changing population dynamics.

Australia's coral reefs have also experienced coral bleaching repeatedly over the past 30 years, with events occurring in 1983, 1987, 1991, 1998, 2002 and in 2006. Fortunately, mortality rates have been relatively low due to the fact that thermal stress has not been as severe or as prolonged as that seen in other regions. In 1998, a very warm core of water sat above the Scott Reef for several months resulting in bleaching and mortality of up to 95% of corals down to 30 m. Recovery of these reef systems has been very slow, probably due to relatively remote location of Scott Reef to other reef areas, which are ultimately the source of new recruits to the atoll system (GCRMN 2004).

Changes are also being recorded in more temperate regions. Changes to ocean circulation in the western Pacific Ocean and Tasman Sea and an upward trend in water temperatures have led to environmental modification in south east Australia as the East Australian Current pushes further south carrying sub-tropical species into temperate waters (Hobday *et al* 2006a). Declines of kelp forests off the east coast of Tasmania have been associated with warming ocean temperatures (Edyvane 2003, Edgar *et al*. 2005).

4.6 Impacts of Climate Change on Recreational Values

As an example, climate change may impact on the recreational values of protected areas in the following ways:

- An increase in temperatures and the incidence of hot days (over 35^{o}C), negatively affecting visitor comfort, including increased incidence of heat stress in visitors and staff;
- An increase in the frequency and intensity of fire, resulting in closure of Park areas (for visitor safety) and damage to infrastructure; and
- Increases in rainfall events leading to flooding will restrict access to some Park areas, and may therefore reduce visitor satisfaction.

Further detail of the potential impacts can be found in the individual protected area chapters

4.7 Impacts of Climate Change on Socio-cultural Values

As an example, climate change may impact on the socio-cultural values of protected areas in the following ways:

- An increase in extreme rainfall, temperatures and extreme events may exacerbate natural erosive processes on cultural values such as rock art
- Increasing temperatures and changing rainfall patterns may increase the transmission of mosquito borne diseases; and
- Climate change may indirectly disadvantage traditional practices, including fishing and hunting through changes to flora and fauna.

Further detail of the potential impacts can be found in the individual protected area chapters.

5 Introduction to Part 2 of the Report

5.1 Background

The above chapters have served several purposes; the first of which was to introduce the scope of this study and the method adopted to determine vulnerability to climate change. Secondly Chapter 2 has introduced generic regulations and principles governing the Australian Government's approach to protected area management. Following this, the current understanding of climate change science and projected impacts as they apply to Australian circumstances have been documented.

In order to set in context specific protected area assessments in Chapters 6 -25, Chapter 4 has provided an up to date discussion on the generic impacts of climate change in both marine and terrestrial environments.

The following chapters detail potential climate change impacts and implications by protected area. Through consultation with DEWHA and DCC, specific chapter structures have been adopted for terrestrial and marine chapters, as seen in Chapters 6-25.

6 Booderee National Park

6.1 Bioregional Setting

Booderee National Park (hereafter referred to as the Park) is located on the south-east coast of Australia, within the Jervis Bay Territory. The Park provides protected status to most of the southern peninsula of Jervis Bay, the Bherwerre Peninsula, Bowen Island, and the waters and seabed in the south part of the bay. The Park covers an area of 6312 hectares, which includes 875 hectares of marine environment. The Park also includes Booderee Botanic Gardens, which, for the purposes of this study, are considered separately (Chapter 13).

The Park is located within the Sydney Basin IBRA region, at its southern most boundary. The Park is located in a transition zone between the Sydney Basin IBRA region and South-east Corner Bioregion and its biota is consequently quite diverse. The Park is specifically within the Jervis Bay sub-region which has about 35% of its area within reserves.

The Park makes a significant contribution to biodiversity conservation at the bioregional and sub-regional levels. It contains representative examples of communities of south-eastern Australia including eucalypt forest, woodland, relic rainforest communities, littoral communities, and wetlands. It has one of the largest and least disturbed areas of heathland in the bioregion. The wetlands are among the least disturbed of their type in the sub-region. The Park also protects the largest *Posidonia* seagrass meadows in NSW and protects coastal dunes systems and their associated habitats which are otherwise disturbed or potentially threatened in the region.

Within these protected habitats, the park supports a high concentration of listed plant and animal species. It provides the largest stronghold in Australia for the endangered Eastern Bristlebird.

The park is becoming increasingly important within the sub-region, which is experiencing with growing fragmentation of vegetation communities in adjacent areas with implications for the long-term viability of some species in the Park.

The marine environment is one of the most diverse recorded in temperate Australia, with representation of both tropical and temperate species (Director of National Parks 2006).

The Park is owned by the Wreck Bay Aboriginal Community which jointly manages the Park with the Director of National Parks. A memorandum of lease to jointly manage the Park was signed in December 1995. The Wreck Bay Aboriginal Community's interests in Booderee are legally reflected in the lease agreement, the *EPBC Act* and the *Land Grant Act* which provide for traditional use of the land in the Park for hunting, food gathering and ceremonial religious purposes.

The Booderee National Park Board of Management has 12 members, including seven representatives nominated by the Wreck Bay Aboriginal Community Council. As the only National Park in the region which is owned by an Aboriginal community, Booderee has a special opportunity and responsibility to provide visitors with an integrated combination of culture and nature.

The significance of the Park is attributable to its rich natural and cultural heritage, the inclusion of both land and seascapes within a single protected area, and its location.

6.2 Management Arrangements

A significant part of the Jervis Bay region is protected through the declaration of Booderee National Park, the NSW Jervis Bay National Park and the Jervis Bay Marine Park. This is extremely important for biodiversity conservation and provides an opportunity for cooperative development of interpretive and educational material (Commonwealth of Australia 2002). The area also has several listings on the Register of the National Estate.

6.3 Climate

Being coastal, temperature extremes are rare at Jervis Bay. Maximum temperatures range from an average of 24ºC in February to 16ºC in July, while average minimum temperatures range from 18ºC to 9.5ºC respectively. Annual rainfall is approximately 1200 mm, which is relatively evenly distributed throughout the year, although there is usually more rain in June and July and less in spring (Commonwealth of Australia 2002).

6.4 Natural Values

- Rich and diverse terrestrial flora and fauna including EPBC Act listed species:
  - 1 critically endangered (grey nurse shark, *Carcharias taurus*),
  - 4 endangered (southern right whale, *Eubalaena australis* Eastern Bristlebird, *Dasyornis brachypterus,* Gould's petrel, *Pterodroma leucoptera* and loggerhead turtle, *Caretta caretta*)
  - 11 vulnerable fauna species (Humpback whale, *Megaptera novaengliae,* shy albatross, *Diomedea (Thalassarche) cauta,* wandering albatross, *Diomedea melanophris,* sooty albatross, *Phoebtria fusca,* superb parrot, *Polytelis swainsonii,* kermadec petrel, *Pterodroma solandri,* giant burrowing frog, *Heleioporus australiacus,* green and golden bell frog, *Littoria aurea* and grey nurse shark, *Carcharias taurus*) and
  - 1 vulnerable flora species (magenta lilly pilly, *Syzygium paniculatum*);
- Diverse range of well-preserved coastal plant communities including remnant rainforest, heath communities, woodland and

coastal littoral communities, a diversity of wetlands and extensive salt marshes;

- Flora and fauna species at edge of their range, of limited distribution or considered rare or threatened (including the endangered eastern bristlebird (*Dasyornis brachypterus*) and vulnerable magenta lilly-pilly (*Syzgium paniculatum*) and endemic *Grevillea macleayana;*
- One of the most diverse marine environments recorded in temperate Australia, with tropical and temperate species represented;
- The Park protects one of the largest *Posidonia* seagrass meadows along the NSW coast;
- The Park is renowned for exceptional water clarity which enables the growth of extensive seagrass beds which support a rich diversity of marine life;
- A large breeding colony of little penguins, *Eudyptula minor,* exists on Bowen Island. The colony is one of the most significant in Australia;
- The Jervis Bay area, particularly the area of the Park, is an outstanding area of natural scenic beauty;
- The Park protects coastal dune systems and their associated habitats that are otherwise disturbed or potentially threatened in the region
- The preservation of the Park as a southern representative of the sandstone ecosystems of coastal New South Wales is highly important; and
- Due to its secure protection and rich diversity of species, the Park is considered a population reservoir for the wider region.

Landscape processes

Fire is a natural part of the landscape and a key influencing factor in ecosystem make-up and processes. Prescribed burning takes place in the Jervis Bay Territory from September to March each year. The ongoing use of fire is essential to the survival of many plant species and plant communities (including coastal heath species such as *Xanthorrhoea*).

Pressures on natural values

The current potential pressures on natural values of the Park include invasive weeds, feral animals, physical disturbance, fire and pollution. These pressures are briefly described below.

- Bitou bush (*Chrysanthemoides monilifera*) is the most significant weed in the Park and is listed as a weed of national significance along with lantana (*Lantana camara*) and blackberry (*Rubus fruticosus agg*.), which also occur in the Park. The continuing spread of bitou bush into otherwise undisturbed native vegetation is a significant threat, one of the most serious facing the ecological integrity of the Park (Commonwealth of Australia 2002). Despite the commitment of considerable resources, bitou bush continues to spread (Director of National Parks 2006). Bitou is listed as a Key Threatening Process under the *Threatened Species Conservation Act, 1995* (NSW) (*TSC Act*). A Threat Abatement Plan (DEC 2006), titled 'Invasion of native plant communities by *Chrysanthemoides monilifera* (bitou bush and boneseed)' has been prepared by NPWS to manage bitou bush in NSW.

- There are 13 known introduced terrestrial vertebrate pest species in the Park including rabbits, foxes, cats, dogs, mice, black rats and seven bird species. With the exception of foxes and black rats around the camping areas, the numbers of these animals in the Park are relatively low. The fox is recognised as the greatest threat and has been identified as an agent in the spread of bitou seed. Lantana, foxes, and cats are also listed as Key Threatening Processes under the *TSC Act*;
- Physical disturbance of the marine environment can occur through inappropriate anchoring, mooring and dredging and can seriously affect the seabed and seagrass meadows. Fishing and collection of specimens can also have negative affects. Erosion of terrestrial areas can occur through heavy visitor traffic and vegetation disturbance;
- Pollution and nutrient enrichment can also impact on the marine environment. Increasing urbanisation in the catchment area and discharge of effluent and stormwater runoff into the wider area of Jervis Bay could significantly diminish water clarity; and
- In 1972 approximately 80 per cent of the Park was burnt by fire. Fires at Booderee have occurred on average every 10 years. Whilst fire is a natural part of the landscape some communities or species are particularly at risk from fire such as rainforest species and the swamp oaks forest. Fire can also indirectly affect marine species as soil exposed through fire is carried into the marine environment via wind and surface water runoff. Both suspended solids and nutrients carried in surface run-off may result in localised impacts on marine biota;
- Increasing fragmentation of adjacent areas has implications for long-term viability of some species within the Park.

6.5 Cultural Values

- The cultural heritage of Booderee includes Koori cultural heritage and the shared cultural heritage of Kooris and non-Aboriginal people. Koori people have always lived in the area and have strong cultural ties. Koori cultural heritage at Booderee includes both tangible cultural heritage such as shell middens and camp hearths, and non-tangible heritage such as oral history and cultural associations with the landscape. The opportunities to educate visitors about Koori culture of the region are among Booderee's most important assets;
- More than 100 prehistoric Aboriginal sites have been recorded on the Bherwerre Peninsula, some probably dating back to the stabilisation of sea level about 6000 years ago. The majority are

shell middens, but there are also rock shelters, burial sites, ceremonial grounds, stone-flaking sites and axe-sharpening grooves; and

- The area is one of the few places in south-eastern Australia where recent and contemporary Koori lifestyles have continued within the setting of a substantially natural environment. The people at Wreck Bay continue to use the Park for traditional hunting, gathering and ceremonial purposes. The *EPBC Act* and the *Land Grant Act* provide for this on-going use of the land. The knowledge of the cultural landscape, including the land and sea, the important places within it and the plants, animals, foods and medicines is still being passed through new generations of people at Wreck Bay.

Pressures on cultural values

- Visitors accessing remote areas;
- Heavy visitor traffic causing damage to cultural values including middens and camp hearths;
- Fire and natural water and wind erosion can result in a gradual deterioration in cultural artefacts within the Parks; and
- Plants, animals and foods of cultural value may also be removed by visitors.

6.6 Recreational and Visitation Values

The scenic qualities of Booderee are widely recognised and are important to the regional tourism industry and local communities. The area of Booderee has long been a popular destination for visitors. Since 1896, when the first tourist accommodation was provided in the area Booderee has become a major tourist destination with estimates of 500,000 visits to Booderee per year (*pers. comm*. M Fortescue). People from Sydney and the large urban centres of Canberra and Wollongong use Booderee for recreation.

Key recreational values within the Park include, but may not be limited to:

- Visitor infrastructure including camping areas with associated facilities, day use areas, roads, car parks, boat ramps and walking tracks, which total approximately 30 kilometres and are located in a variety of landscape and vegetation types;
- Recreational boating, swimming, SCUBA diving and snorkelling.
- Fishing is a major recreational activity in the Park. Prawning is also a popular seasonal activity in St Georges Basin, where foreshore access is provided through the Park;
- A number of commercial tours operate in the Park, providing some recreational opportunities otherwise unavailable to most visitors. Water-based tours in the Park include SCUBA diving and recreational boat tours. Land-based tours include bushwalking, bird watching, plant identification, cycling, bus tours, picnicking, sightseeing and educational tours; and

- No commercial fishing takes place within the Park's marine waters; however, the ocean-going tuna fishing fleet, ranging from as far away as South Australia, considers Jervis Bay to be an important source of baitfish for its industry.

Pressures on recreational and visitation values

- Reduction in water quality from terrestrial runoff after fire events and from litter and pollution from boats;
- Physical damage to infrastructure from fire and closure of park on high fire risk days and associated loss of income;
- Physical damage to marine environment from boating activities;
- Illegal collection of species and illegal fishing;
- Waste accumulation, erosion and vegetation disturbances from illegal access; and
- Freshwater is also a limited commodity within the Park, in particular during the peak tourist season.

6.7 Current Management Approaches

Natural values

Management activities in the Park for natural values are aimed at ensuring that ecological processes are maintained to protect the visual attributes of the Park landscape and ensuring the viability of populations of native plants and animals in Booderee. This currently includes management of threats such as weeds, feral animals, current pest species and invasion by new pest species and inappropriate fire regimes. Management effort is also focused on protecting the clarity and quality of the Park marine waters and freshwater ecosystems.

Cultural values

Cultural heritage management includes activities to protect, conserve and promote cultural heritage at Booderee and to accurately interpret the Park as an Aboriginal-owned, jointly-managed National Park. Management also includes responsibilities to increase public understanding and respect for Aboriginal culture, both traditional and modern, and to promote a positive attitude towards the needs of Aboriginal people especially those who live at Wreck Bay.

Recreational values

A major focus of the Park is the provision for visitor use that allows for a safe, enriching experience while protecting the Park's natural and cultural values. There is also focused on providing a range of visitor facilities that cater for different visitor needs while protecting the Park environment.

6.8 Climate Change Scenarios

The high range global warming scenarios for the NSW region are pertinent to the Park and are presented in Table 6-1. Uncertainty surrounding the scenarios is shown in brackets. CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in Table 6-2.

Table 6-1: Climate change scenarios for NSW (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor		Current (1975-2004)	2030 scenarios	2070 scenarios
Annual average temperature		Max 24.4°C, min 11.1°C	+1.3°C (±0.6°C)	+4.0°C (±1.7°C)
Average sea level		0	+17cm	+50cm
Annual average rainfall[11]		553mm	+4% (±11%)	+11% (±34%)
Seasonal average rainfall	Summer	168mm	+4% (±19%)	+11% (±57%)
Seasonal average rainfall	Autumn	139mm	+4% (±19%)	+11% (±57%)
Seasonal average rainfall	Winter	114mm	-7% (±15%)	-23% (±45%)
Seasonal average rainfall	Spring	132mm	-7% (±15%)	-23% (±45%)
Annual average solar radiation		N/A	-0.6% (±1.9%)	-1.9% (±5.7%)
Annual average potential evaporation		N/A	+6% (±4%)	+17% (±13%)
Annual daily extreme rainfall[12]		N/A	0% (±10%)	+10% (±5%)
Average no. of hot days (> 35°C)		3 days (Sydney)	+3 days	+15 days
No. very high/extreme forest fire danger days		11 days (Richmond) 23 days (Canberra)	+3 days (Rich) +5 days (Canb)	+8 days (Rich) +15 days (Canb)
CO_2 concentration		353ppm	+165ppm	+365ppm

Table 6-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

11 Uncertainty surrounding annual and seasonal rainfall projections in this region is high. Planning for these impacts will need to take into consideration the possibility that rainfall may increase or decrease.
12 # 1-in-40 year intensity, based on 2 climate models (Hennessy *et al*. 2004)

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C
Temperature at 500m depth	Warming of 0.5-1°C
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface winds	Increase of 0-1ms^{-1} surface winds
Surface currents	Decline in strength of surface currents of between 0-1.2ms^{-1}
pH	Decline in pH by 0.2 units

Storms and winds are also expected to intensify under climate change (pers comm. P. Whetton, 2006).

A summary of the potential impacts of climate change on the values identified for the Park are described below. Implications of climate change on management of the Park are also discussed.

6.9 Summary of Potential Climate Change Impacts and Secondary Effects

Both marine and terrestrial environments are conserved within the Park; consequently it is exposed to a unique complement of challenges associated with climate change. The climate is currently moderate i.e. temperate coastal; though climate change scenarios predict an increase in the number of extreme fire danger days (>35ºC), increase in the intensity and frequency of storms, strengthening of the East Australian Current, change to rainfall seasonality, more frequent El Niño Southern Oscillation events and sea level rise.

Fire

Increased intensity and frequency of fire (through increased evaporation, increased number of very high/extreme forest fire danger days and extreme temperature days) may threaten communities which depend on larger intervals between fires to persist. An increase in fire frequency is one of the significant threats for this Park which can be anticipated from climate change scenarios. Species or habitats that are most vulnerable to an increase in fire are those least able to adapt. The most significant impacts are anticipated within rainforest and the swamp oak forest habitats.

Some species may benefit from an increase in fire frequency (i.e. *E. stricta*, *E. schelrophylla*), thus altering composition and structure of some communities. A shift in species dominance to more fire resistant species and communities may be observed (e.g. less obligate seeders) (pers comm., L Hughes, 2007).

Increased fire frequency may also result in the need for more frequent closure of walking tracks and camping areas for visitor safety, leading to a reduction in visitor related revenue.

Sea level rise and increased storm intensity and frequency

Marginal sea level rise combined with an increase in both frequency and intensity of storms can result in direct damage to the coastal fringing areas of the Park; in particular exposed areas such as Bowen Island. The resulting inundation and saline intrusion can impact on the fringing habitat and result in the direct loss of trees and vegetation.

Increased storm intensity may result in erosion of exposed areas and direct inundation and damage to habitat. Many seabirds inhabiting the Park nest at the mean high tide water mark and these sites may be lost as a result of direct climate change impacts. Impacts on the foraging behaviour, diet and nesting areas for little penguins and seabirds are anticipated. Species that may be impacted include the pied oyster catcher (*Haematopus longirostris*) and the hooded plover (*Charadrius rubicollis*). Extreme weather may also result in more frequent mortality events for species such as the short tail shearwater (*Puffinus tenuirostris*) (pers comm. M. Fortescue). Species of seabirds that rely on clear waters for sourcing food, such as little penguins and cormorants, may also be negatively affected by increased turbidity in waters within and surrounding the Park (pers comm. M Fortescue).

Major erosive forces will also result in damage to walking trials and drainage lines. The resulting erosion, sedimentation and disturbance arising from major storm damage will impact upon the marine environment, in particular epiphyte growth on seagrasses and direct loss of seagrass habitat (pers comm. M. Fortescue). Isolated large storm events will result in short term impacts such as the smothering of marine benthos, whereas repeated events at a regular frequency will ultimately lead to loss of habitat and a reduction in biodiversity. Such impacts will also affect the recreational opportunities within the Park including fishing, swimming, snorkelling and scuba diving.

An increase in erosive forces will potentially result in more rapid deterioration of cultural artefacts and resources present within the Park. Examples of cultural assets potentially impacted include shell middens, rock shelters, burial sites, ceremonial grounds, stone-flaking sites and axe-sharpening grooves.

Changes in rainfall variability

Increasing periods of drought and intense periods of storm activity with heavy rainfall will have an impact on the integrity of terrestrial ecosystems. In addition, erosion and sedimentation can result in a deterioration of water quality and also a reduction in dissolved oxygen availability with flow on effects to the quality and diversity of the Park's marine environment. Negative affects from changes in rainfall variability may be seen on species that are dependent on regular rainfall (rainforests amphibians) and also species dependent on ephemeral water bodies (amphibians including the green and golden bell frog) and marine habitat (marine turtles).

Tall open forests and woodlands (wet sclerophyll forest class) and medium and low woodlands (dry sclerophyll forest class) are likely to respond poorly to an increase in intensity of rainfall and may only be slightly affected by temperature change (Pittock, 2003).

Additional pressures are likely to be placed on water supplies for the Park derived from Lake Windermere. Recent studies indicate that the current and projected use of water from Lake Windermere is sustainable, (pers comm. M. Fortescue), however, this may rely on continuing changes to Park management practises that minimise water consumption.

Increase in number of hot days (>35°C)

By 2070 climate scenarios forecast up to an additional 15 days per year that produce temperatures above 35 degrees. At these temperatures the risk of a major fire impacting on the Park increases (as discussed above). In addition, there are direct impacts on flora and fauna within the Park. On New Year’s Day 2005 temperatures within the Park reached 47°C and many plants were killed or severely damaged as a result (Director of National Parks, 2006).

Visitor safety and comfort will also be at risk during extreme temperature days. Extreme conditions may either force closure of the Park altogether or alter visitor behaviour such that areas such as Murray’s beach are subject to greater visitor pressure.

Increased atmospheric CO_2

The structure of plant communities will change as atmospheric carbon dioxide concentrations increase. For example, species that are early-successional, highly-dispersible, or good colonisers, may be strongly advantaged, which may lead to the possibility that many landscapes will become increasingly dominated by a few opportunistic species. This may also lead to a build up of undergrowth in woodland areas presenting a heightened fire risk.

Increased atmospheric CO_2 may also significantly impact the marine component of the Park. Booderee is one of the largest *Posidonia* seagrass meadows along the NSW coast. Increased CO_2 has been shown to have a ‘fertiliser effect’ for flora such as seagrass (Short and Neckles, 1999), though a decline in water clarity amongst other things may mediate this effect.

Changes to the East Australian Current

The EAC currently affects Jervis Bay approximately 50% of the time, providing a mechanism for ocean upwelling and nutrient cycling (Director of National Parks, 2006). Whilst the EAC is oligotrophic, the gyres and eddies that are generated by the current can also cause upwelling of nutrients which is a major source of marine productivity off the south east coast of Australia, and in bays and estuaries. For example, a major Jervis Bay algal bloom in 1992 is considered to have come from that source) (pers comm. L Hughes, 2007). The full impact of a strengthening of the EAC is unknown at this time. Possible impacts include the increasing spread of the highly invasive *Caulerpa taxifolia* through the Park, which can become established in enclosed areas and take over existing habitat. Alternatively it is possible that warmer water will create favourable conditions for seagrass (pers comm. M. Fortescue).

Increased threat from invasive species

Terrestrial ecosystems which are stressed by changing climatic conditions will be more vulnerable to invasive species which are opportunistic by nature. Potential concerns are the increasing spread of kikuyu grass (*Pennisetum clandestinum*) on Bowen Island and the spread of bitou bush (*Chrysanthemoides monilifera*) more generally across the Park (Commonwealth of Australia 2002). Invasive species will also be encountered in the marine waters and may include species previously found only in tropical waters, such as the invasive algal species *Caulerpa taxifolia*. Other species, not currently found within the Park, may enter the Park as they extend their range in response to changing climatic conditions.

6.10 Principal Management Implications

Managing to increase resilience of values

The terrestrial component of the Park is a mosaic of well preserved habitats supporting rich and diverse terrestrial flora and fauna which either:

- Occur at the limit of their range;
- Are of limited distribution; or
- Are considered rare or threatened.

Populations of these species will be most vulnerable to rapid, pronounced changes in climate. The impact of climate change on the ecological value of the Park may be lessened by ensuring that all existing threats to the integrity of the Park are appropriately managed. Existing management strategies and activities may need to be reviewed under changing climatic conditions to address resilience or carrying capacity of species and ecological communities. Areas for review may include:

- Strategies to maintain water quality including erosion and sedimentation controls;
- Fire management strategies - increased temperatures and extreme forest fire danger days will result in narrow and declined opportunities for prescribed burning;

- Access protocols and restrictions for visitors, including commercial operators, in areas particularly vulnerable to the impacts of climate change or under increased threat from invasive species;
- Weed management (including bitou bush) including chemical application and fire management regimes for this purpose;
- Invasive pest management; and
- Ensuring that management of adjacent lands assists in maintaining the long-term viability of species, particularly notable/vulnerable species, occurring within the Park.

Increasing decision-making capacity by improving understanding

Currently there are several gaps in knowledge that may prevent Park management from adequately answering questions regarding resilience, climate change impacts and sustainable use of the Park. Increasing understanding in these areas will in effect increase the decision-making capacity of Park managers. Gaps in knowledge include:

- The extent to which the geographic ranges of both native and introduced species will shift in response to changed climatic conditions. It is likely that some species will disappear from the Park while others will colonise and establish as part of an adaptive response to climate change;
- The effects of climate change on life cycles of particular species, including for example, amphibians and reptiles and migratory species that visit the Park;
- The effectiveness of different strategies to manage invasive species, particularly with regard to interactions with changing fire regimes;
- The potential impacts of climate change on cultural practice and cultural values, including cultural expression;
- The implications of climate change on visitor numbers to the Park and the quality of visitor experiences;
- Future constraints on resources such as water availability and financial resources;
- The interaction between changing fire regimes and the fox;
- The overall impact of a strengthening of the EAC on the Park; and
- Endemic and threatened species which are most likely to be at risk under climate change, including through associated changes to habitat. The capacity for ex-situ conservation of these species is also currently unknown.

Maintaining infrastructure and protocols to ensure visitor safety and enjoyment

Increased temperatures, fire frequency and extreme rainfall events may affect recreational uses and visitor enjoyment of the Park's natural and cultural resources. Current management practices may not be sufficient to ensure visitor safety, comfort or satisfaction under these changed conditions.

The Park receives monies from its entrance fee and use of campsites, largely in the 3 months of summer (pers. comm. M. Fortescue). Closure of the Park due to fire risk, fire events or fire damage will therefore have direct financial implications.

Increases in fire frequency and extreme rainfall events may also place further pressures on Park resources through increased maintenance costs including the replacement and upgrade of visitor infrastructure such as walking trails.

7 Christmas Island National Park

7.1 Bioregional Setting

Christmas Island is an Australian owned territory located in the Indian Ocean at 10°25'S and 105°40'E. It is approximately 2800 kilometres (km) west of Darwin, 2600 km north-west of Perth, and 360km south of the western head of Java. The island has a central plateau that falls away steeply towards the sea in a series of terraces and slopes.

7.2 Management Arrangements

The Christmas Island National Park (hereafter referred to as the Park) was proclaimed on 20 December 1989 from the amalgamation of three existing National Parks (DEH 2002). The Park covers approximately 85 square kilometres of the total 135 square kilometres (63%) of Christmas Island. In addition to the terrestrial area, the Park includes the waters extending 50 metres seaward of the low water mark on the coastline of the island (Christmas Island National Park Management Plan, 2002).

On 16 July 2000 the National Parks and Wildlife Conservation Act 1975 was replaced by the Environment Protection and Biodiversity Conservation Act 1999. Under this Act, the Park was classified as a Commonwealth Reserve.

7.3 Climate

Christmas Island experiences a tropical equatorial climate with wet and dry seasons. The wet season is during the months of December to April when the island is under the influence of the north-west monsoons. During the rest of the year the south-east trade winds bring slightly lower temperatures and humidity, and much less rain to the island. Tropical cyclones occasionally pass close to the island during the monsoon season bringing strong winds, rain and rough seas. Since human settlement, no cyclone has been recorded passing directly over the island. Temperatures and humidity on the island vary little from month to month with an average temperature of 25°C (Christmas Island National Park Management Plan, 2002).

7.4 Natural Values

Vegetation in the Park predominantly comprises evergreen tall closed forest, semi-deciduous forest, deciduous scrub and herb-land (pers comm. P.Steward). Other habitat types in the Park include marine, shoreline rock platforms, beaches, sea cliffs mangrove forest, perennially wet areas, karst comprising caves, overhangs, rock crevices and sinkholes.

The Park's fragmented forest system provides habitat and nesting grounds for several endangered species including habitats for the endemic and endangered Abbott's booby (*Papasula abbotti*) and the endemic Christmas Island Frigatebird (*Fregata andrewsi).* The Abbott's booby nests on tall emergent trees of the western and southern plateau forest. This forest is the only remaining nesting habitat of Abbott's booby left in the world (Christmas Island National Park Management Plan, 2002).

Other natural values of the Park include:

- Existence of a number of species listed under the EPBC act, including:
  - 2 flora species - the endangered *Tectaria devexa var. minor* and the vulnerable *Carmon retusa*;
  - 2 mammal species - the endangered Murray's pipistrelle bat *(Pipistrellus murrayi*) and Christmas Island shrew (*Crocidura attenuata trichura*);
  - 4 reptile species – the Pink blind snake (*Ramphotyphlops exocoeti*), Green turtle (*Chelonia mydas*), Hawksbill turtle *(Eretmochelys imbricata*) and Christmas Island gecko (*Lepidodactylus listeri*). All of which are listed as vulnerable.
  - 4 land and shore bird species– the vulnerable Christmas Island Hawk-owl (*Ninox natalis*), the Eastern Reef Egret (*Egretta sacra*), the endangered Christmas Island goshawk (*Accipiter fasciatus natalis*) and the Australian Kestrel (*Falco cenchroides*)
  - 9 seabird species – the endangered Abbott's booby (*Papasula abbotti*), Brown booby (*Sula leucogaster plotus*), Red footed booby (*Sula sula rubripes*), the vulnerable Christmas Island frigatebird *(Fregata andrewsi*), Great frigatebird (*Fregata minor minor*), least frigate (Fregata ariel), Common Noddy (*Anous stolidus pileatus*), Red-tailed Tropicbird (*Phaethon rubricauda westralis*) and the White-tailed Tropicbird (*Phaethon lepturus fulvus*).
- Wetlands listed under the Ramsar Convention: the Dales and a small landlocked forest at Hosnie's Spring;
- 28 listed species under the Migratory Species (Bonn) Convention, 45 species listed under JAMBA and 48 species listed under the CAMBA. This includes species such as the fork tailed swift (*Apus pacificus*), ruddy turnstone (*Arenaria intrepres*), yellow wagtail (*Motacilla flava)* and the grey plover (*Pluvialis fulva*);
- Over 160 different species of crab in the Park of which 20 are land based. The red crab *(Gecarcoidea natalis)* occurs only on Christmas Island (and sporadically on North Keeling Island); it dominates the forest floor and plays a major role in determining the structure and function of the forest on Christmas Island. Jackson's crab *(Sesama obtusifrons*) may also be endemic as it has not been recorded elsewhere. The blue crab *(Cardisoma hirtipes),* though a widespread species, occurs in its blue form only on Christmas Island. The robber crab *(Birgus latro)* is common on Christmas Island, and although it was once widespread throughout the Indo-Pacific region, many of these populations have been severely

depleted. All species of land crabs migrate to the sea to spawn, and live for the duration of their various larval stages in the ocean.

- Dolly and Greta beaches provide habitat for hermit and ghost crabs and are the only beaches with sufficient stable deposits of sand to support turtle nesting activity for small numbers of green *(Chelonia mydas*) and hawksbill turtles *(Eretmochelys imbricata*), although this remains unconfirmed due to difficulty accessing the area by foot (pers comm. P. Stewart);
- Marine area - whale sharks (*Rhincodon typus*) and manta rays (*Manta birostris*) occur in inshore waters, with higher numbers occurring November to March. Whale sharks (*Rhincodon typus)* also migrate in towards the waters close to the shore to feed on red crabs and are listed as threatened under the *EPBC Act* in Australian waters. The marine area also supports some 575 species of fish typical of Indo-Pacific composition;
- Fringing coral reef – the island is completely encircled by a coral reef. There is virtually no coastal shelf and the sea floor drops to a depth of around 500 metres within 200 metres of the shore. There is little deep reef habitat. Christmas Island has a low diversity of coral species, which is attributed to the small size of the island, its isolation from sources of planktonic coral larvae, and the limited range of marine habitats present. Extensive die-off of corals took place around the island in the early 1980s, and in 1998 large areas of the reef were affected by a widespread coral bleaching event in the Pacific and Indian Oceans and South China Sea. The reef is known to support clownfish sea anemones, numerous sponges, including endemic species and varieties, molluscs and echinoderms. The Christmas Island reef systems include hard coral reefs that are considered to be exceptional in nature (pers comm. P.Stewart);
- Mangrove forest – there are no coastal mangroves, however a stand of normally estuarine *Bruguiera gymnorhiza* and *B. sexangula* occurs at Hosnie's Spring about 50 metres above sea level. Two other mangrove species occur on the east coast;
- Christmas Island supports endemic native mammals such as the Christmas Island flying fox (*Pteropus melanotus natalis*); the Christmas Island pipistrelle *(Pipistrellus murrayi*), which is a small insectivorous bat whose population has declined rapidly in the last decade and is now critically endangered along with the Christmas Island shrew (*Crocidura attenuata trichura*);
- Five native terrestrial reptiles, four of which are in decline (pers comm. P Stewart): the blue-tailed skink (*Cryptoblepharus egeriae*), the forest skink (*Emoia nativitatis*); the giant gecko (*Cyrtodactylus sp. nov*.), the Christmas Island gecko (*Lepidodactylus listeri*); and the pink blind snake (*Ramphotyphlops exocoeti*);
- Seven native land birds and shore birds - the glossy cave swiftlet (*Collocalia esculenta natalis*) feeds on flying insects and nests in caves or overhangs. The imperial pigeon (*Ducula whartoni*) feeds mainly on fruits in the rainforest and settled areas. The emerald dove (*Chalcophaps indica natalis*) feeds on fruits, seeds and insects on the forest floor. The Christmas Island hawk-owl (*Ninox*

natalis– listed as endangered) and the goshawk (*Accipiter fasciatus natalis*– also listed as endangered)) feed on small mammals, birds, reptiles and invertebrates;

- Three endemic seabirds that nest in the Park - the most numerous sea-bird is the widespread red-footed booby (*Sula sula rubripes*), which nests in colonies in trees on many parts of the shore terrace and inland terraces;
- Twenty-five species of endemic plants including rare species such as the fern *Asplenium listeri*, epiphytic herb *Peperomia rossii* and vine *Zeuxine exilis*; and

Pressures on natural values

A suite of pressures affect the natural values of the Park including:

- Loss of habitat due to mining or mining activities, roads and other logistical requirements (over 47% of the island has been cleared either directly or indirectly by mining). Various vegetation types have changed due to micro-climate changes within these habitats due to drill lines and roads. This significant loss of habitat was accompanied by corresponding declines of many forest animals found in the area. Clearing of trees can result in a greater wind shear, which creates greater turbulence in the canopy where the Abbott's booby nests. This increased turbulence may cause Abbott's booby fledglings to be dislodged from their nests.
- Threats to native and endangered island species by invasive species including yellow crazy ant (*Anoplolepis gracilipes),* Asian centipede (*Scolopendra subspinies)* and the Asian wolfe snake, (*Lycodon aulicus capucinus*)*.* The yellow crazy ant (*Anoplolepis gracilipes)* has become widespread on the island, developing supercolonies, where the ants occur at very high densities. All crab species, reptiles and leaf litter fauna are severely impacted, and in some places local extinction of these species has occurred. It is becoming evident that the absence of red crabs is resulting in a changed vegetation profile (Abbott, 2006). Breeding areas of the Christmas Island frigatebird and Abbot's booby are also threatened through threats to individual breeding birds as well as nesting trees. The Common wolfe snake (*Lycodon aulicus capucinus*) is an introduced species which may pose a serious threat to the native fauna on the island (Fritts, 1993). Other introduced species on the island include cats, rats, lizards, snakes and feral chickens which impact on native species and use resources;
- Threats from introduced weed species - approximately 80 out of a total of 180 exotic plant species introduced to the island are now categorised as noxious weeds, or common alien invaders of natural areas on mainland Australia. Exotic trees, shrubs and vines on the island occur mostly in the settled area along road verges and mine fields. Some of the exotic species were introduced deliberately during former minefield rehabilitation operations and have spread to disturbed areas. Exotic plant species compete with native vegetation for space and resources and interrupt natural succession and other natural ecological processes;

- Disturbance from human activities to breeding fauna including endangered bird species;
- Damage to natural values from human disturbance including recreational fishing, over-fishing, anchoring damage to corals and litter and pollution. During the wet season, a significant number of migrating red crabs are crushed by vehicles while crossing roads (pers comm. P Stewart); and
- Plastic marine pollution is a significant problem on the Island, especially on Greta Beach where the pollution has impacted on turtle and crab habitat (pers comm. P.Stewart).

7.5 Recreational and Visitation Values

Scientific research opportunities

Christmas Island provides exceptional opportunities for ecological study and the development of ecological theories such as competition, adaptation and dispersal and other factors affecting the distribution and abundance of species. Numerous research projects have been completed on the island to date and there is scope for broader research projects which consider the regional and global context and significance of the island and its biota.

Tourism

Tourists are attracted to Christmas Island largely because of its natural values including flora, fauna and spectacular views. Recreational activities on the island include sightseeing, bird watching, bushwalking and camping in the rainforest. The coastal areas are used for boating, beach going, swimming, diving and angling. Diving in the site is considered to be critical for the island's economy (pers comm. P.Stewart). There are however, physical restraints on many of the previously stated activities due to the difficult terrain, the climate and sea conditions. Professional photographers and film makers regularly visit to produce wildlife publications and films. Christmas Island currently attracts a small number of tourists; however this is expected to increase. The tourism industry is likely to see upgrades and the development of an eco-tourism industry in the coming years.

Pressures on recreational and visitation values

The recreational values are largely based around the natural values of the island and therefore the pressures are largely the same i.e. introduced pest species, particularly the yellow crazy ant, exotic plant species, disturbance by other users and loss of habitat.

7.6 Cultural Values

There are in excess of twenty Chinese temples on Christmas Island. Since settlement, local Malay and Chinese communities have relied on fish as a main food source. Fishing is considered to be a part of their culture rather than a recreational activity.

Pressures on cultural values

Very few threats to the cultural values of Park have been identified; however pressures on local fishing may impact on the cultural activities of local islanders. Damage to artefacts and cultural values may also occur through inappropriate visitor behaviour and natural erosive processes.

7.7 Current Management Approaches

Natural values

Management activities in the Park for natural values are aimed at ensuring the preservation of native flora and fauna and to perpetuate the natural functioning of the ecosystems to which they are part.

This currently includes management of threatening processes such as preventing the introduction and spread of invasive species, and minimising damage associated with human activity on the island.

Cultural values

Management activities in the Park for cultural values are aimed at preserving cultural or historical artefacts and presenting these for appropriate visitor observation, study and enjoyment.

Recreational/visitation values

Management activities in the Park for recreational values are aimed at promoting and enhancing the visitor experience without compromising the Park's cultural or natural heritage or management. Particular focus is given to managing recreational activities to enable visitor enjoyment with minimal impact on the Park.

7.8 Climate Change Scenarios

Due to its remote location, only regional scenarios data can be applied for Christmas Island (Table 7-1).

Table 7-1: Climate change scenarios (Source: CSIRO, 2006 & pers comm. P Whetton, 2006)

Climate change factor	Current (1975-2004)	2030 scenarios	2070 scenarios
Average sea level	0	+17cm	+50cm
CO_2 concentration	353ppm	+165ppm	+ 365ppm

The trends outlined below may also be applied as an indication of anticipated direction and degree of change only.

- Increases in temperature
- Increases in cyclone and storm intensity
- Changes in rainfall patterns[13]

CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in Table 7-2

Table 7-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C^
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
pH	Decline in pH by 0.2 units

13 - Uncertainty surrounding annual and seasonal rainfall projections in Northern Australia is high. Planning for these impacts will need to take into consideration the possibility that rainfall may increase or decrease. Further, data collected from the Bureau of Meteorology for Christmas Island has shown a shift in rainfall from October -December to late January/February (pers comm. P.Stewart 2007). At the time of writing, there was no accurate standardised information available for rainfall levels specific to Christmas Island, further highlighting the high level of uncertainty associated with long term rainfall projections.

A summary of the potential impacts of climate change on the values identified for the Park are described below. Implications of climate change on management of the Park are also discussed

7.9 Summary of Potential Climate Change Impacts

Increases in atmospheric CO_2

Increases in CO_2 concentrations could favour the expansion of woody vegetation in general. This could lead to alterations in the structure and composition of vegetation communities in the future. This may have negative effects on the forest habitats, although any potential change is also restricted by other factors such as the suitability of surrounding soil and water availability. Increases in atmospheric CO_2 may enhance mangrove growth however this is also limited by water availability.

Given that coral reefs represent a balance between calcification and erosion, it would appear that atmospheric CO_2 concentrations that exceed 500ppm will severely compromise the ability of the island's fringing corals to maintain structural integrity, having flow on effects to the species and communities that they support and their resilience to forces of physical and biological erosion.

Increases in temperature

Increases in temperature will affect both land and marine habitats. For coral reefs, this may translate to an increase in the frequency and intensity of coral bleaching events (pers.comm. O Hoegh-Guldberg 2007). Coral bleaching events and coral mortality will reduce visual amenity for diving and snorkelling activities and degrade the recreational value of the Park.

Increased sea surface temperatures, and changes to mixing depth may alter primary and secondary productivity which is likely to be significant for higher tropic level fish species, including the manta ray*, Manta birostris* (Shuraleff II, G. 2000) and the whale shark*, Rhincodon typus* both of which are filter feeders, feeding on plankton, small fish and squid.

Changes to prevailing currents attributed to increasing sea temperatures may impact in the recruitment of land crab larvae while the increasing sea temperatures themselves may directly impact on land crab larvae development (pers comm. P.Stewart).

Increases in temperatures and sea surface temperatures may skew sex ratios of green (*Chelonia mydas)* and hawksbill turtle (*Eretmochelys imbricate*) hatchlings towards females with potential implications for abundance of future populations of turtles in the region.

Loss of endemic terrestrial flora may also occur as a result of thermal stress.

Increases in cyclone and storm intensity

Increases in cyclone and storm intensity may have negative affects on almost all habitats within the Park. In addition, strong winds and intense rainfall may increase soil erosion and negatively affect the terrace and shallow soil rainforest habitats. Bird nesting habitat may also be negatively affected by increased storm intensity.

Increased wave action and storm surges associated with more intense storms may have damaging effects on the coral reef systems which fringe the island. This damage may reduce the ability of these systems to function as fish and crab nurseries and as foraging grounds for hawksbill turtles which prey on sponges and other invertebrates around coral reefs (Poloczanska & Milton 2006). Increased damage will also impair the reefs ability to recover from bleaching events caused by rising sea surface temperatures. The deterioration of the protective coral systems combined with an increase in storm surges may also result in the inundation of potential turtle nesting habitat at Dolly and Greta beaches.

Changes in rainfall patterns

Future changes to rainfall patterns in the Park remain uncertain. A decrease in annual average rainfall combined with the increases in temperature and potential evaporation may place considerable pressure on many of the island's habitats and their associated fauna. This could result in a reduction in the overall biodiversity on the island (pers comm. P.Stewart). In addition, dry periods followed by heavy rainfall, or cyclone events will result in increased soil runoff, which may negatively affect surrounding water clarity and disturb the nutrient balance.

Sea level rise

Flat, low lying areas such as Flying Fox Cove are at risk of potential sea level rise. Communities that live in these areas are currently affected by storm surges and will be inundated with future rises in sea level (pers comm.. P.Stewart).

7.10 Principal Management Implications

Managing to increase resilience of values

The impact of climate change on the ecological values of the Park may be lessened by ensuring that all existing threats to the integrity of the Park are appropriately managed. Existing management strategies and activities may no longer be appropriate under changing climatic conditions and may therefore require review to address resilience or carrying capacity of species and ecological communities. Areas for review may include:

- Management strategies and activities aimed at preventing species loss and population decline for endemic and threatened species including Abbot's booby and Christmas Island frigatebird; Christmas Island shrew, Christmas Island pipistrelle, Christmas Island gecko, pink blind snake, Christmas Island goshawk, marine turtles and whale shark;
- Access protocols and restrictions to areas, habitats or species which may be particularly vulnerable to climate change. Further disturbance and any associated increased threat of introduced

animals, woody weeds and exotic plants may reduce resilience of these values;

- Existing recovery plans for threatened fauna species may require review to ensure that risks posed by climate change are incorporated;
- Existing erosion, stabilisation and revegetation strategies may not be appropriate under changing climatic conditions including the incidence of heavy storms or extreme rainfall events; and
- In the short term (prior to 2020) there may be significant risks to the coral reef systems. Current levels of funding (including for research) and staffing may not be appropriate to manage these risks.

Increasing decision-making capacity by improving understanding

Currently there are several gaps in knowledge that may prevent Park management from adequately answering questions regarding resilience, climate change impacts and sustainable use of the Park. Increasing understanding in these areas will in effect increase the decision-making capacity of Park managers. Gaps in knowledge include:

- Endemic species which are most likely to be at risk under climate change, including through changes to habitat. The capacity for ex-situ conservation of these species is also currently unknown;
- Potential impacts of climate change on red, blue and robber crab populations and on forest regeneration. In particular, further research is needed into the potential impacts of:
  - increased temperature, evaporation and decreased rainfall;
  - increased sea surface temperatures and acidification of the ocean on larval stages of land crabs;
  - changes in yellow crazy ant and land crab populations on rainforest regeneration; and
  - sea level rise on red crab migration.
- Impacts of climate change on the effectiveness of existing control measures for the yellow crazy ant; and the Christmas Island Rainforest Rehabilitation Programme;
- Species that utilise the fringing reef for habitat, foraging or as a nursery and that may therefore be vulnerable to climate change;
- Investigation on the benefits of restricting recreational fishing and boating on the reef;
- Flow on impacts of changing primary and secondary productivity on species of high conservation significance within the Park e.g. whale sharks;

- Potential impacts of increased sediment load and reduced water availability on Hosnie's Springs mangrove forest and measures that may be employed to protect the freshwater spring; and
- Implications of vegetation fragmentation and landscape disruption on ecological processes necessary for ecosystem (population) persistence on Christmas Island (pers comm. P.Stewart).

Existing research to increase knowledge of the distribution, abundance and status of the flora and fauna, and of the ecological processes of Christmas Island may be used to identify species most at risk.

Maintaining infrastructure and protocols to ensure visitor safety

Increased temperatures, cyclonic activity and extreme rainfall may affect visitor enjoyment of the Park's natural and cultural resources. Current management practices may also not be sufficient to ensure visitor safety and comfort under these conditions.

Increases in cyclonic activity and extreme weather will also place further pressures on Park resources through associated increases in maintenance costs.

8 Kakadu National Park

8.1 Bioregional Setting

Kakadu National Park, (hereafter referred to as the Park), is considered one of the most biologically diverse places within the Australian continent. The Park is located 200 km east of Darwin in the wet-dry tropics of the Alligator Rivers Region of the Northern Territory and extends almost 2 million hectares. The Park encloses most of the catchment areas of the perennial East and South Alligator rivers, including the Arnhem Land plateau and escarpment, southern hills and basins, coastal river plains and the Koolpinyah surface (IUCN 1992).

The Park lies adjacent to Arnhem Land, which is Aboriginal land, is bordered by several pastoral properties to the west, and Nitmiluk National Park to the south. There is a generally high degree of connectivity with adjacent areas – many land management issues are shared with neighbours and this is a particular focus of management. Mining of uranium takes place within the catchment area beyond the Park. Site boundaries and environmental controls are in place with a view to preventing damage to wetlands. The effects of mining the known on-site deposits of uranium, gold, tin and copper remain controversial. Commercial fishing takes place offshore and may have an impact on the biodiversity of species to be found in rivers and estuaries.

The Park is both representative and unique. It is representative of the ecosystems of a vast area of Northern Australia. It is unique because it incorporates one drainage basin (the South Alligator River) and all of the major habitat types of the Top End. A number of plant and animal species that occur in Kakadu do not occur in any other national park. Kakadu is important as a wildlife conservation area for the region because it is a large area managed as a National Park, whereas other areas of Top End habitats are managed primarily for other purposes. Unlike many other areas of Australia, Kakadu still has nearly all the plant and animal species that are thought to have been present in the area 200 years ago.

Kakadu makes a significant contribution to the National Reserve System, which aims to contain samples of all regional ecosystems across Australia, their constituent biota and associated conservation values, in accordance with IBRA. Kakadu spans two biogeographic regions—Arnhem Plateau and Pine Creek. The Arnhem Plateau biogeographic region encompasses the Territory's most important area for biodiversity with very high levels of endemism and extraordinary richness of many groups of flora and fauna. About 20 per cent is within reserves, Kakadu accounting for most of this. The Pine Creek biogeographic region is the most extensively reserved of the Territory bioregions, with 43 per cent in reserves, most of which is in Kakadu. These are amongst the highest levels of protection in the country (Department of Natural Resources, Environment and the Arts 2005).

8.2 Management Arrangements

Since the late 1970s, traditional owners have leased their country to the Director of National Parks (the Director). The Park is co-managed by the Director and the traditional owners in accordance with provisions under the *EPBC Act*. Joint management is administered by the Board of Management, comprised of a majority of members who are nominated by the traditional owners. *Bininj* is the term used to refer to traditional owners of Aboriginal land in the Park, and other Aboriginals entitled to enter, use or occupy the Park in accordance with Aboriginal tradition.

The Park was declared under the *National Parks and Wildlife Conservation Act 1975* (*NPWC Act*) in three stages between 1979 and 1991. Each stage of the Park includes Aboriginal land under the Land Rights Act that is leased to the Director, or land that is subject to a claim to traditional ownership under the *Land Rights Act*. The Park is jointly managed with the traditional owners under legally binding agreements.

The Parks' significant values have been recognised in a number of international conventions and agreements, including World Heritage, Ramsar, Bonn (Migratory Species) China-Australia Migratory Birds Agreement and Japan- Australia Migratory Birds Agreement.

The Park has been assigned to the IUCN Protected Area Category II: National Park. The focus of management is to protect the natural and cultural values of the Park while providing for visitor enjoyment and recreation. The overall aims for the Park are that:

- The cultural and natural heritage of the Park is protected and the living culture of *Bininj* is respected;
- *Bininj* (traditional owners) guide and are involved in all aspects of managing the Park;
- Knowledge about country and culture is passed on to younger *Bininj*; and
- Tourism is culturally, environmentally and socially sustainable.

Kakadu plays a pivotal role at the regional level, and is also a major visitor attraction at national and international levels. To *Bininj*, Kakadu is of particular importance as a home and they have important cultural obligations to look after their land. They also continue to seek economic support from the Park. The Park also contributes significantly to the regional economy through tourism.

8.3 Climate

The climate of the Park is monsoonal with a hot wet season from November to March accounting for 1,300–1565 mm of rainfall each year, or 90% of the average annual rainfall. Rainfall intensities are among the highest in Australia. Mean monthly temperatures range from the low 20's to mid 30's (degrees Celsius). The coolest months are in the dry season.

8.4 Natural Values

The Park consists largely of the following landscape units:

- Floodplain (13% of total area) – mostly made up of sedgeland vegetation. These areas contain extensive wetland habitats such as inter-tidal mud flats, mangroves, hyper-saline flats, freshwater floodplains and streams (Finlayson *et al*. 2006). The tidal influence on the saline wetlands is pronounced, as is the influence of the wet-dry cycle of the monsoonal climate on the floodplains and streams. The vegetation is diverse and highly dynamic.
- Lowland (65% of total area) – made up of eucalypt woodland and open forest. This area includes monsoon forest which typically occurs across northern Australia as small (<5ha), floristically simple island-like patches surrounded by fire-prone eucalypt savanna (Russell-Smith, 1991, Russell-Smith and Setterfield, 2006).
- Arnhem Land plateau (21% of total area) - consisting of sandstone woodland and spinifex. This landscape has complex topography and its geomorphology provides a diverse array of microclimatic environments, thus providing a biodiversity 'hotspot" for vegetation (Woinarski *et al.* 2006); and
- River landscape (1% of total area).

(Source: Gill *et al*. 2000)

The ecosystems within these landscapes contain biological diversity of significant value at an international scale.

The Park contains almost half the plant species known in the Northern Territory (Woinarski *et al*. 1996). Nearly 1600 plant species have been recorded, many of which are found only in the Alligator Rivers region, including restricted and endemic species such as *Eucalyptus koolpinensis.* The Park contains nine fire-sensitive species, six of which are listed as vulnerable under the *EPBC Act* (*Boronia laxa, B. rupicola, B. suberosa, B. verecunda, B. xanthastrum,* and *Sauropus filicinus*).

The Park contains over one third of Australia's bird fauna. Of particular significance are high concentrations of waterbirds, including the largest concentration of breeding magpie geese (*Anseranas semipalmata*); large numbers of migratory waders and a number of bird species restricted to sandstone habitat. Five bird species listed under the *EPBC Act* also occur within the Park including the endangered gouldian finch (*Erythura gouldiae*) and the vulnerable red goshawk, (*Erythrotriorchis radiatus*), northern shrike-tit (*Falcunculus whitei*), partridge pigeon (*Geophaps smithii*), and the masked owl (northern) (*Tyto novaehollandiae kimberli*).

The Park contains about one quarter of Australia's land mammals; including the following five species listed under the *EPBC Act*: the critically endangered bare-rumped sheathtail bat (*Saccolaimus saccolaimus*), the endangered northern quoll (*Dasyurus hallucatus*), and the vulnerable golden-backed tree-rat (*Mesembriomys macrurus*), water mouse (*Xeromys myoides*) and golden bandicoot (*Isoodon auratus*).

The Park contains representatives of all major Australian reptile groups including several restricted species and the following five species of turtle listed under the *EPBC Act*: the endangered loggerhead turtle (*Caretta caretta*) and olive ridley turtle (*Lepidochelys olivacea*), and the vulnerable flatback turtle (*Natator depressus*), hawksbill turtle (*Eretmochelys imbricata*) and green turtle (*Chelonia mydas*). The turtles nest on the Park's coastline.

The region has the most species-rich freshwater fish fauna in Australia. The Park contains three fish species listed under the *EPBC Act*: the critically endangered speartooth shark (*Glyphis* species A), the endangered northern river shark (*Glyphis* species C), and the vulnerable freshwater sawfish (*Pristis microdon*).

The Park also contains an estimated 10,000 species of insect, some of which are endemic to the Park and many of which remain undescribed. One notable species is Leichhardt's grasshopper (*Petasida ephippigera*) which is dependent on *Pityrodia* (fire-sensitive vegetation), and is of cultural significance to *Bininj* as it is related to the creator of lightning.

Landscape processes

The Park's landscape has been continually shaped by sea level changes (and associated saltwater intrusion), flooding and fire.

Saltwater intrusion

The low-lying coastal plains in Kakadu are just 0.2-1.2m above mean high water level (Eliot *et al*. 1999) and therefore particularly vulnerable to saltwater intrusion i.e. where saline water is able to overcome natural (or man made) barriers that act as a partial barrier between the fresh and salt water systems, and move into low-lying areas formerly dominated by freshwater.

Saltwater intrusion already occurs where feral animals, such as buffalo, have trampled and eroded the tidal banks; however, it can also result from storm surges and land subsidence and may be accelerated by loss of marsh vegetation. Saltwater intrusion in the Park has resulted in dieback of paperbark (*Melaleuca*) and freshwater grasses in areas across the plains (Bell *et al*. 2001, pers comm*. A.Ferguson*). Surveys in 1998 and 1999 showed there has been an expansion of salt-tolerant mangrove species along tidal rivers over a 41 year period (Lucas *et al*. 2002).

Fire

Fire is one of the major forces that influence the environments of Northern Australia (Edwards *et al*. 2003). Fires in the Park and surrounds may be annual to biennial and mostly occur late in the seven-month dry season under severe fire-weather conditions (Williams *et al.* 2002, Russell-Smith *et al* 2003). In the Lowlands approximately 50% of the landscape is burnt each year (Gill *et al.* 2000), mainly in the grass layer, and rarely, if ever reaching the canopy. Over the period 1995-2000 the mean annual extent of burning in the Park was 40.3% (Edwards *et al.* 2003). Fuel loads can reach over 90 t/ha on the sandstone escarpment with rates of accumulation generally sufficient to support intense, late dry-season fires every 13 years (Russell-Smith *et al.* 1998).

The distinct seasonality of rainfall in the region is the primary determinant of both the biota and the fire regime; however humans have and continue to play a large part in shaping fire regimes in the area with over 99% of ignition being anthropogenic. The traditional owners of the Park, the *Bininj*, have always used, and continue to use, fire as an important tool for managing and expressing ownership of country. The traditional fire regime practised by *Bininj* created a mosaic of unburnt, early and late burnt patches that was important for maintaining species and habitat diversity (Russell-Smith 1995), and that allowed for the survival and maintenance of a diversity of animal species (Woinarski 2005).

Occupation of the land and the arrival of pastoralism, disrupted traditional fire management practices resulting in an increase in the intensity and frequency of fire in the landscape. Today, fire management is designed to mimic traditional burning practices. Fires are started by conservation managers early in the dry season (May-June) in order to promote patchiness and reduce the incidence of intense fires later in the dry season through reduction of fuel load. This helps to stop late dry season fires covering large areas, and ensure that communities and assets vulnerable to fire are protected.

Flooding

The hydrology of the Park is characterised by the drainage systems of several major rivers and the reliable inundation of large areas of floodplain each wet season. During the wet season, run off can carry huge volumes of water into estuaries and flood plains can be underwater for up to four months. During the dry season the floodplains drain and water evaporates from the persistent backswamps. As water levels drop, remaining water bodies become important as refuge areas for many animals and plants to survive in the dry season (Director of National Parks 2007).

Pressures on natural values

Introduced species are a significant pressure on the natural values of the Park, including aquatic weeds (such as *Salvinia molesta*) and pasture grasses (including *Mimosa pigra*, Olive *Hymenachne* and Para grass), the cane toad (*Bufo marinus*), feral pigs and invasive ant species. The ecological impacts of *Salvinia* have been reduced through biological agents and flooding in recent years but still requires continuous intervention. It is thought that *Salvinia* mats may return when flooding subsides in the drier season (pers comm. A.Ferguson). Negative affects of these introduced species include:

- Buffalo can damage vegetation and natural levees through trampling and grazing (Werner 2005). Disturbance of wetland margins increases the susceptibility of these areas to invasive weed species such as *Mimosa pigra* (Cook *et al*. 1996), with the most severe infestations occurring in riparian habitats frequented by buffalo (Cowie and Werner 1993);
- Invasive alien grasses (including mission grass, *Pennisetum Pedicellatum* and gamba grass, *Andropogon gayanus)* can increase the fuel load in fire-prone areas. Savanna areas invaded by these species can have fuel loads up to seven times greater than those dominated by native grasses. This higher fuel load

supports fires that can be on average eight times more intense than those recorded in native grass areas (Rossiter *et al*. 2003);

- Disturbances from tourism and human activities including contamination of groundwater supplies due to leaching from rubbish dumps and toilet facilities in certain areas of the Park. Heavy use of groundwater can also cause localised impacts on wildlife populations. Disturbed areas are also more susceptible to invasive plant species (Director of National Parks 2007);
- Invasion by cane toads has been found to cause a 4-fold increase in amphibian biomass and therefore act as a massive sink in the floodplain ecosystem as they consume vast amounts of invertebrates, but are largely invulnerable to frog-eating predators (Greenlees *et al.* 2006); and
- Feral pigs have been found to contaminate water supplies and disturb soil in areas of the Park. The ecological impact of this species is currently unknown (pers comm. A.Ferguson).

Fire management is a fundamental management issue in the Park. Fires within and beyond the Park's boundaries have the capacity to seriously encroach upon the Park's ecosystems. There are many species that are disadvantaged by frequent burning (Woinarski, *et al*. 2004). Even low intensity fires that spread from areas of eucalypt savanna into patches of monsoon rainforest can lead to mortality of seedlings and have severe affects on regeneration. Adults are also vulnerable, especially dominant species such as *Allosyncarpia ternata,* despite the fact they have lignotubers (Russell-Smith and Setterfield 2006). Patches of vegetation on seasonally dry sites dominated by slow-growing species are particularly vulnerable. Other vulnerable vegetation types in the Park include *Callitris* stands in the lowlands (*C. intratropica*) and mature *Melaleuca* stands on the floodplain (Russell-Smith 1994, 1995).

Studies have shown that savanna biota is remarkably resilient to fire, even of high intensity. Experimental burn plots show little impact of fire on the composition of the grassy layer and the invertebrate communities. Riparian vegetation and associated stream biota, as well as small mammals however, are not resilient with small mammal populations declining dramatically in areas that are frequently burnt (Andersen *et al*. 2005). In addition, late and extremely intense fires have negative impacts on tree growth rates in the savannas and early fires can also have negative impacts on saplings (Prior *et al*. 2006). The timing of fires (early or late in the dry season) can also affect the flowering and fruiting of species (Vigilante and Bowman 2004).

8.5 Cultural Values

Bininj have been using and managing land within the Park for 50,000 years and as such, hold a number of related cultural values including:

- An estimated 15,000 rock art sites along the Arnhem Land escarpment, some of which date back 18,000 years and record animal species now extinct from the area;

- There are several kinds of significant cultural heritage sites within the Park. These sites reflect and express Aboriginal cultural beliefs and practices and include areas that relate to the activities that took place during the creation era and the travels of *Nayuhyunggi* (Gundjeihmi language), the first people. They may also include significant rock art and occupation sites. Ceremonial areas and other sites of special significance to *Bininj* are located throughout the Park;
- *Bininj* have used the land and its resources for many generations and continue to use many of the Park's natural resources for a wide variety of customary uses (Director of National Parks 2007). This includes the use of plants and animals for food, art and craft and other cultural purposes; and
- *Bininj* cultural heritage also includes detailed knowledge of beliefs regarding the creation era, plants, animals, landscapes, fire, languages, seasonal changes, traditional skills and the history of the Kakadu region.

Pressures on cultural values

Pressures on the cultural values of the Park include:

- Damage to cultural values through fire, including loss of flora and fauna or changes in ecological composition;
- Damage to cultural sites through natural erosive processes and extreme weather events;
- Damage from water deposition of salts and minerals on painted surfaces;
- Damage to flora and fauna of cultural value from introduced and invasive species including feral animals and weeds;
- Inappropriate visitor behaviour including access to remote areas, vandalism, littering and damage; and
- Illegal collection of cultural artefacts.

8.6 Recreational and Visitation Values

The Park is a popular tourist destination, attracting an estimated 209,506 visitors in 2006 (pers comm. A.Ferguson). The area is used for recreational activities such as scenic touring, bushwalking, commercial charter tours, scenic flights, photography, boating, fishing and camping.

The Park has traditionally enjoyed peak tourism visitation in the milder months of the year, from April to September. Increasingly the wet season has also attracted visitors as the impact of monsoonal rains builds the spectacle of Kakadu waterfalls and wetlands. Many of the Park's sites however can be inaccessible due to heavy rainfalls and flooding. Approximately half of the Park's visitors come from overseas.

Pressures on recreational and visitation values

The current potential pressures on recreational and visitation values of the Park include:

- Restricted access to Park areas during the wet season;
- Resource constraints - demand for bushwalking permits exceeds supply in the high season. Some groundwater resources are unsuitable or of limited use due to naturally occurring contaminants including uranium, arsenic and high salt levels. The availability of suitable potable water supplies is an issue at some ranger stations and campgrounds; and
- Inappropriate recreational use of the Park – overcrowding, littering, illegal access and vandalism can significantly reduce the enjoyment of other users of the Park.

8.7 Current Management Approaches

Natural values

Management activities in the Park for natural values are aimed at ensuring that ecological processes are maintained to ensure the viability of populations of native plants and animals, while considering the rights and interests of traditional land owners. This currently includes management of threatening processes such as weeds and feral animals. Fire management incorporating traditional burning methods, aims to maintain the biodiversity values of the Park while protecting life and property. While savanna burning is the highest contributor of greenhouse gas emissions in the Northern Territory, the Park's approach to fire management may help reduce greenhouse gas emissions. Greenhouse gas emissions from low intensity fires that typically occur in the Park during the relatively benign early dry season are substantially less than emissions from intense fires more typical of late dry season fires (Director of National Parks 2007).

Research efforts are aimed at assessing status and effectiveness of management effort of significant species including turtles, crocodiles and some wetland species. Research efforts are also focused on other species that may be affected by inappropriate fire practices and introduced pests such as cane toads.

Cultural values

Kakadu is a living cultural landscape and a key focus of management is assisting the traditional owners in their traditional cultural practices and responsibilities for protecting cultural heritage, notably rock art and other significant sites. Cultural heritage management also includes responsibilities for historic buildings and other sites within the Park, many of which are reminders of the pastoral industry. Management approaches also strive to record and maintain local indigenous oral cultural heritage.

Recreational values

A major focus of the Park is providing for the appropriate and safe use and enjoyment of the Park in ways that do not significantly affect its natural or cultural values of its traditional owners. Management aims to maintain roads and tracks to provide access for residents, visitors and staff without significantly affecting the Park's values. Emergency services and water access are also managed to ensure visitor safety. There is increasing focus on providing new ways to experience the Park, including opportunities for visiting throughout the year and optimising the natural seasonal variations in Kakadu. The Park's vision addresses five key areas of need: Protection; Respect; Involvement; Management; and Promotion. A key part of this vision is to promote greater involvement of the traditional owners in tourism enterprise ownership, management and joint ventures and training.

8.8 Climate Change Scenarios

The high range global warming scenarios pertinent to Kakadu National Park are presented in Table 8-1. Uncertainty surrounding the scenarios is shown in brackets.

Table 8-1: Climate change scenarios for TE (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor		Current (1975-2004)	2030 scenarios	2070 scenarios
Annual average temperature		max 34.2°C min 21.9°C	+1.3°C (±0.6°C)	+4.0°C (±1.7°C)
Average sea level		0	+17cm	+50cm
Annual average rainfall[14]		1077mm	0% (±7%)	0% (±23%)
Seasonal average rainfall	Summer	691mm	0% (±7%)	0% (±23%)
	Autumn	267mm	0% (±15%)	0% (±45%)
	Winter	6mm	N/A[15]	N/A
	Spring	113mm	+4.0% (±19%)	+11.0% (±57%)
Annual average potential evaporation		N/A	+4.0% (±4%)	+11.0% (±11%)
Annual average relative humidity		53%	-1.1% (±1.9%)	-3.4% (±5.7%)
Annual daily extreme wind-speed		N/A	0% (±2.5%)	0% (±7.5%)
Annual average no. of hot days (> 35°C)		11 days (Darwin)	+62	+295
CO_2 concentration		353ppm	+165ppm	+365ppm

A summary of the potential impacts of climate change on the values identified for Kakadu National Park is described below. Implications of climate change for management of the Park are also discussed.

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14 Uncertainty surrounding annual and seasonal rainfall projections in this region is high. Planning for these impacts will need to take into consideration the possibility that rainfall may increase or decrease.

15 % changes were not provided for seasons with very low rainfall.

8.9 Summary of Potential Climate Change Impacts

In the Arnhem Land–Kakadu region, the predicted effects of climate change include sea level rise, rise in temperatures, variation in amount and pattern of rainfall, and changes in the frequency and intensity of extreme weather events. The potential impacts of climate change on natural, cultural and recreational values of the Park are discussed below.

Sea level rise

Changes to both the salt and freshwater wetlands through saltwater intrusion have already occurred in the Park (see Chapter 8.4) and sea level rise is anticipated to exacerbate these existing pressures (AGO 2004). An increase in sea level of up to 50cm by 2070, and an associated coastal recession means that further saltwater intrusion is highly likely.

In some instances, the natural barriers are less than half a metre in height (Hare 2003). The existing trend of displacement of existing habitats (e.g. *Melaleuca* wetlands) with encroaching habitats (e.g. mangroves and saline mud flats) can therefore be anticipated to continue under rising sea levels (Bayliss 1997). The increased salinity in the region is likely to alter the structure and composition of existing freshwater plant and animal species as well as shift the spatial zoning of the coastal and floodplain ecosystem. Woodroffe *et al*. (1986) suggests similar impacts for all extensive seasonally inundated freshwater swamps and floodplains in Northern Australia, predicting a possible return of the "big swamp", mangrove dominated conditions of 2000-3000 years ago with a sea level rise of 1-2m.

Whilst mangroves are important wetlands in their own right, the loss of freshwater wetlands and subsequent changes in vegetation communities will have negative affects on the dependent wildlife including birds, with flow on effects to bird watching activities by tourists, and to the availability of important traditional food resources such as magpie geese, barramundi and freshwater turtles.

Increase in temperature and the number of hot days (>35°C)

Many amphibian species aestivate during the dry season to avoid seasonal severity. In temperate zone amphibians, climate warming has been found to have the potential to deleteriously affect physiology, during and after hibernation, causing increased female mortality rates and decreased fecundity in survivors (Reading 2007). It is possible therefore that increases in temperature and higher evaporation may lead to a decline in the Park's amphibian populations; however the mechanisms by which this may occur are unknown.

The projected temperature increases in this region may also have consequences for sex ratios of reptile species such as the pig nose turtle (*Carettochelyes insculpta)*, and salt and fresh water crocodiles, (*Crocodylus porosus* and *C. johnsoni).* In these species nest temperature determines the sex ratio of offspring (Webb *et al* 1986). It should be noted that other studies have shown that some species have compensated for climate change through adaptation in nest site choice (Doody *et al* 2006).

The physiology and distribution of freshwater fish is directly or indirectly affected by water temperature (Ficke *et al.* 2007). Increases in temperature may therefore result in local extirpations and range shifts of freshwater fish species found within the Park. Climate change is also expected to affect fish populations through its influence on other aspects of water quality. Warmer water contains less dissolved oxygen than colder water. Since fish metabolism increases with elevated water temperature, climate change will likely result in increased oxygen demand and reduced supply (Ficke *et al.* 2007). Sharks and rays are generally slow-growing animals that mature after an extended period and produce low numbers of well-developed offspring. They are therefore particularly vulnerable to climate change unless they are able to shift their distributions as the water warms. In the Park, there are three such species:

- The speartooth shark (*Glyphis* species A) listed as critically endangered under the *EPBC Act*;
- The northern river shark (*Glyphis* species C) listed as endangered under the *EPBC Act*; and
- The freshwater sawfish (*Pristis microdon*) listed as vulnerable under the *EPBC Act*.

An increase in annual average temperatures and the incidence of the number of hot days (projected as an additional 295 days a year over 35^{o}C by 2070, from a current average of 11 days per year) may also impact on visitor comfort and satisfaction and increase the incidence of heat stroke and heat stress in visitors and Park staff.

Virtually all modelling studies performed to date in Australia indicate an increased probability of more intense and frequent fires in the future (e.g. Hennessy *et al*. 2005). Increasing temperatures will increase the number of days on which ignition is likely. Increased rainfall and atmospheric CO_2 will also result in higher fuel loads building up in the wet season.

There are many species that are disadvantaged by frequent burning (Woinarski, *et al*. 2004). Any change in the invasion success of exotic perennial grasses such as Gamba grass (*Andropogon gayanus*) will be of concern because of their capacity to alter fire regimes (D'Antonio and Vitousek 1992; Brooks *et al.* 2004). These introduced grasses often grow taller and/or thicker than the native grasses they replace, not only producing more fuel for fires, but often more interconnected fuel. Similar “grass-fire” cycles of invasion have been documented in Hawaii, North America, Central and South America, and Australia (Rossiter *et al.* 2003). Species already vulnerable to fire, will therefore be placed be under greater pressure. For example:

- The weed *Senna obtusifolia* is predicted to expand in distribution with climate change. Coastal regions of the Northern Territories are predicted to be particularly vulnerable (Dunlop *et al*. 2006);
- *Callitris* stands in the lowlands (*C. intratropica*) and mature *Melaleuca* stands on the floodplain are also vulnerable to fire (Russell-Smith 1994, 1995); and

- Increasing fire frequency and intensity will also threaten areas of monsoon rainforest that exist as small patches (sometimes less than 5 ha) within the savanna matrix (Russell-Smith 1991, Russell-Smith and Setterfield 2006). Even low intensity fires in these patches can have severe impacts as seedlings are killed and adults are also vulnerable. Even dominant species such as *Allosyncarpia ternate* are at risk, despite the fact they have lignotubers (Russell-Smith and Setterfield 2006). Patches on seasonally dry sites dominated by slow-growing species are particularly vulnerable.

Mammal declines may be most rapid during periods of frequent and late fires (Woinarski *et al.* 2001). Small mammals are therefore likely to be vulnerable to increased intensity and frequency of fire as a result of climate change. Small mammals within the Park that may be at risk include:

- Northern quoll, (*Dasyurus hallucatus*), listed as endangered under the *EPBC Act*;
- Golden-backed tree-rat (*Mesembriomys macrurus*) listed as vulnerable under the *EPBC Act*; and
- Golden bandicoot (*Isoodon auratus*) listed as vulnerable under the *EPBC Act*.

Changes in fire frequency and intensity may reduce the abundance and productivity of the mid-story fleshy-fruit producing trees and shrubs, the abundance of large, hollow-bearing trees, fallen logs and litter, and both the composition and diversity of the grassy understory. A decline of this nature has been observed to be mirrored by that of the granivorous bird fauna (Franklin *et al*. 1999). Changes in fire regime and a reduction in seasonal rainfall may be detrimental to the granivorous birds in the Park as they depend on substantial rainy seasons and fire for grass seed production (Franklin *et al.* 2005). This includes the following species:

- Gouldian finch (*Erythura gouldiae*) listed as endangered under the *EPBC Act*; and
- Eastern partridge pigeon (*Geophaps smithii smithii*) listed as vulnerable under the *EPBC Act*.

Changes in rainfall patterns

Whilst no changes in annual average rainfall are projected by CSIRO (2006), there is a large degree of uncertainty i.e. in the order of ±23% for annual average rainfall and ±45% and ±57% for autumn and spring rainfall respectively. The potential effects of both a decrease and increase in rainfall are therefore discussed below.

Periods of below average rainfall may increase the risk of local extinctions in several mammal species (Braithwaite and Muller 1997) through negative affects on groundwater levels and vegetation productivity. The decline in mammals is complementary with that of granivorous birds (Franklin *et al* 1999), where the diet of these birds overlap with many of the small mammals monitored (Woinarski *et al*. 2001) in the same region. Franklin *et al* (1999) noted that declines were more severe in areas with greater year-to-year variation in rainfall.

Reduced average rainfall and associated change in hydrological cycles in the region could increase the vulnerability of fish and amphibian populations to detrimental exposures of UV-B (Kiesecker *et al.* 2001, Mims *et al* 1997). The Alligator Rivers in the Park may also be affected by changes in rainfall which will affect runoff and streamflow, in turn affecting delivery of sediments and nutrients to downstream habitats. As noted above, sharks and rays are particularly vulnerable to climate change include the three EPBC listed taxa found in the Park, the speartooth shark (*Glyphis* species A), the northern river shark (*Glyphis* species C) and the freshwater sawfish (*Pristis microdon*).

Any increase in rainfall, especially if the wet season is extended, will also enhance both the spread and productivity of mangrove, saltflat and samphire communities, although increased storminess will inflict some damage on these vegetation communities (Bayliss *et al.* 1997). Bird, fish and invertebrate communities dependent on these areas for foraging and habitat may be advantaged by an expansion in habitat range.

Alterations to the predictability or variability of the seasons in the region may interrupt life cycles and species population dynamics. In addition, changes in the availability of water may offset the ability of amphibian species to cope with climate warming (Arujo *et al*. 2006). Limited dispersal ability may further increase the vulnerability of amphibians (and reptiles) to changes in climate (Arujo *et al*. 2006).

Changes to flora and fauna abundance and distribution may disrupt traditional practices including hunting for food resources such as magpie geese (*Anseranas semipalmata*).

Rising temperatures and changing rainfall patterns are likely to have significant impacts on the transmission of mosquito borne diseases such as Ross River virus (RRv) in the Northern Territory (Hennessy *et al*. 2004). The disease is a significant public health issue in Australia. There is no treatment for the disease and, in the absence of a vaccine; prevention remains the sole public health strategy.

Increasingly the wet season attracts visitors to the Park as the impact of monsoonal rains builds the spectacle of Kakadu waterfalls and wetlands. Many of the Park's sites can be inaccessible due to heavy rainfalls and flooding. Any increase in rainfall or extreme events in the wet season will further restrict access to Park areas.

Increases in atmospheric CO_2

Rising CO_2 concentration acts to increase photosynthesis, plant biomass and plant water-use efficiency in many plant species. These impacts on water use efficiency in particular are generally considered to be likely to alleviate water limitations and thus enhance primary production (Smith *et al.* 2000).

Differences among species in their responses to elevated CO_2 will affect competitive interactions and thus community structure and composition in the Park. Experimental manipulations in other arid systems have shown that invasive annual grasses may be relatively advantaged over native species, thus promoting increased invasion (Smith *et al.* 2000; Dukes, 2002). Where these grasses increase fuel loads, an accelerated fire cycle may also be promoted, as noted in the previous section (Smith *et al.* 2000).

Enhanced CO_2 may also enhance the growth of woody shrubs, relative to grassy species, leading to changes in the structure of the savanna communities in particular. Under increased CO_2 conditions C3 plants may be advantaged over C4 plants. Species which are early successional, highly dispersible or good colonisers may be favoured (pers comm. L.Hughes). This includes weeds and invasive species which may result in loss of biodiversity, higher fuel loads and increased CO_2 emissions.

Increase in cyclonic intensity and extreme weather events

In April 2006, as Cyclone Monica moved across the Gulf of Carpentaria, it strengthened and became the strongest tropical cyclone worldwide in 2006; as well as the strongest ever recorded in the Southern Hemisphere. Widespread vegetation destruction resulted, with 90% of vegetation destroyed in the worst-affected areas. The area of greatest destruction was estimated to be approximately 7000km^2 in Arnhem Land with coastal mangrove habitats, *Melaleuca* swamps, sandstone country and eucalypt woodlands all affected (Tropical Savannas CRC 2006).

The future impacts of increased frequency and or intensity of cyclones and extreme weather events on wetland and mangrove communities is largely unknown; however, certain vegetation types including large trees, such as *Eucalyptus porrecta*, will be particularly sensitive to high intensity cyclones and the accompanying destructive winds (Williams and Douglas 1995). A survey of the damage caused by Cyclone Monica in Kakadu revealed that the smaller shrubs, such as paperbark trees, were able to withstand the high destructive winds (CRES 2006). In addition, mangroves often sustain damage following cyclonic activity but can display considerable resilience and re-sprout readily following catastrophic weather events (Bardsley 1995).

Extreme weather events, such as tropical cyclones, have the potential to generate severe waves and storm surges, which in turn can have significant impacts on the coast (CSIRO 2002). In the case of Cyclone Monica, there is evidence of a 5-6m storm surge zone in Junction Bay (in NT) where trees were totally defoliated, snapped or uprooted (Bureau of Meteorology 2007).

Disturbance caused by increased cyclone intensity not only destroys habitat but will also create conditions for weed invasion by creating canopy gaps. This may lead to increased coverage of grassy weeds which in turn could increase fuel loads for fire.

Increased cyclone intensity combined with projected sea level rises will also further contribute to saltwater inundation of low lying coastal areas in the Park.

Loss of critical habitat of coastal vegetation communities and wetlands will have negative affects for the flora and fauna they support including dugongs (*Dugong dugon*) which feed on seagrass beds in the coastal areas of the Park, black flying foxes (*Pteropus alecto*), and red-flying foxes (*P. scapulatus*).

Sea level rise, combined with an increased intensity of cyclones and extreme weather events will pose a significant threat to amphibians and marine turtles in particular that nest on the Park's coastline and islands. Particularly at risk are the following species:

- Loggerhead turtles (*Caretta caretta*) listed as endangered under the *EPBC Act*;
- Olive ridley turtles (*Lepidochelys olivacea*) listed as endangered under the *EPBC Act*;
- Flatback turtles (*Natator depressus*); listed as vulnerable under the *EPBC Act*;
- Hawksbill turtles (*Eretmochelys imbricata*) listed as vulnerable under the *EPBC Act*; and
- Green turtle (*Chelonia mydas*) listed as vulnerable under the *EPBC Act*.

8.10 Principal Management Implications

Managing to increase resilience of values

Existing management approaches with regards to rehabilitation plans, documentation of species and management strategies may not be appropriate under worst case climate change scenarios. Weed expansion appears inevitable under changed conditions. Current management arrangements to prevent the spread of weeds into the Park may no longer be appropriate. In particular, working with neighbouring Parks and land managers to manage fire and prevent the introduction and spread of pest species will become increasingly important.

Priority consideration must also be given to species that are most at risk from climate change such as:

- Refuge dependent species - Loss of critical habitat will have implications for species restricted to particular refugia such as pockets of monsoon rainforest patch, steep sheltered gorges on the sandstone escarpment, freshwater wetlands (including *Melaleuca*) and coastal environments (including marine turtles) will be particularly vulnerable to climate change;
- Species particularly vulnerable to frequent, intense fires such as *Callitris* stands in the lowlands (*C. intratropica*) and mature *Melaleuca* stands on the floodplain;
- Species dependent on freshwater wetlands such as barramundi, freshwater turtles and bird species such as jabiru (*Ephippiorhynchus asiaticus*), magpie geese (*Anseranas semipalmata*) and wandering whistling ducks (*Dendrocygna eytoni*) some of which have cultural significance;
- Species and communities particularly vulnerable to invasion by weeds and pests; and
- Species largely restricted to the Park and surrounding region.

Fire management strategies employed at the Park may also need to be reviewed to ensure they are appropriate under increased temperatures and an increase in the number of hot days (with an additional 295 days above 35^{o}C projected for 2070, from a current average of 11 days) and subsequent fires in and outside Park boundaries.

The role of indigenous people in land management and conservation may need to be reviewed in the light of potential impacts of climate change. Increased pressures and declines in populations of some flora and fauna may restrict traditional fire management practices and the maintenance of traditional hunting and gathering activities. An increase in extreme weather events will exacerbate natural erosive processes on rock art within the Park, adding to pressures such as vandalism and from excessive visitation. In addition, rainwater flowing over rock surfaces can result in extensive rock art damage and atmospheric conditions, rock moisture, pH and fire can also influence the extent of rock art deterioration. Management strategies will therefore need to be responsive to such pressures, for example visitor access to cultural sites of significance may need to be reviewed to build resilience of these values to climate change.

Increasing decision-making capacity by improving understanding

Currently there are several gaps in knowledge that may prevent Park management from adequately answering questions regarding resilience, climate change impacts and sustainable use of the Park. Increasing understanding in these areas will in effect increase the decision-making capacity of Park managers. Gaps in knowledge include:

- The extent to which the geographic ranges of both native and introduced species will shift in response to changed climatic conditions. It is likely that some species will disappear from the Park while others will colonise and establish as part of an adaptive response to climate change. In the case of exotic species, existing management strategies may need to be strictly enforced. In the case of “invading” native species, new management strategies that take a more bioregional approach to conservation, rather than one limited to considering only lands within the existing park boundaries, may need to be considered;
- The effects of climate change on life cycles of particular species, including for example, amphibians and reptiles and the interaction between the timing of invertebrate distribution and abundance and migratory birds;
- The effectiveness of different strategies to manage invasive species, particularly with regard to interactions with changing fire regimes;
- The potential impacts of climate change on cultural practice and cultural values; and
- The implications of climate change on visitor numbers to the Park and the visitor experiences. The applicability of responses and approaches may be identified through a comparative analysis of similar ecological systems elsewhere in the world which support a strong tourism industry.

Maintaining infrastructure and protocols to ensure visitor safety

Increased temperatures and fire frequency may affect recreational uses and visitor enjoyment of the Park's natural and cultural resources. An increase in heat-related illnesses (including heat stroke), expansion of mosquito-borne diseases, and injuries from extreme weather events will decrease visitor comfort and satisfaction. Any increased rainfall during the wet season will also reduce access to areas of the Park and have a negative effect on visitor satisfaction. Changes in seasonal rainfall variability may place further constraints on groundwater availability. Current management practices may not be sufficient to ensure visitor safety and comfort under these changed conditions.

Increases in fire frequency and intensity and an increase in cyclonic activity and extreme weather will also place further pressures on Park resources through increased maintenance costs including the replacement and upgrade of visitor infrastructure. Building and infrastructure may also need to be relocated from high risk areas (Kakadu National Parks Management Plan 2007-2014).

Kakadu is a popular destination for both inbound and domestic markets. The impact of the 'peak oil' phenomena together with carbon taxes on tourism services may significantly increase the price of tickets from long haul destinations to Australia, including traditional markets such as Europe, United Kingdom, United States and Canada. This change in pricing structure may lead to several changes, including:

- Diminishing growth of inbound tourism, or at least inbound tourism markets from long haul destinations;
- Move to higher spending demographic markets from these traditional markets (where ticket prices play less role in decision making);
- Increasing growth from the Asian and South East Asian markets which are short haul (reflecting a switching from long haul trips to Europe and USA);
- Longer travel plans (where travellers recoup relatively higher investment in transport costs); and
- Greater demand from the domestic travel market (who are travelling more within Australia rather than investing in higher cost international travel).

If some or all of these factors come into play the implications for the Northern Territory and Kakadu may be quite significant. For example if growth of the inbound market switched to Asian and South East Asian source markets then there may be implications for guiding services, transport modes and hotel infrastructure. If traditional markets from Europe, UK and USA move to higher spend markets, there may be a need to provide higher levels of service, professionalism in guiding and higher standard transport and hotel accommodation. Changes will not occur overnight, but they will evolve as the current market responds to changing pricing structures and societal responses to climate change.

Under conditions that see more intense and frequent cyclones it is possible that summer visitation will decline. Similarly, summer months may be less appealing due to the hotter temperatures and number of days which experience extreme heat (a projected additional 295 days per year by 2070, from a current annual average of 11 days).

In relation to temperature rises and related fire events, the key implication for management of tourism will be the need to:

- Re-schedule activities to other sites not fire or cyclone affected – this may include alternative regions; and
- Plan activities around the fact that overall temperatures are hotter - this may involve commencing activities earlier in the day, undertaking more evening and spotlighting activities, and providing more shade facilities, water points and swimming sites. In general there may be a need for the tourism industry and consumers of tour products to become more flexible about touring itineraries.

It should be noted that many tourism destinations across the globe will be similarly dealing with the impacts of climate change and that issues such as the predictability of weather will be an issue for many destinations. As climate variability increases the certainty of travel to many destinations will diminish. Just as cruise ship itineraries must integrate bad weather alternatives, terrestrial destinations may need to have bad weather alternatives integrated within travel packages (pers comm. T Charters 2006).

9 Norfolk Island National Park

9.1 Bioregional Setting

The Territory of Norfolk Island is located in the South Pacific Ocean, at latitude 29°02' S and longitude 167° 57' E. The Territory includes Nepean and Phillip Islands, (small, uninhabited islands that lie to the south of Norfolk Island), as well as numerous rocky islets dotted about Norfolk Island's coastline. Norfolk Island is approximately 1700km from Sydney, Australia and 1100km from Auckland, New Zealand.

With few oceanic islands occurring between latitude 25°S and 35°S this island group is an important link between tropical and temperate environments. Norfolk, Nepean and Phillip Islands along with other smaller islets are important as nesting or roosting habitats for seabirds, such as the whale bird or sooty tern (*Sterna fuscata*) which migrates between Norfolk Island and the northern hemisphere.

Norfolk Island National Park, (hereafter referred to as the Park), was established in 1984 and consists of two sections, the Mt Pitt section (460 ha, 2 x 3 km), that includes the Forestry Zone, and the Phillip Island section (190 ha). The Mt Pitt section of the Park covers 15% of the island's land area. The two highest points, Mt Pitt (316m) and Mt Bates (319m) are contained within the Park. The Mt Pitt section is bounded by the sea on the north east side, by roads to the north west and west and by private property to the south.

Soil in the Mt Pitt section is of volcanic, basaltic origin and is very nutrient rich though porous and friable. It is prone to landslip after heavy rain, such as experienced in August 1998 when major flood damage forced extended road closures (Norfolk Island National Park and Norfolk Island Botanic Garden, Plans of Management, 2000).

The Forestry Zone in Mt Pitt section was originally cleared for banana plantations during the 1930s. When the banana industry collapsed the area became infested with African Olive which has been removed for eucalypt and pine plantings. Some small areas of remnant vegetation still exist in the Zone. 4 ha of Norfolk Island pine are planted per annum. No non-native species can now be planted in the area with the exception of eucalypts.

Vegetation on Norfolk Island is mostly described as subtropical rainforest, only about 5% of native vegetation is considered undisturbed and is contained within the Park. Much of the vegetation is dominated by the Norfolk Island pine which can grow to 55 m.

Phillip Island is 6 km from Norfolk Island and is denuded of vegetation through past grazing of introduced herbivores (e.g. pigs, rabbits and goats). Remnant vegetation is recovering slowly with active rehabilitation and planting. However, much of the topsoil on the Island has already been lost, hampering restoration efforts (Norfolk Island National Park and Norfolk Island Botanic Garden, Plans of Management, 2000).

9.2 Management Arrangements

The Park (including Phillip Island) was proclaimed under both the (Commonwealth) National Parks and Wildlife Conservation Act 1975 (subsequently updated by the EPBC Act) and the (Norfolk Island Local Government) Norfolk Island National Park and Norfolk Island Botanic Garden Act 1984. Both Acts specify that a park or reserve declared under the Acts must be managed in accordance with a plan of management. The current management plan expires in mid 2007.

The Mt Pitt section is managed as IUCN Category II (managed mainly for ecosystem conservation and recreation) whereas Phillip Island is managed as IUCN Category IV (managed mainly for conservation).

9.3 Climate

Norfolk Island experiences a sub-tropical climate influenced by the surrounding sea and belt of high pressure, which oscillates north and south over the island annually. Temperature ranges on Norfolk Island are small and the humidity is relatively high. The region experiences some rainfall, ranging from 75mm to 130mm per month (Bureau of Meteorology 2007). Thunderstorms are most common during winter and spring, with the occasional hail storm accompanying thunderstorms in winter. Tropical cyclones are rare, but can occasionally affect the Park in the early months of the year.

9.4 Natural Values

The Mt Pitt section of the Park consists of a small remnant (less than 10%) of the subtropical rainforest which originally covered Norfolk Island. The remnant is subdivided into smaller communities (pers comm. B.Watson).

- Viny hardwood rainforest;
- Palm and tree fern forest; and
- *Araucaria*-dominated forest.

The Islands are of particular biological significance as their flora and fauna are partially derived from the transfer of plants and animals over vast distances of ocean and can evolve into unique, or endemic, island forms (Norfolk Island National Park and Norfolk Island Botanic Garden, Plans of Management, 2000).

- The Park contains examples of biological evolution at both the species and community levels;
- With few oceanic islands occurring between latitude 25S and 35S this island group are an important link between tropical and temperate environments;
- Sub tropical rainforests of Norfolk Island host a diversity of native and endemic species, including Norfolk Island morepork or boobook owl (*Ninox novaeseelandiae undulate),* Lord Howe Island (Phillip Island) Gecko*, (Phyllodactylus guentheri)* and Skink, (*Leiolopisma lichenigerum)* and the Norfolk Island green parrot (*Cyanoramphus novaezelandiae cookii*);

- Phillip Island has a vascular flora of 68 species, including 5 species endemic to the Norfolk group, 32 native species and 31 exotic, such species include the Phillip Island Hibiscus (*Hibiscus insularis*), Norfolk Island Pine (*Araucaria heterophylla*) and the Norfolk Island Palm (*Rhopalostylis baueri*)
- Of the some 15 species and subspecies of birds endemic to Norfolk Island only seven definitely remain. Two species, the white-breasted white-eye *(Zosterops albogularis)*, and the island thrush or grey-headed blackbird *(Turdus poliocephalus)* have not had confirmed sightings for some time and may be extinct. The remaining two species, the Norfolk Island morepork or boobook owl *(Ninox novaeseelandiae undulata)* and the Norfolk Island green parrot (*Cyanoramphus novaezelandiae cookii)*, are endangered;
- At least 42 plant species have been identified as being at risk from extinction (Sykes and Atkinson 1988). These include the Norfolk Island abutilon *(Abutilon julianae)*, the Phillip Island wheatgrass (*Elymus multiflorus* var. *kingianus*) and the Phillip Island hibiscus (*Hibiscus insularis)*. Also, the conservation status and taxonomic status of Norfolk Island ferns has important biological value. Eight taxa are endemic and these are a conservation priority, as Norfolk Island is the only locality where they exist in the wild. Within the Park, these taxa are represented by only one or a few populations in the wild (Braggins 1996);
- The islands are of significance for migratory birds and therefore have regional conservation value. A number of species of seabirds which nest in the Park are listed as migratory under JAMBA, the Bonn Convention, and CAMBA. These include species such as the Norfolk Island green parrot (*Cyanoramphus cookii*), the wandering tattler (*Heteroscelus incanus*), the Norfolk Island boobook owl (*Ninox novaeseelandiae undulata*), The masked booby (*Sula dactylatra fullagari*), the Norfolk Island silver eye (*Zosterops albogularis*) and the flesh footed shearwater (*Puffinus carneipes*);
- Five endemic species of snail on the island have been nominated to be listed as critically endangered. These include *Advena campbellii* and *Mathewsoconcha suteri.* (pers comm. B.Watson); and
- The island supports a wide variety of microfloral and fungal species which have not been fully researched. (pers comm. B.Watson).

Pressures on natural values

Pressures on the natural values of the Park include:

- Introduced fauna species particularly the black rat (*Rattus rattus)* as well as introduced house cats and feral chickens (pers comm. B.Watson). More recent introduced species such as the Asian house gecko (*Hemidactylus frenatus*) and the Argentine ant (*Linepithema humile*) are not currently considered a pressure but may be in the future;
- Invasive weed species such as the African olive (*Olea europaea ssp Africana*), Hawaiian holly (*Schinus terebinthifolius*), kikuyu grass (*Pennisetum clandestinum*) and the cherry guava (*Psidium cattleianum);*

- The Park is located in a cyclone prone area. Tropical cyclones and other extreme weather events have the potential to cause damage to plant species and habitat;
- Current and historic impacts of human habitation; and
- Increasing demand from tourism and the need for supporting infrastructure and resources.

9.5 Cultural Values

Norfolk Island has an important cultural history in colonial settlement. Many assets of cultural value and historical significance exist on the Island including:

- A monument to Captain James Cook and a scenic lookout on the northern part of the coast;
- Shipwrecks associated with colonial settlement can be found on and around the island;
- St Barnabas Chapel;
- Kingston ruins and the Kingston jetty;
- Historic cemetery, houses and structures;
- World War II relics exist within the Park area of the island; and
- Descendants of the Pitcairn settlers utilise resources on the island for traditional and cultural heritage.

Pressures on cultural values

The pressures on the cultural values of the Park include:

- Human disturbance associated with habitation and visitation;
- Increasing tourism demands for infrastructure and basic amenities;
- Lack of resources and expertise to maintain and manage cultural assets; and
- Impacts of natural erosive forces, such as wind and rain, on cultural assets.

9.6 Recreational and Visitation Values

The Park offers both educational and recreational facilities for visitor enjoyment. Facilities range form natural history collections to recreational walking trails to Mt Pitt and Mt Bates offering spectacular views of the islands. Activities on offer include bush walking, bird watching, fishing, scuba diving and kayaking. Scientific research is also conducted within the Park

The Park and surrounds offer significant potential for eco-tourism offering, adventure travel combined with an educational experience of the islands flora and fauna.

Pressures on recreational and visitation values

The pressures on the recreational and visitation values of the Park include:

- Provision and maintenance of infrastructure, services and basic amenities in response to growing visitor numbers;
- Long term security of potable water supply to meet local population and visitor needs;
- Increasing costs associated with Park maintenance of infrastructure including, but not limited to, roads, walking paths and drainage.

9.7 Current Management Approaches

Management activities in the Park for natural values are aimed at ensuring:

- Ecological processes are maintained to protect the visual attributes of the Park landscape;
- Viability of populations of native and endemic flora and fauna;
- Encouragement of public understanding and enjoyment of the Park and its natural resources, whilst ensuring the protection of these resources for the future;
- Balancing the competing demands of managing threatened species and providing for increasing tourism demands; and
- Maintenance of the water catchment values of the Park for other users and to manage water, where appropriate, for biodiversity.

This currently includes management of threats such as weeds, feral animals, current pest species, invasion by new pest species and inappropriate fire regimes. Management approaches will continue to be aligned with the future challenges faced by the Park.

A ten year strategy is being implemented to ensure long term forest rehabilitation for Norfolk Island, the Botanic Garden and Phillip Island. The strategy works across broad areas of management in the conservation of native and endemic flora and fauna, including weed control, forest regeneration and species specific survival strategies.

9.8 Climate Change Scenarios

- The high range global warming scenarios in Table 9-1 have been projected for the New South Wales region. Due to the remote location of the Park, these scenarios can be an indication of anticipated direction and degree of change only. Uncertainty surrounding the scenarios is shown in brackets. CSIRO have also projected changes to the marine realm by 2070 as shown in
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Table 9-2.

Table 9-1: Climate change scenarios for NSW Source: CSIRO, 2006 & pers comm. P Whetton, 2006)

Climate change factor		Current (1975-2004)	Scenarios for 2030	Scenarios for 2070
Annual average temperature		Max 24.4 °C, min 11.1°C	+1.3°C (±0.6°C)	+4.0°C (±1.7°C)
Average sea level		0	+17cm	+50cm
Annual average rainfall[16]		553mm	+4% (±11%)	+11% (±34%)
Seasonal average rainfall	Summer	168mm	+4% (±19%)	+11% (±57%)
	Autumn	139mm	+4% (±19%)	+11% (±57%)
	Winter	114mm	-7% (±15%)	-23% (±45%)
	Spring	132mm	-7% (±11%)	-23% (±45%)
Annual average potential solar radiation		N/A	-0.6% (±1.9%)	-1.9% (±5.7%)
Annual average potential evaporation		N/A	+6% (±4%)	+17% (±13%)
Annual average no. of hot days (> 35°C)		3 days (Sydney)	+3 days	+15 days
Annual average no. of cold nights (<0 °C)		62 days (Sydney)	-21 days	-52 days
Annual average no. very high/extreme forest fire danger days		11 days (Richmond) 23 days (Canberra)	+3 days (Rich) +5 days (Canb)	+8 days (Rich) +15 days (Canb)
CO_2 concentration		353ppm	+165ppm	+ 365ppm

16 Uncertainty surrounding annual and seasonal rainfall projections in this region are high. Planning for these impacts will need to take into consideration that rainfall trends may increase or decrease.

Table 9-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*. 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C
Temperature at 500m depth	Warming of 0.5-1°C
Incident solar radiation	Increase between 2 and 7 units W/m^2
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface winds	Increase of 0-1m/s surface winds
Surface currents	Decline in strength of surface currents of between 0-1.2m/s
pH	Decline in pH by 0.2 units

A summary of the potential impacts of climate change on the values identified for the Park are described below. Implications of climate change on management are also discussed.

9.9 Summary of Potential Climate Change Impacts

Changes in rainfall patterns

Changes in seasonal rainfall can have negative effects on species and their habitats within the Park. Montane cloud forests and other sensitive microclimates found in parts of Norfolk Island will be particularly at risk from seasonal changes in rainfall (Pittock 2003) due to their high dependence on current conditions. It is possible that large changes in the structure of the forests may result from small changes in precipitation.

Potential decreases in precipitation during the cooler months could result in a lower moisture balance for the soils in the Park. This may negatively affect species that require constant damp conditions to survive, such as certain insects, snails and flora (pers comm. B.Watson).

Heavy rainfall events will negatively affect soils in the Park through increased erosion and runoff. Soils on Phillip Island are already very degraded (and almost non-existent in many areas); and therefore any increase in erosion and landslips after heavy rain will place remnant and rehabilitated vegetation at further risk. The soils on the main island are less vulnerable; however landslips and road closures have occurred previously in the Park after heavy rain (particularly in 1998) and therefore may become more frequent (Norfolk Island National Park and Norfolk Island Botanic Garden, Plans of Management, 2000).

Increased intensity and frequency of storms

Increased intensity of storms and associated storm surges may result in a greater degree of erosion from the islands and direct damage to the islands' flora. In particular, impacts to on-going rehabilitation works are anticipated with loss of flora and damage to already fragmented rainforest habitat. This will impact on the direct habitat available for local bird populations such as the Norfolk Island Morepork or Boobook Owl (*Ninox novaeseelandiae undulata*).

Potential increases in surface water runoff associated with storm events will add suspended solids to coastal waters and increase nutrient and pollutant loads such as agricultural chemicals. Species and communities negatively affected by these impacts may include sea birds that breed on the island such as the providence Petrel (*Pterodroma solandri*) and benthic marine fauna. Isolated large storm events can also result in short term impacts such as the smothering of marine benthos, whereas repeated events at a regular frequency will ultimately lead to loss of habitat and a reduction in biodiversity. Such impacts could alter marine food chains and ultimately affect seabird food supply.

An increase in erosive forces will potentially result in more rapid deterioration of cultural artefacts and resources present within the Park. Examples of cultural assets potentially impacted include shell middens, rock shelters, burial sites, ceremonial grounds, stone-flaking sites and axe-sharpening grooves. Major erosive forces can also result in damage to walking trials and drainage lines in the Park, thus impacting on its recreational value.

Increased temperatures

An increase in extreme temperature days may result in heat stress in plants within the Park. Further constraints to water resources may also result. Plants under heat and water stress (which will be further exacerbated through an increase in potential evaporation) will be more susceptible to weeds. Plant mortality is also anticipated where there are extreme temperature days in succession.

Seasonal temperature increases will enhance biological activity of soil micro-organisms, leading to more rapid breakdown of soil organic matter and faster nutrient release. Increased availability of soluble soil nutrients will bring about faster and more vigorous plant growth; however, it will also increase the loss of soil nutrients through leaching. The effects of increasing temperatures on fungal and micro-floral species within the Park are currently unknown. The effects of increased temperature, combined with increases in potential evaporation will most likely have a negative effect on the snails, which are endemic to the island (pers comm. B.Watson).

Potential increases in sea surface temperatures may have a negative effect on the marine food chains in the region, which will have implications for top predators including sea birds (pers comm. B.Watson).

Many seabirds feed on small pelagic fish and zooplankton and are therefore sensitive to changes at lower trophic levels. Some seabirds may be able to rapidly shift their distributions depending on restrictions to habitat requirements at particular life stages such as availability of nursery areas, feeding grounds or breeding grounds.

An increase in annual average temperatures and the incidence of the number of hot days may affect visitor comfort and satisfaction.

Increased atmospheric CO_2

Higher atmospheric levels of carbon dioxide can generate conditions that are favourable for opportunistic species and weeds such as the African Olive (*Olea Africana*) which is a persistent pest problem in the Park. In such circumstances ground cover vegetation is expected to build up at a faster pace, building fuel loads and increasing the risk to the Park from fire.

9.10 Principal Management Implications

Managing to increase resilience of values

The impact of climate change on the ecological value of the Park may be lessened by ensuring that all existing threats to the integrity of the Park are appropriately managed. Existing management strategies and activities may no longer be appropriate under changing climatic conditions and may therefore require review to address resilience or carrying capacity of species and ecological communities. Areas for review may include

- Increasing erosion during heavy storms may mean that existing measures for managing soil stabilisation and revegetation will not be adequate in the future;
- It is possible that other native species will colonise Norfolk Island as the islands are a major link between tropical and temperate environments. This will pose a significant challenge to Park management in identifying which species should be conserved and which should be identified as pests and therefore eradicated;
- Water management and securing water supplies for resident populations and for fire fighting may require further intervention. Furthermore, critical water storage functions of the Park may be pressured from drought conditions and more intensive rainfalls resulting in erosion and sedimentation;
- Fire management strategies may not be adequate to reduce the risk of fire under climate change. Opportunities for prescribed burning may decrease as the number of high fire danger days increases (Hennessy *et al*. 2005) directly impacting on the management of fuel loads on the surrounding areas;
- weed management including chemical application and fire management regimes for this purpose; and
- Parks management may need to consider extending current propagation programme for native flora and fauna to off-island repositories as insurance.

There will be an increasing need to ensure that all recovery plans for species listed as threatened under the EPBC Act are up to date and implemented (at present these are only available for the Green Parrot and the Morepork). The recovery plans need to specifically consider the potential threat of climate change. Additional management resources may need to be applied to prevent species loss and population decline for those increasingly vulnerable to pressures as a result of climate change;

Increasing decision-making capacity by improving understanding

The management plan is now due for re-drafting therefore management approaches will be reviewed based on an evaluation of progress to date and consideration of additional issues such as climate change. Currently there are several gaps in knowledge that may prevent Park management from adequately answering questions regarding resilience, climate change impacts and sustainable use of the Park. Increasing understanding in these areas will in effect increase decision making capacity of Park managers. Gaps in knowledge include:

- Bioclimatic modelling of important endemic flora and fauna species such as the Norfolk Island pine to assess potential impacts from climate change;
- Temperature tolerances of the only two native reptile species (Lord Howe Island (Phillip Island) Gecko*, Phyllodactylus guentheri* and Skink, *Leiolopisma lichenigerum*) now confined to Phillip Island;
- The potential effects of climatic changes and Psittacine Circovirus Disease (PCD) and the brown root rot fungus *Phellenius noxius* to their hosts;
- Baseline data including an inventory for existing invertebrate fauna with respect to vegetation type and altitude;
- Trends in the abundance, breeding success and phenology of seabirds and potential arrival and establishment of new species, for example, in Western Australia there are several examples of seabird species colonising and breeding at progressively more southerly locations; this is thought to be associated with climate-induced changes in the Leeuwin current);
- Potential changes to occult precipitation and the implication for vegetation communities in the higher elevation areas of the Park. There is evidence in Costa Rica that rising sea surface temperatures have raised the cloud base in adjoining mountainous areas, reducing mist days, negatively affecting species, including driving at least one frog species to extinction (Lawton *et al*. 2001);
- Impacts of climate change on the fungal and microfloral life in the forest and effects of losing this life on the surrounding vegetation (pers comm. B.Watson); and
- Impacts of feral chickens on the habitats within the Park (pers comm. B.Watson).

Maintaining infrastructure and protocols to ensure visitor safety and enjoyment

An increase in the number of extreme fire danger days and days over 35°C may result in an increase in enforced Park closure to ensure visitor safety. This will result in negative affects on visitor satisfaction and an increase in management and resources required to control fire risk.

The timing and nature of maintenance works within the Park, such as road improvement works, should continue to be planned so as to minimise disturbance to birds, particularly during nesting periods; however, restrictions on visitor access to certain areas of the Park may prove insufficient to minimise stress on native bird populations.

If Phillip Island becomes the last refuge for more endemic species, strategies to minimise human disturbance and quarantine measures may need to be reviewed.

10 Pulu-Keeling and Cocos (Keeling) National Park

10.1 Bioregional Setting

The Pulu Keeling National Park (hereafter referred to as the Park) is located in the Cocos (Keeling) Islands. This island territory of Australia is situated approximately 2900 kilometres north west of Perth in the Indian Ocean.

These islands formed on top of old volcanic seamounts surrounded by a growing fringe reef taking tens of thousands of years to develop. The Cocos (Keeling) Islands are made up of two main regions, North Keeling Island and the South Keeling Islands, with a total land area of 14 square kilometres. North Keeling Island is a single C-shaped atoll with an opening to a central lagoon. This island is in its natural state and uninhabited, and is therefore relatively undisturbed by humans. The South Keeling Islands support a small population of about 500 and are made up of 26 separate islands forming part of a coral atoll. The atolls are connected by a submerged ridge, comprising a single tropical feature rising from the ocean floor (Director of National Parks 2004).

North Keeling Island is a remote oceanic island which has always been isolated from any large land mass. Floral and faunal colonisation of the island has occurred via wind, pelagic drift, flight or animal carriage. This isolation has resulted in a unique assemblage of species and ecology which is of great fascination to biologists (Director of National Parks 2004).

The Park is situated on North Keeling Island and includes 12 square kilometres of land area, a central lagoon, and 1.5 kilometres of water extending out from the high tide mark. The Park's most outstanding feature is its intact coral atoll habitat. Comparisons with other Indo-Pacific atolls reinforce the notion of Cocos (Keeling) Islands as one of the last areas of pristine reef systems in the world. With the rapid decline of similar coral island environments, the conservation and protection of this habitat is of international importance (Director of National Parks 2004).

10.2 Management Arrangements

The Cocos (Keeling) Islands have been an Australian External Territory since 1955. The Commonwealth of Australia handed over the land of the Cocos (Keeling) Islands to the Cocos (Keeling) Islands Shire Council to be held in trust for the people who lived on the islands. This trust specified that North Keeling Island was to be managed to conserve the unique flora and fauna of the island. On 12 December 1995, the Pulu Keeling National Park was proclaimed under the *National Parks and Wildlife Conservation (NPWc) Act 1975* and continues to be managed under the EPBC Act. .

The primary purpose of the Park is to preserve its flora and fauna species, as well as the pristine marine environment. The Parks' significant values have been recognised in a number of international conventions and agreements, including the Ramsar Convention (Wetlands), Bonn Convention (Migratory Species), CAMBA and JAMBA.

10.3 Climate

The Cocos (Keeling) Islands are located in the tropical zone at the southern edge of the equator. This region is dominated by a low pressure belt which migrates northward or southward depending on the season. Relatively strong trade winds from the south-east are constant throughout the year and add to the monsoon season. Monsoons, or cyclones, in this region are influenced by oceanic conditions and can have serious effects on the local fauna and flora. Cyclones are most common in the months of January to May (Director of National Parks 2004) and since 1952 there have been 27 tropical cyclones which have caused severe wind gusts of at least 90 km/h. On average this equates to approximately one causing damaging winds every 2 years and one causing destructive winds every 14 years. *Cyclone Doreen*, one of the most damaging cyclones, occurred in 1968, where winds reached 176 km/h (Bureau of Meteorology 2007). Historically, the most significant cyclone to affect the Islands occurred in 1909 where wind gusts were estimated at speeds of 225 km/h (Bureau of Meteorology 2007).

10.4 Natural Values

The Park has a number of natural values which are associated with the isolation and uniqueness of North Keeling Island:

Internationally recognised seabird rookery

- Seabirds remain in large numbers on the island due to its isolation and absence of feral predators. There are approximately 24 bird species currently found on the island, of which 15 breed in the Park (Pulu Keeling Management Plan, 2004). North Keeling Island is one of the major seabird breeding grounds in the Indian Ocean that is relatively undisturbed by humans. It is a focal bird nesting place within the central-eastern region of the Indian Ocean;
- Seventeen of the seabird species recorded in the Park are listed under CAMBA and JAMBA. These include the common noddy (*Anous stolidus*), cattle egret (*Ardea ibis*), great sand plover (*Charadrius leschenaultii*) and the Christmas Island frigatebird (*Frigata andrewsi*);
- The island also provides habitat for the Cocos buff-banded rail (*Gallirallus phillippensis andrewsi*) which is listed as endangered under the *EPBC act* and the Round Island petrel (*Pterodroma arminjoniana*) considered critically endangered under the *EPBC Act;*
- North Keeling Island supports the largest breeding population of the *EPBC* listed red-footed booby in the world; and
- The Park also remains one of the few examples in the Indian Ocean of a seabird colony habitat that is relatively unaffected by feral animals and only rarely visited by humans.

Habitat for endangered species

- The Park is home to EPBC listed species including 1 critically endangered, 4 endangered 5 vulnerable, 24 migratory and 36 marine fauna species. Examples include the extremely rare Cocos buff-banded rail (*Gallirallus phillippensis andrewsi)*, the critically endangered Round Island petrel (*Pterodroma armijoniana)*, the internationally vulnerable robber crab (*Birgus latro*) and the green (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys imbricate*), (both vulnerable under the *EPBC Act*). Both turtle species have been known to forage on the seagrass beds located in the southern lagoons of the island. The Park is also known to be an important nesting area for the green turtle.

Several Endemic Species

- Since the island has not had any contact with any large landmass, it supports a number of endemic species. Before any form of human occupation the island could only be colonised via wind and sea, such as flight or other means of animal carriage. Thus the flora and fauna found in the Cocos (Keeling) Islands are of a unique assemblage of 'travelling species' (Director of National Parks 2004); and
- Nine species out of the 99 species of coral found in the Cocos (Keeling) Islands have not been recorded anywhere else in the eastern Indian Ocean, two of these are endemic. Further endemic species can be found within these coral systems including the Cocos angelfish (*Centropyge joculator*) (Director of National Parks 2004).

Pressures on natural values

Potential pressures as a result of human presence and disturbance include:

- Accidental introduction of pest species have lead to the establishment of a number of weeds, which are most prominent at the southern atoll of the Park. These include Mossman River grass, *Cenchrus echinatus,* para grass, *Brachiaria muticam* buffel grass, *Cenchrus ciliarus* and siam weed, *Chromolaena odorata*;
- Yellow crazy ants, *Anoplolepis gracilipes,* exist on the island but as yet have not developed into supercolonies (as seen in other locations, such as Christmas Island), probably in part due to the absence of scale insects. However a species of scale insect has recently been accidentally introduced to the southern atoll;
- Disturbance to nesting sites and habitat degradation from walking tracks and trampling may also impact on the success of seabird fledglings to develop;
- Although camping is prohibited, rubbish and waste from visitors are a potential threat to the environment;
- Marine pollution and debris from commercial shipping (pers comm. I.Macrae); and

- Poaching of seabirds is an ongoing problem and a significant management issue for the Park. Illegal fishing can also reduce the abundance of marine species by disturbing the habitat or directly removing large quantities of species from the Park. Foreign fishing vessels also have the potential to introduce pests and diseases.

Natural pressures on the Park include:

- Depending on ocean conditions, outbreaks of crown of thorns starfish (*Acanthaster planci)* are known to occur within the Park impacting on local corals;
- Tropical cyclones, although a natural occurrence, can damage vegetation and result in loss of habitat. In 2001 around 61% of the canopy was felled due to *Cyclone Walter.* Loss of habitat impacts on the breeding cycles of several seabirds species. Strong winds and rough seas can remove seaweed habitat important for fish nursery areas (Director of National Parks 2004); and
- The deoxygenation of water in the southern lagoon due to a natural closing of its entrance and increasing water temperature has the potential to reduce the number of coral and fish species found in the island lagoon (pers comm. I.Macrae).

10.5 Cultural Values

A number of historic shipwrecks, including some listed in the *Historic Shipwrecks Act 1976,* are located in the Park.

The Cocos (Keeling) Islands are of cultural value to scientific literature on coral atolls. The coral reefs of these islands were the only reefs explored by Charles Darwin on foot. Darwin's explorations in the Cocos (Keeling) Islands lead to his well-known theory of coral reef formation.

The people living in the Cocos (Keeling) Islands are of Malay decent. They were brought here from parts of Indonesia as workers for the coconut plantations established in 1830. Seabird hunting trips to the North Keeling Island by the local Cocos-Malay people have been a common tradition since the mid 1900s. Groups of small sailing boats would travel out to the North Island whenever the weather would allow them. Thousands of seabirds would be brought back for festivals, taken down by shotguns and traditional flails.

Pressures on cultural values

Cyclones are the main occurrence putting pressure on the above cultural values. *Cyclone John* in 1989 devastated the red-footed booby population by the removal of suitable breeding habitat and all legal hunting was ceased to allow the species to recover. By 1996 it was concluded that the species had recovered to its initial population prior to 1989. Currently, further harvesting by the Cocos-Malay people is subject to the provisions of the *EPBC Act*.

10.6 Recreational and Visitation Values

North Keeling Island is significant to studies of island biogeography because of its evolution in isolation. It continues to be a site of scientific research (Director of National Parks 2004).

- North Keeling Island provides an ideal site for scientific research and investigations into island biogeography and coral reef development. Due to its undisturbed environment, the island supports a rare intact atoll ecosystem. Ecological interest in the marine biota also stems from the extreme isolation and relatively small size of the atolls;
- Some of the species found on North Keeling Island have been extinct from other islands of the Cocos (Keeling) group. Therefore, the species pool of North Keeling Island can potentially be used to recolonise the species lost on other nearby islands; and
- Special interest groups such as bird-watchers, divers and surfers visit the Park. Access to North Keeling Island is arranged by local licensed tour groups from the South Keeling Islands. No camping is permitted in the Park, so visitors are accommodated on and transported to and from the southern atoll. This provides income opportunities for local islanders.

Pressures on recreational and visitation values

Pressures on recreational and visitation values are largely from the weather, particularly cyclones. Access to the island for recreational activities and scientific research and monitoring is governed by the weather conditions. Many of the recreational and visitation values in the Park are primarily based on the natural values and therefore are exposed to similar pressures, such as pest species and disturbance from other users.

10.7 Current Management Approaches

Natural values

Management activities are aimed at ensuring the Park's ecological assets and processes are maintained and preserved in their undisturbed condition. This includes managing the native vegetation communities of North Keeling Island in order to ensure that the introduction of invasive species is prevented. This control of invasive species includes exotic or feral species which may negatively impact on the Park's native fauna. Management objectives are also in place to manage and maintain marine flora and fauna and preserve habitats in their natural condition.

Cultural values

A number of cultural relics are found in the Park which provide historical evidence of past activities associated with the Cocos-Malay workers and the two World Wars. Management activities are in place to ensure that its cultural heritage is protected and preserved. This includes the maintenance of Malay graves in accordance with an agreed standard and minimising impacts on cultural heritage material.

Recreational and visitation values

Management activities have been set in place for the Park to ensure that its recreational and visitation values are used in a sustainable manner. This includes conducting and supporting research to gain a better understanding of the values of the Park, identifying changes that may have occurred and providing an indication of the effectiveness of management. Management activities are also in place to protect and preserve the Park from any adverse impacts of visitation whilst ensuring a safe and enjoyable experience for all visitors. This includes the management of commercial operations and educational programs within the Park.

10.8 Climate Change Scenarios

Due to its remote location, only regional scenarios data can be applied for the Pulu-Keeling and Cocos (Keeling) National Park (Table 10-1).

Table 10-1: Climate change scenarios (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor	Current (1975-2004)	2030 scenarios	2070 scenarios
Average sea level	0	+17cm	+50cm
CO_2 concentration	353ppm	+165ppm	+ 365ppm

The trends outlined below may also be applied as an indication of anticipated direction and degree of change only.

- Increases in temperature
- Increases in cyclone intensity and frequency
- Changes in rainfall patterns[17]

CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in (Table 10-2).

Table 10-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*. 2006a).

Physical climate change indicators	Projected climate change impacts by 2070

17 - Uncertainty surrounding annual and seasonal rainfall projections in Northern Austrlaia is high. Planning for these impacts will nee to take into consideration the possibilily that rainfall may increase or decrease.

Sea surface temperature	Warm by 1-2°C^
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
pH	Decline in pH by 0.2 units

^ Pulu Keeling is located outside of the biogeographic range of these scenarios.

A summary of the potential impacts of climate change on the values identified for the Park are described below. Implications of climate change on management are also discussed.

10.9 Summary of Potential Climate Change Impacts

The values of the Park are exposed to a number of climate change factors. These key impacts are described below

Sea level rise

The Park is located on a low lying island which is only about 3 – 5m above sea level (per comm. I.Macrae). Projected sea level rise, combined with cyclones and associated storm surges may therefore have significant negative affects on low-lying habitats and compound coastal erosion.

Increases in atmospheric CO_2

Rising CO_2 concentration acts to increase photosynthesis, plant biomass and plant water-use efficiency in many plant species. Differences among species in their responses to elevated CO_2 will affect competitive interactions and thus community structure and composition. Species which are early successional, highly dispersible or good colonisers may be favoured (pers comm. L. Hughes). This includes weeds and invasive species such as Mossman River grass, *Cenchrus echinatus,* para grass, *Brachiaria muticam* buffel grass, *Cenchrus ciliarus* and siam weed, *Chromolaena odorata* which occur on the southern atoll but not in the Park.

Increase in sea surface temperatures and ocean acidity

Increases in temperatures will have negative effects both on land and in the marine environment. For coral reefs, this may translate to an increase in the frequency and intensity of coral bleaching events (pers.comm. O Hoegh-Guldberg 2007). Given the current projected future rates of warming, it is likely that coral bleaching and mortality will significantly increase in the coming decades (Hoegh-Guldberg 1999, 2004).

Negative affects from bleaching will be further compounded by an increase in ocean acidity. Given that coral reefs represent a balance between calcification and erosion, it would appear that should atmospheric CO_2 concentrations exceed 500ppm the ability of the coral reefs to maintain structural integrity and provide habitat for numerous marine species, such as the endemic Cocos angelfish (*Centropyge joculator*) may be severely compromised.

Increase in cyclone intensity and frequency

Perhaps the most obvious and the most threatening impact to the Park in the short term is increasing cyclone damage. Current scenarios suggest an increase in the intensity of cyclones in this area due to rising sea surface temperatures associated with climate change. Increases in cyclone and storm intensity may have damaging effects on almost all habitats within the Park. Strong winds and intense rainfall may increase soil erosion on the islands, negatively affecting the terrace and shallow soil rainforest habitats. Bird nesting habitat may also be negatively affected. An increase in cyclone intensity may cause greater destruction to the area and an associated increase in recovery time for ecosystems to return to a steady state. Seagrass beds located in the southern lagoon may be particularly vulnerable to mechanical disruption as a result of this activity. A reduction in seagrass beds could have potential negative knock on effects on the green turtle (*Chelonia mydas)* which depends on these habitats as a feeding ground.

Increased intensity of cyclonic activity may also accelerate the deterioration of the shipwreck the *SMS Emden*.

Loss of existing biodiversity and increased rates of extinction

Unlike reef systems on the north east coast of Australia, the Park is an isolated reef system. Christmas Island is stated to be one of the only areas for transfer of propagules for reef replenishment and colonisation. Scientific research in this subject is limited but suggests that Christmas Island's fish fauna is closely linked to the Pacific Ocean where as Cocos is more similar to the Indian Ocean. This implies a barrier to propagation of certain species between the two islands (pers comm. J. Hueston). The geographic location does not therefore support southern range shifts for marine fauna and flora. It is however, possible that species from more northerly regions of Indonesia may colonise the area.

The Park supports a number of endemic and endangered species. Climate change may place further pressures on these species and in some instances may result in their extinction. Species particularly at risk include:

- Endemic species – two species found in the Cocos (Keeling) Islands are known to be endemic while nine species of coral have not been recorded elsewhere in the eastern Indian Ocean (Director of National Parks 2004). The Cocos angelfish (*Centropyge joculator*) is an endemic fish species which may be negatively affected by the loss of coral habitat;
- The robber crab is considered vulnerable to extinction internationally. Climate change may place the crab further at risk through rising sea temperature which affects the development of the larvae, and changes in ocean currents which may affect recruitment (pers comm. J.Hueston);

- The hawksbill turtle (*Eretmochelys imbricate*) uses the Park for feeding. Any changes to foraging areas will place the Hawksbill turtle at further risk;
- The green turtle (*Chelonia mydas*) uses the Park for both feeding and nesting, and may therefore be particularly vulnerable to the impacts of climate change (pers comm. J.Hueston). The green turtle is a temperature dependant species (TDS). Small increases in temperature may therefore alter their reproduction cycles, altering the sex ratio of hatchlings towards an increased number of females and reduce the viability of future turtle populations. The green turtle also feeds on a number of crabs which are present on the island (i.e. the robber crab). Any decline in population of the crab (as described above) will further increase the vulnerability of the green turtle.
- Increases in sea level and other impacts of climate change have the potential to significantly diminish the habitat for the Cocos buff-banded rail (*Gallirallus phillippensis andrewsi*) and the Round Island petrel (*Pterodroma armijoniana)*. The island supports significant populations of these endangered species and is currently undergoing programs to reintroduce the Cocos buff-banded rail (*Gallirallus phillippensis andrewsi*) to previously populated habitats in the Park (pers comm. I.Macrae).
- North Keeling Island supports the largest breeding population of the *EPBC* listed red-footed booby in the world.
- The Park is one of the major seabird breeding grounds in the Indian Ocean that is relatively undisturbed by humans. It is a focal bird nesting place within the central-eastern region of the Indian Ocean. Any loss of disturbance of breeding habitat may have negative affects on seabird populations in a regional context.

Potential changes to seabird populations will have flow on effects to the common tradition of seabird hunting by the local Cocos-Malay people.

10.10 Principal Management Implications

Managing to increase resilience of values

Climate change poses a significant threat to remote Parks such as Pulu Keeling and the values they contain. By 2070, climate change is likely to have considerable impacts on the physical habitat in the Park and on the distribution, abundance and composition of species within it. Efforts to protect the Park's values may however be limited to management of non-climate stressors; in effect, helping to build their resilience to climate change.

Existing strategies and activities to manage pressures may no longer be appropriate under changing climatic conditions, and therefore require review, including management of weeds, invasive pest animals, visitor access and commercial activities (such as recreational fishing) in and around the Park. Priority areas for consideration will include minimising disturbance to seabird and turtle habitat and protecting the coral reef from pollution and destructive activities such as anchoring and mooring.

Habitat loss, coral bleaching and coral death may negatively affect visitor satisfaction and reduce recreational opportunities in the Park.

Climate change may negatively affect the scientific values of the Park as loss of existing species abundance and diversity will reduce opportunities for scientific research and significantly impede knowledge gathering on the values and threats in the Park. Research opportunities may however be presented through the almost intact reef shark population for example, which is important for scientific research and as a potential reef health indicator (pers comm. J Hueston).

Increasing decision-making capacity by improving understanding

Currently there are several gaps in knowledge that may prevent Park management from adequately answering questions regarding resilience, climate change scenarios and sustainable use of the Park. Increasing understanding in these areas will in effect increase the decision-making capacity of Park managers.

Gaps in knowledge include:

- The potential effects of climate change on the Park's water chemistry, including temperature and pH and the adaptive capacity of endemic species such as coral to cope with these changes;
- The potential effects on ocean productivity around the Park and the potential flow on effects to the Park's marine life abundance and diversity including marine turtles and seabirds;
- The inter-relationships between the terrestrial and the marine environment, and the significance of ongoing sea level rise;
- Turtle dispersion and population connectivity in and around the Park; and
- Species likely to migrate in and out of the Park as a result of an anticipated southward shift in species distribution under climate change.

Maintaining infrastructure and protocols to ensure visitor safety

Strategies and activities to ensure visitor safety, including researchers and Park managers, may no longer be appropriate under climate change, in particular under increased risks from cyclones. A regular review of safety risk assessments, contingency plans and communication strategies will be imperative.

11 Uluru-Kata Tjuta National Park

11.1 Bioregional Setting

The Uluru-Kata Tjuta National Park (hereafter referred to as the Park) is located close to the centre of Australia and covers some 132,566 hectares of arid ecosystem. The Park is located in the traditional lands of the Pitjantjatjara and Yankunytjatjara Aboriginal people (locally known as Anangu), and is a place of great spiritual and cultural importance. The Park is listed on the World Heritage register for both its cultural and natural values.

The Park is the only Commonwealth Park in Central Australia. Other parks in the central Australian region generally cover hill, mountain range or riverine country and are managed under relevant Northern Territory and state legislation.

The Park is located in the Great Sandy Desert bioregion and is one of only two protected areas in this bioregion in the Northern Territory. The existing network of protected areas (Federal and state combined) does not offer comprehensive protection for NT biota and the distribution of reserves is heavily biased towards the Top End (Whitehead, *et al* 1992). The Wet Tropical Zone has more than 19% reserved whereas the Central Arid Zone, in which Uluru is located, has less than 1%. Protected areas are also clumped at each end of the North-south gradient such that the maximum distance north-south between protected areas is >800 km.

The Park is considered to provide significant ecological refuges, with the relatively moist environments of the monoliths at Uluru and Kata Tjuta providing habitat for rare, relict and unusual species (Morton *et al*. 1995).

The Ayers Rock Resort at Yulara adjoins the Park's northern boundary and both the Park and the Resort are surrounded by Aboriginal freehold land.

11.2 Management Arrangements

On 24 May 1977, the Park was declared under the Commonwealth *National Parks and Wildlife Conservation Act 1975* as the Uluru (Ayers Rock - Mount Olga) National Park. The Uluru-Kata Tjuta Aboriginal Land Trust was granted title to the Park on 26 October 1985. In 1993 the official name of the Park was changed to Uluru-Kata Tjuta National Park.

The Park is under joint management by Anangu (western desert Aboriginal) and Parks Australia. Joint management is the term used to describe the working partnership between all traditional owners and relevant Aboriginal people and the Director of National Parks as lessee of the Park.

The Park has been assigned to the IUCN Protected Area Category II: National Park. The Parks' significant values have been recognised in a number of international conventions and agreements, including

UNESCO's Man and the Biosphere Programme (as a Biosphere Reserve), Bonn (Migratory Species), CAMBA and JAMBA.

The overall management intent for the Park is (Parks Australia 2000):

- Maintaining Tjukurpa (Anangu law);
- Supporting a healthy Anangu culture and society;
- Looking after country and protecting a national symbol; and
- Protecting World Heritage natural and cultural environments of the Park in harmony with Australian social and economic aspirations.

11.3 Climate

Annual average temperatures in Central Australia range from a maximum of 30.5°C to a minimum of 15.8°C. In summer, temperatures can reach extremes of 50°C on Uluru and Kata Tjuta. Rainfall in the arid zone is low with an annual average for Central Australia of 296mm. The rainfall is highly unpredictable and highly variable, temporally and spatially. Over half the annual average falls during summer. Major rainfall events are rare and very important, hydrologically and ecologically, in recharging groundwater systems and eliciting a massive pulse of life through ecosystems (Parks Australia 2000).

11.4 Natural Values

The Park contains outstanding examples of arid zone flora and fauna including:

- More than 400 species of plants, including rare and endangered species, generally restricted to the moist areas at the bases of Uluru and Kata Tjuta including acacias and native grasses. Examples of such species include sand hill wattle (*Acacia ammobia*), native lemongrass (*Cymbopogon dependens*), yellow guinea flower (*Hibbertia glaberrima*), trigger plant (*Stylidium inaequipetalum*) and early nancy (*Wurmbea centralis*) (pers comm. M. Jambrecina 2007);
- 21 species of native mammals, including several species of small marsupials and the following 12 species listed under the *EPBC Act*: the endangered mala or rufous hare-wallaby (*Lagorchestes hirsutus*); Itjaritjari or central marsupial mole (*Notoryctes typhlops*); red-tailed phascogale (*Phascogale calura*); sandhill dunnart (*Sminthopsis psammophila*) and central rock-rat (*Zyzomys pedunculatus*) and the vulnerable golden bandicoot (*Isoodon auratus*); murtja or mulgara (*Dasycercus cristicauda*); bilby (*Macrotis lagotis*); waru (black-footed rock-wallaby) (*Petrogale lateralis*); alice springs mouse (*Pseudomys fieldi*); numbat (*Myrmecobius fasciatus*) and chuditch (*Dasyurus geoffroii*);
- Numerous and diverse range of species of reptiles (including the great desert skink, *Egernia kintorei,* listed as vulnerable under the *EPBC Act*), invertebrate species and a number of amphibian species (found predominantly at the base of Uluru and in Kata Tjuta following summer rains); and

- A representative and moderately diverse arid zone bird population which is rich by Central-Western Desert standards. Over 178 species have been recorded including 17 migratory, 36 marine (birds) and the endangered princess parrot (*Polytelis alexandrae*) all listed under the *EPBC Act*

Landscape processes

Fire

Fires have been a part of central desert land management for thousands of years shaping the landscape, habitats, survival of animals and patterns of vegetation. Aboriginal burning practices are thought to have consisted mainly of frequent but low intensity fires. In particular, traditional fire management practices involved burning spinifex in small patches, often only a few hectares in size, clearing the area for walking and promoting new growth. The new growth would provide bush tucker for the Anangu and created a mosaic of differently-aged vegetation patches, providing a range of habitats (DEW 2007). This regime was maintained for thousands of years and resulted in the inhibition of large-scale and intense fires.

After the arrival of Europeans in Central Australia and displacement of many Anangu, burning regimes changed from the previous mosaic of patch burns to extensive areas of the landscape carrying increasing fuel loads associated with unburnt vegetation. As a result, there was an increased incidence of intense and extensive fires following periods of above-average rainfall. In 1976, for example, fires burnt approximately three-quarters of the Park. Fires can now be very widespread, covering many thousands of square kilometres. Large intense fires are thought to have contributed to a decline in the distribution of 'fire-sensitive' species such as mulga (*Acacia aneura*). CSIRO, in collaboration with the then Conservation Commission of the Northern Territory, developed a fire management strategy to mitigate the destructive effects of fires (Parks Australia 2000).

Current fire intervals in the Uluru area are 3-30 years. Most fires occur in the period from October to January (Griffin *et al.* 1983). In the period 1976-1998 an average of 3.2 % of the area was burnt per annum. Fire return time is currently just over 30 years, with fires occurring in 15 years of the 23 year period 1976-1998 (Allan and Southgate 2002). Fires are usually started by the lightning strikes of dry electrical storms from the north-west. When the storms arrive the weather is usually hot, dry and windy, ideal conditions for raging fires which can cause severe and widespread damage.

Today, fire management is a fundamental joint management practice in the Park with management burns carried out in the winter months.

Rainfall

Rainfall in the arid zone is low, highly unpredictable and highly variable, temporally and spatially. Major rainfalls are rare and very important, hydrologically and ecologically, in recharging groundwater systems and eliciting a massive pulse of life through ecosystems. Any disruption to flows can result in adverse effects on soils and vegetation in these areas.

Pressures on natural values

The current potential pressures on natural values of the Park are weeds and introduced pest animals, damage and disturbance by visitors, inappropriate fire regimes and water availability. These pressures are briefly described below:

- Fire – fire management including prescribed burning is a fundamental management practice in the Park; however, fires including those from beyond the Park's boundaries, have the capacity to seriously encroach upon ecosystems in the Park, as was seen in 1976 (described above). In particular, fire can become a pressure when climatic conditions result in fuel loads that carry hot fires. The changes in fire management following the reduction of mosaic burning (described above) is thought to have contributed to the loss of >40% of mammal species in the Central Australian region. There is strong evidence that the presence of mature spinifex, in particular, is very important for the maintenance of diversity of fauna; diversity is reduced in areas where fire is too frequent for spinifex to mature. Fire regimes can also affect the structure and composition of mulga (*Acacia aneura*) communities because mulga, has a low tolerance of fire (Hodgkinson and Griffin 1982). Fire stimulates germination of *A. aneura* but frequent fires or lack of follow-up rain can deplete the soil seed bank. Overall, high intensity and frequent fires can cause long-term changes, especially in combination with drought (Griffin and Friedel 1985);
- Weeds - the most significant environmental weed in the Park is the perennial buffel grass (*Cenchrus ciliaris*) which typically invades water and nutrient rich drainage lines resulting in monoculture, altered fire regime, altered surface hydrology exacerbating erosion problems around the Uluru monolith (pers comm. M. Jambrecina 2007). Couch grass and other sleeper weeds such as red natal (*Rhynechelytrum repens*) also exist in the Park in small pockets and have the potential to spread (pers comm. M. Jambrecina 2007);
- Introduced pest species – pressures exerted by introduced predators and herbivores upon the original animals of Central Australia played a major role in the extinction of approximately 40% of the native species (Parks Australia 2000). Of the 27 mammal species found in the Park, six are introduced: the house mouse, camel, fox, cat, dog and rabbit. These introduced species are distributed throughout the Park, although their densities are greatest in the rich run-off areas of Uluru and Kata Tjuta. Pest animals have a detrimental impact on the highly significant fauna of the transitional sandplain habitat, especially the vulnerable mulgara and the great desert skink (Parks Australia 2000). Recently, the big headed ant *Pheidole megacephala* has been identified at the resort at Yulara. There is concern that this pest species may spread to the National Park (pers comm. M. Jambrecina 2007);
- Impacts caused by visitors including littering, vandalism, encroaching on areas of conservation significance and damage by off-road driving. Arid zone systems have limited capacity to

accommodate particular activities without long-lasting adverse effects;

- Constraints on water availability - groundwater, in the form of two aquifer systems, is the only reliable water supply in the region. Rainfall is low, highly unpredictable and highly variable, temporally and spatially. Waterholes and soaks in the Park support several rare and significant species and therefore constraints on water availability and water quality can negatively affect the ecology of these areas. Major rainfall events are rare and very important, hydrologically and ecologically, in recharging groundwater systems and eliciting a massive pulse of life through ecosystems. Any disruption to flows (such as through development) can result in adverse effects on soils and vegetation in these areas (Parks Australia 2000); and
- Informal Development – informal construction of roads and walking tracks by local and visiting people has been identified as a source of increased erosion (pers comm. M. Jambrecina 2007).

11.5 Cultural Values

The Park's outstanding natural and cultural heritage values are acknowledged through inscription on the World Heritage list, being one of only 22 sites listed for both natural and cultural heritage. In 1994 it became the second National Park in the world to be recognised as a cultural landscape by the World Heritage Committee.

Anangu have lived in and maintained the landscape at Uluru and Kata Tjuta for many thousands of years. The Park is a place of great spiritual and cultural importance to Anangu men and women. Key cultural values include:

- Hunting and gathering of plants and animals for food, fire, medicines, raw materials and for use in ritual ceremony;
- Maintenance of waterholes in the area (pers comm. M. Jambrecina 2007);
- Oral history and traditional knowledge which are integral to the programmes for reintroducing rare and endangered species, for fire management, waterhole maintenance, flora and fauna identification, and the control of introduced animals;
- Archaeological sites, rock art and engravings which document the Park's history of occupation in the context of that of Central Australia during the last 30,000 years and its adaptations, social and economic, to the changing environmental history of the region; and
- Other historical sites and artefacts.

Pressures on cultural values

The current potential pressures on the cultural values of the Park are:

- Inappropriate visitor activity including unauthorised entry and vandalism;

- Decreased accessibility to waterholes (pers comm. M. Jambrecina 2007);
- Resource constraints;
- Damage from fire; and
- Natural erosive processes, which can be compounded by fire which removes vegetative cover and further exposes cultural sites.

11.6 Recreational and Visitation Values

The outstanding scenic beauty of the Park, combined with the spiritual significance of the site, has made the Park a major tourism attraction, with 351,968 visitors in 2005 (Director of National Parks 2006). Tourism to the Park is central to the regional economy, particularly in terms of employment and Park use fees provide essential revenue for Park management.

The key recreational and visitation values of the Park include:

- Dramatic scenery, including Uluru, arguably the most distinctive landscape symbol of Australia;
- Opportunity for visitors to engage in a number of activities including wildlife viewing, appreciation of Anangu culture and art sites, walking, climbing Uluru, sunset and sunrise viewing, scenic driving, picnicking and photography; and
- Visitor facilities and infrastructure including established walking tracks, cultural centre, viewing areas, shade and seating areas, access roads, car parks, picnic areas, barbecues and toilet facilities.

Pressures on recreational and visitation values

The current potential pressures on the Park's recreational and visitation values include:

- Resource constraints - increasing cost of maintaining facilities and infrastructure. Park fees do not supply sufficient funding to cover all aspects of Park management;
- Extreme temperatures - temperatures on Uluru and at Kata Tjuta can rise above 50°C in summer. When it is felt that conditions such as this compromise safety, the climb on Uluru and other areas of the Park are closed to visitors; and
- Inappropriate recreational use of the Park – overcrowding, littering, illegal access and vandalism can significantly reduce the enjoyment of other users of the Park.

11.7 Current Management Approaches

Natural values

Management activities for natural values in the Park are aimed at maintaining the natural values of the Park while respecting the rights, needs and interests of Anangu including traditional hunting and gathering activities. This currently includes management of threatening processes on native fauna and flora such as weeds and introduced animals and the maintenance of traditional ecological knowledge.

Cultural values

Uluru-Kata Tjuta is a living cultural landscape. Management activities in the Park are aimed at maintaining traditional activities and use of the Park without compromising the natural values. The management of cultural sites is largely undertaken by Anangu working together with Park staff. Activities also include the protection of sacred sites from fire and inappropriate visitor use and protection of the Park's World Heritage values.

Recreational values

A major focus of the Park is the provision for appropriate recreational use of the Park, in ways that do not significantly impact on Park values or traditional owners. This includes active management of erosion in heavily used areas and the provision of visitor facilities.

11.8 Climate Change Scenarios

The high range global warming scenarios in Table 11-1 have been projected for the Central Australia region where the Park is located. Uncertainty surrounding the scenarios is shown in brackets.

Table 11-1: Climate change scenarios for central Australia (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor		Current (1975-2004)	2030 scenarios	2070 scenarios
Annual average temperature		Max 30.5°C, min 15.8°C	+1.7°C (±0.6°C)	+5.1°C (±1.7°C)
Annual average rainfall[18]		296mm	0% (±15%)	0% (±45%)
Seasonal average rainfall	Summer	152mm	0% (±15%)	0% (±45%)
	Autumn	73mm	0% (±15%)	0% (±45%)
	Winter	29mm	N/A[19]	N/A
	Spring	42mm	N/A	N/A
Annual average potential evaporation		N/A	+6% (±3%)	+17% (±9%)
Annual average relative humidity		32%	-1.1% (±1.9%)	-3.4% (±5.7%)
Annual daily extreme wind-speed		N/A	+1.2% (±2.5%)	+3.8% (±7.5%)
Annual average no. of hot days (> 35°C)		89 days (Alice Springs)	+36 days	+102 days
Annual average no. of cold nights (<0°C)		16 days	-11 days	-16 days
CO_2 concentration		353ppm	+165ppm	+365ppm

A summary of the potential impacts of climate change on the values identified for the Park are described below. Implications of climate change on management are also discussed.

18 Uncertainty surrounding annual and seasonal rainfall projections in this region are high. Planning for these impacts will need to take into consideration that rainfall trends may increase or decrease.
19 % changes were not available for seasons with very low rainfall.

11.9 Summary of Climate Change Impacts

Increase in annual average temperatures

Annual average temperatures are projected to increase by an additional 5.1°C by 2070. This may result in the following impacts:

- In small desert birds such as those from the Honeyeater family, even modest temperature increases of 1-2°C have a significant impact on rates of water loss and this is predicted to greatly reduce survivorship (Wolf 2000). These conditions could potentially cause significant episodes of direct mortality in desert bird communities as was seen in Australian deserts in the last century (Serventy 1971); and
- Increased temperatures may be accompanied by more frequent severe droughts. This may exacerbate pressures on native fauna and flora from increased competition for resources from introduced pests such as rabbits and cats (CRES 2006).

Increase in CO_2 concentrations

Arid and semi-arid ecosystems are predicted to be one of the most responsive ecosystem types to elevated CO_2 and associated climate change (Smith *et al*. 2000; Lioubimtseva 2004). Primary production in arid areas is strongly limited by nitrogen and water resources. Rising CO_2 concentration acts to increase photosynthesis, plant biomass and plant water-use efficiency in many plant species. These impacts on water use efficiency in particular are generally considered to be likely to alleviate water limitations and thus enhance primary production (Smith *et al.* 2000). Results of Free Air CO2 Enrichment (FACE) experiments in arid zones in the United States indicate that semi-desert plants respond especially strongly to raised CO_2 during the occasional years when above average rainfall is received (Lioubimtseva 2004).

Differences among species in their responses to elevated CO_2 will affect competitive interactions and thus community structure and composition in the Park. Experimental manipulations in other arid systems have shown that invasive annual grasses may be relatively advantaged over native species, thus promoting increased invasion (Smith *et al.* 2000; Dukes 2002). Where these grasses increase fuel loads, an accelerated fire cycle may also be promoted (Smith *et al.* 2000). Of particular concern in this context is the perennial Buffel grass (*Cenchrus ciliaris*), which has been shown to be more responsive to elevated CO_2 than some other C4 grasses (Rudmann *et al.* 2001).

Enhanced CO_2 may also enhance the growth of woody shrubs, relative to grassy species, leading to changes in the structure of arid and semi-arid vegetation communities.

Increase in potential evaporation

Annual average temperature and potential evaporation are projected to increase; however, whilst estimates of annual average rainfall project no change in the amount of rainfall, there is a large degree of uncertainty surrounding these estimates i.e. in the order of ±45%. Should rainfall decrease or change in variability, further constraints on water resources may result in the following:

- Increased competition between species for water resources and declines in the population and robustness of flora and fauna species restricted to moist areas and waterholes at bases of monoliths, including rare and endangered plant species such as *Stylidium inaequipetalum* and *Parietaria debilis* and frogs such as the knife-footed frog *Cyclorana cultripes* and the water-holding frog *C. platycephalus*;
- Increased demands on the region's aquifer may also impact deleteriously on the habitat of a range of animals of conservation significance including the southern marsupial mole (*Notoryctes typhlops*), woma python (*Aspidites ramsayi*) and great desert skink (*Egernia kintorei*); and
- By 2070, increases in fire frequency and intensity and pressures on water resources are likely to place significant additional pressure on rare, endangered and vulnerable species and habitats. These potential pressures emphasise the importance of providing special protection for these species and habitats and may inhibit efforts to reintroduce species such as the mala (*Lagorchestes hirsutus*) and burrowing bettong (*Bettongia lesueur*).

Increase in the number of hot days (>35°C)

An increase in annual average temperatures and the incidence of the number of hot days (projected to reach 191 days a year by 2070, compared to a current annual average of 89 days) may affect visitor comfort and satisfaction and increase the incidence of heat stroke and heat stress for visitors and Park staff. An increase in the number of extreme temperature days will also result in more frequent closure of the Uluru climb and other areas of the Park.

Fire

Projected increases in temperature and evaporation rates with no change in rainfall will result in an increase in fuel dryness (Hughes 2003) but may be expected to also reduce plant growth and therefore lower fuel loads. However, fuel loads may actually increase, if the distribution of the introduced Buffel grass (*Cenchrus ciliaris*) increases with The Park.

Buffel grass has been shown to be more responsive to elevated CO_2 than some other C4 grasses (Rudmann *et al.* 2001). Grasses such as this are "fire-weeds" which can change fire regimes via a 'grass-fire cycle' (D'Antonio and Vitousek 1992; Brooks *et al.* 2004). Introduced grasses often grow taller and thicker than the native grasses they replace, not only producing further fuel for fires, but often more interconnected fuel. They kill competing native plants and replace them. Similar grass-fire cycles of invasion have been documented in Hawaii, North America, Central and South America, and Australia (Rossiter *et al.* 2003).

These factors may result in increased fire frequency and intensity, which could reduce vegetation cover and may disturb important habitat (including mulga and spinifex landscapes) for mulgara and other marsupial populations, reptiles and native birds.

More frequent or intense fires may also result in restrictions on visitor access to ensure visitor safety.

Opportunistic pest species such as rabbits may be placed at a competitive advantage as a result of more frequent and intense fires. This will have flow on effects through increasing grazing pressure on native vegetation and soil disturbance.

Climate change may have some affect on the morphology of the region including accelerated weathering through increased temperatures and wind speed; however, this is a natural and ongoing process and the integrity of the monoliths and the scenic amenity of the Park are unlikely to be significantly reduced by climate change in the near to medium future i.e. to 2070.

The cultural significance of the site to the Anangu is unlikely to be affected by climate change; however, cultural practices and beliefs that are intimately associated with the Park's ecosystem may be affected by fire and increased evaporative demand (CRES 2006). In the short term, action by residents and visitors are more likely to negatively affect carvings, paintings and archaeological artefacts than climate change (CRES 2006).

Indirect impacts of climate change

Climate change may considerably alter the population distribution of Australia over the longer term (by 2070). Under scenarios where Northern Australia obtains significantly greater rainfall than South-eastern Australia it is possible that population growth will significantly increase in Northern Australia. This process may occur both through the demand for agricultural lands and through the redistribution of urban population growth into Northern Australia. Under this scenario increased domestic tourism demand could be anticipated for Uluru Kata-Tjuta (pers comm. T Charters, 2006).

Additionally there are global pressures which may have a strong bearing on the future scenarios related to Park visitation. These include the impacts of carbon taxes or equivalent on long haul aviation travel. This impact may result in Australia seeking out high end markets which will be largely unaffected by increased prices for long haul travel. Additionally travellers may spend a longer period at a destination given the increased proportion of travel costs that will be invested into the long haul flight. Domestic tourism numbers may also grow through a combination of an aging population (a significant factor over the next 20 years) and increased costs to travel outbound due to carbon related costs or taxes (pers comm. T Charters 2006).

11.10 Principal Management Implications

Managing to increase resilience of values

In comparison to most of mainland Australia, the Northern Territory in general is relatively undisturbed. If we consider a gradient from north to south there is an absence of either natural of human barriers that would inhibit migration and spatial reorganisation of the flora and fauna (i.e. the habitat is fairly continuous). A regional approach to minimising the effects of intense fire, introduced fauna and weeds including existing infestations must remain a management priority.

Existing management approaches with regards to rehabilitation plans, documentation of species and management strategies may not be appropriate under worst case climate change scenarios. Species restricted to particular refugia such as pockets of vegetation or run-on areas around the base of the monoliths will be particularly vulnerable to climate change. Consideration must also be given to species most at risk from subsequent invasion by weeds and pests.

Fire management strategies employed at the Park may also need to be reviewed to be appropriate under increased temperature conditions, including an increase in the number of hot days and subsequent fires in and outside Park boundaries. Reid *et al* 1993 provided 5 rules for the use of fire in the management of fauna at Uluru, it is considered that these still hold true under climate change conditions i.e.:

- The majority of standing mulga and much of the regenerating 1976 mulga be protected from fire;
- The majority of 1976 aged spinifex be protected from fire at least until surveys to search for rare species are concluded;
- Mallee-spinifex areas be protected from fire until they have been surveyed for rare species;
- Surveys of these habitats be carried out to assess and map their habitat quality for wildlife, and that recommendations arising from the research be formally written into the fire management strategy; and
- Notwithstanding the above points, the patch-burn strategy be vigorously pursued to promote landscape and faunal diversity.

As a consequence of climate change and biota response, the role of indigenous people in land management and conservation may need to be reviewed. Increased pressures and declines in populations of some flora and fauna may restrict traditional fire management practices and the maintenance of traditional hunting and gathering activities. Visitor access to cultural sites of significance may also need to be reviewed to build resilience of these values to climate change.

Increasing decision-making capacity by improving understanding

Currently there are several gaps in knowledge that may prevent Park management to adequately answering questions regarding resilience, climate change scenarios and sustainable use of the Park. Increasing understanding in these areas will in effect increase decision making capacity of Park managers. Gaps in knowledge include:

- The link between the duneplain aquifer and traditional sandplain environment. This may contribute to understanding the vulnerability of species restricted to waterholes and aquifer-dependent habitats. Future demands on the aquifer based on climate change scenarios, which may have implications for accommodating tourist numbers, are also unknown;
- The implications of climate change on life cycle events of specific species, including for example the interaction between the timing of invertebrate distribution and abundance and migratory birds;
- The extent to which the geographic ranges of both native and introduced species will shift in response to changed climatic conditions. It is likely that some species will disappear from the Park while others will colonise and establish as part of an adaptive response to climate change. In the case of exotic species, existing management strategies may be further enforced. In the case of "invading" native species, new management strategies that take a more bioregional approach to conservation, rather than one limited to considering only lands within the existing Park boundaries, may need to be considered;
- The potential impacts of climate change on cultural practice and cultural values. This includes waterhole management which was previously carried out by the Anangu (pers comm. M. Jambrecina 2007); and
- The implications of climate change on visitor numbers to the Park and the impacts of climate change on visitor experiences. The applicability of responses and approaches may be identified through a comparative analysis of similar ecological systems elsewhere in the world which support a strong tourism industry.

Maintaining infrastructure and protocols to ensure visitor safety

Whilst climate change is unlikely to tangibly affect the "exceptional natural beauty" of Uluru-Kata Tjuta, increased temperatures and fire frequency may affect recreational uses and visitor enjoyment of the Park's natural and cultural resources through increased incidence of closure of walking trails and climbs and decreased visitor comfort in extreme temperatures.

Climate change will also place further pressures on Park resources through requirements to replace and upgrade visitor infrastructure in response to shading needs, damage from fires and additional funding for emergency operations. Climate change impacts may also significantly alter the seasonal variability of visitor numbers resulting in more visitors at certain times of the year.

Current management practices may not be sufficient to ensure visitor safety and comfort. Increased temperatures and the significant increase in the number of very hot days may require management innovation to maintain visitor interest and satisfaction. Under a ‘business as usual’ model the region may become less attractive to visitors.

Management responses that can ameliorate the negative impacts of climate change include:

- In summer, the development of activities utilising the cooler parts of the day (pre-dawn and dawn and sunset and evening experiences);
- In winter, scheduling activities that commence earlier than current activities (walks, rides etc);
- Provision of more shade structures, water points and shorter walking tracks/activities,
- Provision of greater educational material that enables guests to pre-plan for their visit and to arrive with appropriate clothing and equipment for the activity they intend to pursue; and
- Use of personal transport with integrated shade structures and water storage (e.g. Segway® Personal Transporter off-road variety). Such vehicles may be used for guided walks utilising formed and hardened tracks.

(Source: pers comm. T. Charters 2006).

12 Australian National Botanic Gardens

12.1 Bioregional Setting

The Australian National Botanic Gardens (hereafter referred to as the Gardens) is located in Canberra, ACT and is a major scientific, recreational and educational resource. It was one of the first botanic gardens in the world to adopt the study and display of native Australian species as one of its major goals. The Gardens occupy an 85 hectare site on the lower slopes of Black Mountain in Canberra.

The Gardens have been recognised internationally for their role in encouraging the study, conservation and use of Australian plants. They have made a significant contribution to the natural biodiversity objectives of Australian Government environmental portfolios and also contribute to the public's learning, understanding and appreciation of Australian native plants and biodiversity. The Gardens also display the beauty and diversity of Australian native flora, for public enjoyment and education.

12.2 Management Arrangements

The Gardens were proclaimed as a reserve by proclamations on 17 September 1991 under the *National Parks and Wildlife Conservation (NPWC) Act 1975.* They cover an area of approximately 85 hectares and have both natural and cultivated portions. The developed sections of the Gardens make up 40 of the 90 hectares and have been identified as an outstanding example of landscape design and horticulture using Australian plants (DEW 2001).

The *NPWC Act* was replaced by the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*) and, the Gardens continue to be managed by the Australian Government. They were declared for the purposes of increasing knowledge and appreciation for Australia's plant heritage, a collection of living and herbarium specimens of Australian plants, and for other related plant study, conservation and display (DEW 2001).

The scientific framework of the Gardens is provided through the Australian National Herbarium, a facility jointly managed with CSIRO Plant Industry as part of the Centre for Plant Biodiversity Research (CPBR) on the CSIRO Black Mountain campus on the northern boundary of the Gardens (pers comm. J Croft 2007).

The Gardens supports Australia's obligations under a range of conventions including:

- Convention on Climate Change by promoting education, training and public awareness on the importance of sustaining plant biodiversity;

- World Heritage Convention, mainly by supporting the network of listed sites through research, plant collections, horticultural and educational programs;
- Ramsar Convention, particularly in relation to cultivation and conservation of rare and endangered aquatic plants; and;
- Convention on International Trade in Endangered Species (CITES), particularly in relation to codes of practice on plant trade.

The Gardens are also included on the Commonwealth Heritage List (under the EPBC Act), recognised for their importance for cultivating rare and endangered native plant species and as a centre for research and teaching. (DEW 2001)

12.3 Climate

The Gardens experience a relatively dry, continental climate with warm to hot summers and cool to cold winters with mild to severe frosts; snow is uncommon. The Canberra climate is strongly influenced by a band of high pressure systems located around the globe at about 30-40S, known as the sub-tropical ridge. During the summer, the sub tropical ridge is located over southern Australia resulting in warm to hot conditions with winds generally from the east through to the northwest. During winter, cold fronts extend over southern Australia bringing colder conditions, as a result of the ridge migrating north (Bureau of Meteorology 2007a).

The average annual rainfall is just over 630 mm distributed more or less throughout the year (c. 103 rainy days), with a tendency for more rain in spring and autumn; the mean evaporation rate is 3.8 mm per day (Bureau of Meteorology 2007b). The pattern is very erratic and long periods without usable rainfall are not uncommon. The low annual rainfall and extremes of climate and poor Black Mountain soils provide significant horticultural challenges for management of the Gardens (pers comm. J Croft 2007).

12.4 Values of the Gardens

Natural values

Natural values of the Gardens include:

- The world's largest living collection of Australian native plants including about one third of the known flowering plant species that occur in Australia and half the known eucalypt trees. The living collection has been developed to encourage public enjoyment and appreciation for native flora and has particular conservation significance to rare or at-risk flora species. The collection contains a vast range of plants from several biogeographical regions, such as alpine to tropical and coastal to central;
- The Herbarium houses a collection of dried or preserved plant specimens with an associated scientific database. The Herbarium consists of around 1,265 000 specimens, of which 90% are directly related to the study of Australian plants. The herbarium provides a

means of scientific authentication and a means of ensuring that the public are provided with the correct names of plants in the collection;

- The Australian Plant Image Index – an ancillary collection, in some ways parallel to the Herbarium and adding to aggregate knowledge of Australian plants (APII 2007);
- The link between the collections and database is the foundation of the value of the ANBG (pers comm. J Croft 2007). The identity of every living plant in the living collection is provided by a scientific voucher specimen in the herbarium, linked by the data database; and
- Nursery - most of the plants are grown in beds open to the environment; however, some plants that are sensitive to the cold are grown in research glasshouses and pots. A production nursery complex is one of the features of the Gardens. The nursery produces around 15,000 plants per year and is used for the study of Australian plants and to add to the Gardens horticultural displays, as well as other Australian botanic gardens.

Scientific values

The Gardens are important for conservation, research, training, plant identification and monitoring. They are a repository of genetic material and aid in the conservation and use of Australian native plants. The collections are used by a range of national and international scientists for research into Australian botany and taxonomy. The Gardens also contain a horticultural research laboratory, horticultural maintenance depots and a botanical library contributing further to the Gardens' scientific importance.

The Gardens are a leader in the development of botanical data standards, the storage and exchange of botanical information and act as a custodian for a number of botanical datasets (DEW 2001). Some activities have been initiated since the Plan of management was approved. Significant among these are contribution to the Australian Biodiversity Information Facility (ABIF) and the *Atlas of Living Australia* as a focus for the Gardens botanical information management (pers comm. J Croft 2007).

The genetically linked Living Collection and scientific Herbarium Collection are of significant scientific value, and considered to be fairly unique globally (pers comm. M Fagg 2007).

The Gardens work in co-operation with the CSIRO, Australian Government departments, State and territory agencies and other bodies to collaborate research into botany and horticultural activities, contributing to the knowledge and skills of the specialists working in the Gardens.

Recreational and visitation values

Over 487,000 people including local, interstate and international visitors visited the Gardens in 2006 (ANBG 2007). Cultural activities include concerts, theatres, dance performances, art work displays and the celebration of cultural events in co-operation with the Ngunnawal people.

A range of guided tours and visitor facilities are provided including facilities for weddings, workshops, meetings and other social functions.

12.5 Pressures on the Gardens' Values

Pressures on the Gardens' values include:

- Natural incursion or accidental introduction of insect pest species and noxious weeds;
- The living collections can be affected by diseases and soil fungi. *Armillaria lutebubalina* is a naturally occurring soil pathogen and is responsible for the death of trees in the Gardens. Another water-borne fungus *Phytophthora cinnamomi,* has also been identified in the Gardens;
- Vertebrate pests include rabbits, rats, cats, foxes, feral cats, blackbirds, native mammals such as the Eastern grey kangaroo *(Macropus giganteus*) and the Australian wood duck (*Chenonetta jubata).* Pressures include grazing and trampling, the spread of weeds and diseases, fouling and competition with native wildlife for resources and space;
- Increasingly hot and dry conditions have increased the occurrence of fire, which threatens natural values and infrastructure;
- Water resource management continues to be a major challenge for the Gardens. This is due not only to the continuing drought and associated water use restrictions, but also the sharp increase in the unit price of water in Canberra. Water is lost from the Gardens through runoff, evaporation in the summer and leakages from irrigation pipes; and
- The Gardens are periodically subject to high winds, periodic hail and storm damage. Loss of trees and large branches is not uncommon (pers comm. J Croft). Periodic closure of the Gardens can occur when conditions are thought to threaten visitor safety.

12.6 Current Management Approaches

Management activities in the Gardens are aimed at achieving a range of strategic objectives as follows:

- Growing Australian plants;
- Study of Australian plants;
- Promotion of Australian plants;
- Conservation of Australian plants;
- Site environmental management;
- Site development;
- Administration and management; and
- Evaluation and monitoring.

Management focus includes maintaining comprehensive information on the status of the living collections for public information and facilitating curation and research. This currently includes management of threatening processes such as pests, disease, weeds and fire.

Pest and disease management is important to maintain the health of the collection so that virus-free seeds can be propagated. The orchid collection is particularly susceptible to viruses, thus the Gardens' Orchid Research Group is currently developing techniques to produce virus-free plants from seed. The water-borne fungus *Phytophthora cinnamomi* is currently being monitored to minimise infections in the collection.

A vegetation buffer zone around the Gardens has been developed to assist with fire management. The buffer zone consists of native shrubs and several eucalypt species such as *Eucalyptus mannifera, E. rossii, E. macrorhyncha.* Firebreaks are also maintained along the western and southern boundaries of the Gardens. A dedicated high volume sprinkler system has been installed along the Black Mountain perimeter to help prevent the incursion of fire to the site and fire fighting services are provided by the ACT fire authorities (pers comm. J Croft 2007).

The management of water supplies is a key activity at the Gardens. Water is supplied from the ACT water supply via an extensive electronic computer controlled irrigation system. Water supplies from other sources such as Lake Burley Griffith or groundwater bores have been investigated but would not be able to meet the full amount for required horticultural use (DEW 2001). An updated water management strategy is currently being developed to determine realistic options for sustainable future supply. Possibilities include Lake water, bore water, recycled water, and treated effluent (pers comm. J Croft 2007).

Management strategies are in place to ensure visitor safety during extreme weather events. The Gardens has a program of identifying and removing dangerous trees and branches in areas of high visitor use. During storm events the Gardens are closed to ensure visitor safety (pers comm. J Croft 2007).

Management strategies are also in place to retain healthy remnant and regenerating native vegetation on the Gardens site for conservation and wildlife habitat and as a buffer between the developed Gardens and the surrounding Canberra Nature Park.

12.7 Climate Change Scenarios

The high range global warming scenarios for the NSW region are pertinent to the Gardens and are presented in Table 12-1. Uncertainty surrounding the scenarios is shown in brackets.

Table 12-1: Climate change scenarios for NSW (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor		Current (1975-2004)	2030 scenarios	2070 scenarios
Annual average temperature		Max 24.4°C, min 11.1°C	+1.3°C (±0.6°C)	+4.0°C (±1.7°C)
Annual average rainfall[20]		553mm	+4% (±11%)	+11% (±34%)
Seasonal average rainfall	Summer	168mm	+4% (±19%)	+11% (±57%)
	Autumn	139mm	+4% (±19%)	+11% (±57%)
	Winter	114mm	-7% (±15%)	-23% (±45%)
	Spring	132mm	-7% (±15%)	-23% (±45%)
Annual daily extreme rainfall[21]		N/A	0% (±10%)	+10% (±5%)
Annual average potential solar radiation		N/A	-0.6% (±1.9%)	-1.9% (±5.7%)
Annual average potential evaporation		N/A	+6% (±4%)	+17% (±13%)
Annual average no. of hot days (>35°C)		5 days	+7 days	+30 days
Annual average no. of cold nights (<0°C)		62 days	-21 days	-52 days
Annual average no. very high/extreme forest fire danger days		23 days	+5 days	+15 days
CO_2 concentration		353ppm	+165ppm	+365ppm

A summary of the potential impacts of climate change on the values identified for the Gardens are described below. Implications of climate change on management of the Gardens are also discussed.

20 Uncertainty surrounding annual and seasonal rainfall projections in this region is high. Planning for these impacts will need to take into consideration the possibility that rainfall may increase or decrease.

21 1-in-40 year intensity, based on 2 climate models (Hennessy *et al*. 2004)

12.8 Summary of Potential Climate Change Impacts

The natural and scientific values of the Gardens are largely actively managed and therefore human intervention may prevent a number of negative affects occurring. However, in the living collection, the ability for human intervention is limited. A summary of the potential impacts on the Gardens is provided below.

Increased temperatures and atmospheric CO_2 concentrations

An increase in temperatures and concentration of CO_2 may result in increased plant growth rates for some species in the living collection; however this may also favour weed species.

Increase in the number of hot days (>35°C)

An increase in the number of hot days and the number of extreme temperature days may result in heat stress in plants in the living collection. Further constraints to water resources may also result. Plants under heat and water stress (which will be further exacerbated through an increase in potential evaporation) will be more susceptible to weed invasion. Plant mortality is also anticipated where there are extreme temperature days in succession.

An increase in annual average temperatures and the number of days over 35°C will also increase the fuel load surrounding the Gardens and increase the susceptibility of Black Mountain to fire and therefore also increase the risk to the Gardens.

An increase in annual average temperatures and the incidence of the number of hot days may also affect visitor comfort and satisfaction.

Reduction in the number of cold nights (<0°C)

Less cold nights will result in a reduction in frost damage to plants in the living collection; however this may also result in higher survival rate for some soil pathogens and plant diseases (pers comm. J.Croft).

Change in rainfall patterns

Whilst a small increase in annual, summer and autumn average rainfall is projected, there is a large degree of uncertainty surrounding these figures i.e. in the order of ±34% for annual average rainfall and ±57% for summer and autumn and ±45% for winter and spring rainfall.

Any decline in water availability, or prolonged drought conditions will place further constraints on water availability in the Gardens. Prolonged drought may also result in an increase in grazing and trampling pressure from native animals entering the Gardens for food and water.

Changes to seasonal rainfall may have negative affects on species dependant on seasonal rainfall. The range of effects however will depend on the capacity of management to intervene and artificially water these areas where required. These changes to rainfall patterns may also favour the spread of invasive weeds through the Gardens.

An increase in extreme rainfall may lead to damage to the living collection through soil erosion, direct plant damage, chemical runoff and increased vulnerability to pests and pathogens. Any potential increase in high winds or storm events will also result in an increase in tree and branch damage and potential closure of the Gardens to visitors to ensure their safety.

12.9 Principal Management Implications

Managing to increase resilience of values

Fundamentally, the Australian continent is faced with the increased pressure and risk of extinction of flora species as a direct consequence of changes and rates of change in climatic conditions. The Gardens are ideally placed to respond to this challenge and to provide national leadership in the preservation of native flora. This would build upon early initiatives such as the Centre for Plant Biodiversity Research which was established during the 1990s through a joint venture involving CSIRO Plant Industry, the Director of National Parks and national initiatives such as the *Australian Virtual Herbarium and Atlas of Living Australia projects*. The Australian National Herbarium is likely to play a key role in these efforts.

The role of *ex situ* botanic gardens collections will become increasingly important as reserves of genetic material as climate change impacts on natural populations of plant species (pers comm, J Croft 2007). As a result, there may be increased pressure on space in the Gardens for plant conservation and preservation.

A reduction in the number of cold nights i.e. below zero degrees may reduce the demand for poly-houses for some frost sensitive species. In addition, there may be some opportunity to expand the range of species that are able to be grown outdoors in the Canberra climate.

Climate change may exacerbate existing pressures on the values of the Gardens, requiring a review of existing management strategies including:

- Changes in rainfall patterns may mean that fertiliser application regimes in the Gardens are no longer appropriate;
- A decline in water availability within the Gardens may mean restrictions on water use within the Gardens. A decline in water availability in general may also mean that the cost of water rises and therefore the cost of maintaining the Gardens increases prohibitively. It is likely that flexibility to utilise a range of options will become essential over time (pers comm, J. Croft 2007). Discussions about the type of species (and their individual water requirements) that should be grown in the Gardens in the long term may also be required;
- Fire management strategies in light of increased fire risk, restrictions of prescribed burning opportunities and potential constraints on water availability; and
- Strategies to control and minimise weeds and pests may no longer be appropriate. Under climate stressed conditions a number of

factors will combine resulting in further risk of pest and weed infestations including:

- southerly expansion of species range;
- changes in seasonal rainfall;
- heat and water stress, increasing plant vulnerability to pests; and
- increased growth through increased photosynthetic activity resulting in lower nutritional value and greater pest activity.

The Gardens currently play a significant role in education and awareness of native flora. This role is likely to become increasingly significant in contributing to building awareness about climate change.

Increasing decision-making capacity by improving understanding

There are several gaps in knowledge that may prevent management from adequately answering questions regarding resilience, climate change impacts and sustainable use of the Gardens. Gaps in knowledge include:

- The role the Gardens will be expected to play in the national effort to preserve and conserve native flora i.e. how many additional species may need to be managed within the Gardens. Water and land constraints may reduce the capacity of the Gardens to contribute to national efforts. In this instance a bioregional prioritisation process may be required;
- The role the Gardens may play in co-ordinating national effort in identifying the necessary funds to support an innovative co-ordinated national approach to the *ex situ* conservation of species and their genetic material;
- A detailed analysis of the effects of climate change on the biology of the species within the Gardens;
- The role of knowledge and experience gained at Gardens in propagation, horticulture and management of Australian native plants, for the Gardens and for use more broadly in ex situ conservation, translocation and reintroduction of plants at risk (pers comm. J Croft, M Fagg 2007); and
- The requirement and capacity for land acquisition to accommodate additional species (regional or national) that may be threatened by climate change.

Maintaining infrastructure and protocols to ensure visitor safety and enjoyment

An increase in temperature and extreme temperature days may result in increased fire risk and narrow and declining opportunities for prescribed (hazard reduction) burning. The ability to protect the collection from fire damage may therefore be impeded. In addition, an increase in the use of fire management systems such as sprinklers will place further constraints on water resources within the Gardens.

The Gardens' growing role as a tourist attraction will remain a key focus for management; however, changing climatic conditions such as increased temperatures, increased fire risk and increased intensity of storm events may require additional expenditure on maintenance of public facilities including shading, seating and first aid facilities.

13 Booderee Botanic Gardens

13.1 Bioregional Setting

Booderee Botanic Gardens (hereafter referred to as the Gardens) are located within the Booderee National Park on the southern peninsula of Jervis Bay.

The Gardens are unique in being owned by an Aboriginal community (Wreck Bay Aboriginal Community) and being within a National Park. The Gardens contain a significant collection of plants collected over the last fifty years and are unique in its presentation of regional Koori plant utilisation, i.e. plants used historically and currently by Aboriginal (Koori) communities in the region.

The Gardens provide a more intensively managed landscape and recreational opportunities generally complementary to those in the rest of the Park. The features of the Gardens are diverse and provide numerous opportunities for education and interpretation. As with botanic gardens elsewhere, the major focus is the interpretation of Australia's flora, covering plant relationships, adaptations, specialisations, conservation needs, value as habitat as well as use in landscaping and methods of cultivation (Commonwealth of Australia 2002).

The Gardens offer a range of interpretive services, aimed at the general visitor, school or holiday groups and specialist groups such as bird-watching or plant interest groups, or those interested in traditional Aboriginal use of local plants.

13.2 Management Arrangements

In 1951 the Jervis Bay Botanic Gardens was declared as a frost free annex of the Australian National Botanic Gardens (ANBG). From the 1980s, development was on the basis of in-fill rather than expansion further into the bushland. There was also increasing recognition that the bushland area was an important component of the Gardens' collection, as it represents the regional flora, contributes to the landscape setting of the developed areas, and provides a transition from the developed areas to the naturally occurring vegetation of the Park. Large patches of naturally occurring vegetation remain between much of the planted area of the Gardens and the surrounding area. The bushland area acts as an important buffer between the planted areas and the rest of the National Park, inhibiting the spread of non-local species and providing wildlife habitat (Commonwealth of Australia 2002).

The Gardens are listed under the Register of the National Estate as an important example of mid-twentieth century botanic gardens established to display native plants. They are assigned to IUCN protected area category IV: 'habitat / species management.

13.3 Climate

Being coastal, temperature extremes are rare at Jervis Bay. Maximum temperatures range from an average of 24ºC in February to 16ºC in July, while average minimum temperatures range from 18ºC to 9.5ºC respectively (Commonwealth of Australia 2002).

13.4 Values of the Gardens

Natural values

The Gardens contain a diversity of environments and facilities within a compact area. There are two main components to the Gardens: the planted living collection and the surrounding areas of natural vegetation. The following points provide a summary of the key natural values presented within the Gardens:

- Open ground plantings of some 1600 taxa representing regional flora (south east coastal Australia east of the Great Dividing Range);
- Representatives of species listed as endangered or vulnerable under the *EPBC Act*. One species (*Syzygium paniculatum*) occurs naturally on the site while others have been introduced into the living collection for display or conservation purposes;
- Taxonomic, horticultural (including cultivars) and ecological and geographic displays. The latter displays plant species from similar environments or from the same geographic areas. The rainforest section is the main ecological theme;
- Conservation programmes - propagation and cultivation of threatened species to provide a source of plants for reintroduction into their natural habitats. A secure ex situ population also provides insurance against total extinction of the species in the event that its wild populations becoming extinct. The rainforest area contains some threatened species from the region, including *Syzygium paniculatum*;
- The Gardens nursery is an essential component of the management of the living collection, for propagating plants for planting out in the Gardens, but it has a valuable additional function producing plants for use in the Park and elsewhere in the local region for vegetation restoration and rehabilitation;
- Lake McKenzie is described as a perched lake or a dune barrage lake and could be described as a centrepiece of the Gardens. Lake water is used to irrigate the living collection and is a major landscape feature. It is regularly used by tertiary institutions for ecological and hydrological studies; and
- The diversity and accessibility of the wildlife is a major asset of the Gardens. The natural area provides an extension of the wildlife habitat of the National Park including many local trees remaining in the developed part of the Gardens. In this area, old trees with hollows are retained for wildlife.

The natural vegetation of the Gardens can be divided into three main vegetation communities:

- Heathland community - predominantly shrub vegetation dominated by *Hakea teretifolia*, *Banksia ericifolia* and *Casuarina distyla* with a diversity of other shrub, sedge and ground cover plants;
- Woodland - the dominant trees in this vegetation type are bloodwoods (*Eucalyptus gummifera*), white scribbly gums (E. *sclerophylla*) and *Banksia serrata*. The shrub vegetation includes a number of other heath species. This vegetation type occurs on infertile and drier soils of the Gardens; and
- Open forest - the main tree species are blackbutt (*Eucalyptus pilularis*) and Sydney Peppermint (*Eucalyptus piperita*) with an understorey of *Acacia longifolia* and *A. suaveolens*. A number of smaller shrubs and ground covering ferns are also present. Other species present include turpentine (*Syncarpia glomulifera*), pigeon berry (*Monotoca elliptica*), Christmas bush (*Ceratopetalum gummiferum*) and she-oak (*Allocasuarina littoralis*). This vegetation type occurs in areas where the soil is deeper and slightly more fertile.

Cultural and visitational values

- Interpretative programmes based on human uses of plants are present in the Park and are educationally and culturally valuable.
- As Booderee is the first major botanic gardens in Australia to be owned by an indigenous community, there is great potential to demonstrate traditional and current links with the native flora; and
- The Gardens offer a range of visitor information and interpretive services aimed at different audiences. Methods of information dissemination range from information boards, brochures and ranger guided walks.

Scientific values

- The Gardens are important for conservation, research, training, plant identification and monitoring. The Gardens are a repository of genetic material and aid in the conservation and use of Australian native plants. The collections are used by a range of national and international scientists for research into Australian botany and taxonomy;
- The Gardens have a close relationship with ANBG in Canberra and the collections form part of the national collection of Australian flora;
- The Gardens have significant potential scientific value. The Gardens have been used for scientific research although this has been done on a largely *ad hoc* basis. There is scope for more scientific research to occur in the Gardens (Commonwealth of Australia 2002);
- The Gardens herbarium is being developed to represent the flora of the region and other groups of plants under study or growing in the Gardens. It is presented as a reference set of selected duplicates of vouchered specimens held at the Australian National Herbarium in

Canberra. Access to the Herbarium is available for research purposes and to the visiting public; and

- The Herbarium is an essential component of the scientific functioning and use of the Gardens. Links with other botanic gardens, especially the ANBG and the regional gardens at Wollongong and Eurobodalla, are also vital to maintaining the scientific value of the Gardens. The relationship between the ANBG and the Gardens changed significantly with the transfer of ownership to the Wreck Bay Aboriginal Community and the incorporation of the Gardens in the Park. In order to ensure the continuation of effective working relationships, an agreement between the two Gardens was made in 1997, while the Gardens were still part of the ANBG.

13.5 Pressures on the Gardens' Values

The current potential pressures on the values of Gardens are invasion by pest animals and weeds, fires and inappropriate fire regimes and pressures on fresh water availability and quality. These pressures are described below:

- The term 'pest' refers to introduced animals as well as to native animals that can damage the Gardens, largely due to the high numbers generated by the conditions in the Gardens. By virtue of their relative isolation, surrounded by natural bushland, the Gardens do not suffer from the same levels of pest damage found in Gardens located in more modified regions;
- Some species of native animals thrive in the modified landscape, and can damage young plants. Grazing and trampling by kangaroos and wallabies can prevent the establishment of some plants, and high numbers of these animals can become a nuisance. Other grazers include some native duck species as well as rabbits, possums and bandicoots. Non-native rats can be a problem, particularly in the herbarium and nursery areas. Kangaroo damage has diminished since the erection of the perimeter fence and the protection of young susceptible plants with mesh cages;
- Invertebrate pests are not a major concern at the Gardens, possibly as a result of their relative isolation providing a quarantine effect, the high numbers of resident birds and the selective removal of susceptible plants;
- Weed species of the Gardens include bitou bush (*Chrysanthemoides monilifera*), bladey grass (*Imperata cylindrica*), wandering jew (*Tradescantia albiflora*) and hydrocotle. Some introduced weeds date from early settlement days. Some non-local native plants such as kangaroo paw (*Anigozanthus* sp) and *Cordyline stricta* have become serious environmental weeds, and occur outside the planted area;
- Exclusion of fires has been the prevailing policy in fire management of the Gardens. To this end, a fire break is maintained around the perimeter fence and fire hydrants have been installed in some vulnerable areas. While essential to protect the developed

Gardens, it may not be ideal for the naturally occurring vegetation, particularly the heath community. Some prescriptive burning to encourage community diversity has been undertaken, with good results; and

- Water from Lake McKenzie is used to irrigate the living collection with the Gardens. Most of the developed areas of the Gardens are within the catchment of the lake. A series of wet gullies direct surface runoff to the lake exposing it to potential pollution from chemicals and fertilisers used in the Gardens. Water is lost from the lake through evaporation, seepage and pumping for irrigation in the Gardens.

13.6 Current Management Approaches

Management activities for the Gardens are structured as follows:

- Living collection and natural vegetation management: aimed at maintaining a living collection representative of regional plants and their use by aboriginal people. This includes the support of recovery programmes to retain natural vegetation and plant communities for conservation, education and wildlife habitat purposes;
- Nursery management: to ensure that nursery facilities fully support the gardens activities;
- Management of Lake McKenzie: to ensure that the lake continues to be a viable freshwater ecosystem and water supply;
- Weed management in the gardens: to identify and control weed species in the gardens and to minimise the introduction of weeds into the gardens and their potential dispersion to the Booderee National Park. Weeds are controlled using mulching, hand removal and chemical treatment where necessary although this is kept to a minimum to reduce the risk of adverse affects on the complex ecosystems of Lake McKenzie and, in the north-west corner of the Gardens, of Lake Windermere;
- Pest and pathogen management; to focus on protection of the living and herbarium collections. Attention to watering regimes has been the main method used to minimise the outbreak and movement of soil-based pathogens including *Armillaria luteobubalina*, which has been identified in a section of the Gardens;
- Herbarium management: to ensure that the collection is a reliable reference set of local and regional flora as a subset of that held at ANBG and to present the collection in a form suitable for public examination. Another management focus is to ensure protection of the collection from fire, pest and pathogen damage; and
- Management of information, education and interpretive facilities: to ensure the spread of knowledge and facilitate public enjoyment of the facilities and to inform and educate users of the traditional aboriginal owners of the land. Management is also focused on developing commercial opportunities for Wreck Bay people in the day to day running of the Gardens.

13.7 Climate Change Scenarios

The high range global warming scenarios for the NSW region are pertinent to the Gardens and are presented in Table 13-1. Uncertainty surrounding the scenarios is shown in brackets.

Table 13-1: Climate change scenarios for NSW (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor		Current (1975-2004)	2030 scenarios	2070 scenarios
Annual average temperature		Max 24.4°C, min 11.1°C	+1.3°C (±0.6°C)	+4.0°C (±1.7°C)
Annual average rainfall[22]		553mm	+4% (±11%)	+11% (±34%)
Seasonal average rainfall	Summer	168mm	+4% (±19%)	+11% (±57%)
	Autumn	139mm	+4% (±19%)	+11% (±57%)
	Winter	114mm	-7% (±15%)	-23% (±45%)
	Spring	132mm	-7% (±15%)	-23% (±45%)
Annual average potential solar radiation		N/A	-0.6% (±1.9%)	-1.9% (±5.7%)
Annual average potential evaporation		N/A	+6% (±4%)	+17% (±13%)
Average no. of hot days (> 35°C)		3 days (Sydney)	+3 days	+15 days
Average no. of cold nights (<0°C)		62 days (Canberra)	- 5 to -21 days	-11 to -52 days
No. very high/extreme forest fire danger days		23 days (Canberra)	+ 3 to +5 days (Canb)	+5 to +15 days (Canb)
CO_2 concentration		353ppm	+165ppm	+365ppm

A summary of the potential impacts of climate change on the values identified for the Gardens are described below. Implications of climate change on management of the Gardens are also discussed.

22 Uncertainty surrounding annual and seasonal rainfall projections in this region is high. Planning for these impacts will need to take into consideration the possibility that rainfall may increase or decrease.

13.8 Summary of Potential Climate Change Impacts

The natural and scientific values of the Gardens are largely actively managed and therefore human intervention may prevent a number of negative affects occurring. However, in the natural vegetation areas, irrigation does not take place. A summary of the potential impacts on the Gardens is provided below.

Increase in temperature and atmospheric CO_2

An increase in the number of hot days and the number of extreme temperature days may result in heat stress in plants in the living collection. Further constraints to water resources may also result. Plants under heat and water stress (which will be further exacerbated through an increase in potential evaporation) will be more susceptible to weed invasion. Plant mortality is also anticipated where there are extreme temperature days in succession.

Increases in CO_2 supply may also encourage thickening of vegetation in eucalypt woodlands (Hughes 2003). In contrast the present temperature range of 25% of Australian *Eucalyptus* trees is less than 1°C in mean annual temperatures.

An increase in annual average temperatures and the number of days over 35°C will also increase the fuel load surrounding the Gardens and may increase fire risk to the Gardens (despite fire exclusion activities including maintenance of a fire break around the perimeter fence and fire hydrants installed in vulnerable areas).

An increase in annual average temperatures and the incidence of the number of hot days may also affect visitor comfort and satisfaction including closure of the Gardens on extreme fire danger days.

Change in rainfall patterns

Whilst a small increase in annual, summer and autumn average rainfall is projected, there is a large degree of uncertainty surrounding these figures i.e. in the order of ±34% for annual average rainfall and ±57% for summer and autumn and ±45% for winter and spring rainfall.

Any decline in water availability, or prolonged drought conditions will place further constraints on water availability in the Gardens and may increase pressure on Lake McKenzie (excerbated by increases in potential evaporation). Increased temperatures for the region may result in greater demand for water for irrigation of the living collection. Potential soil loss increases greatly when ground cover falls below about 70% (Pittock 2003), therefore any increase in intensity and frequency of fire within the catchment, coupled with more intense rainfall events (e.g. summer storm events) would increase soil erosion and sediment loadings of runoff into Lake McKenzie. Any pollutants within the catchment may also run into the Lake.

Prolonged drought may also result in an increase in grazing and trampling pressure from native animals entering the Gardens for food and water.

Changes to seasonal rainfall may have negative affects on species dependant on seasonal rainfall. For example, 23% of Australian

Eucalyptus trees have ranges of mean annual rainfall of less than 20% variation (Pittock 2003). The range of effects however will depend on the capacity of management to intervene and artificially water these areas where required. These changes to rainfall patterns may also favour the spread of invasive weeds through the Gardens.

An increase in extreme rainfall may lead to damage to the living collection through soil erosion, direct plant damage, chemical runoff and increased vulnerability to pests and pathogens. Any potential increase in high winds or storm events will also result in an increase in tree and branch damage and potential closure of the Gardens to visitors to ensure their safety.

Increased pressure on collection from range expansion by invasive weed species and pathogens

Changes in climate, including atmospheric CO2 and temperatures, may increase invasion by weed species including bitou bush (*Chrysanthemoides monilifera*) and bladey grass (*Imperata cylindrica*): The likelihood that pests, parasites and pathogens will spread southward, or become established once introduced, increases with climate warming (Pittock 2003). Increases in temperature, atmospheric carbon dioxide concentrations may favour existing or invasive species that are physiologically adapted to exploit such conditions (Pittock 2003). Some non-local native plants such as kangaroo paw (*Anigozanthus* sp) and *Cordyline stricta* may also have a competitive advantage to changed climate. Pathogen dispersal may also alter with changes in rainfall seasonality and intensity. These impacts may also apply to the natural vegetation area of the Gardens.

13.9 Principal Management Implications

Managing to increase resilience of values

Increased vulnerability of species through climate change in the National Park and region in general may place additional pressures on the resources of the Gardens including water resources. Maintenance of Lake McKenzie as a viable freshwater ecosystem may be impeded by direct and indirect impacts of climate change for example:

- Increased fire events in the catchment;
- Erosion of exposed soil will potentially reduce clarity and quality of water in the Lake;
- Storm events and changes in rainfall seasonality will compound these impacts as will a greater emphasis on pest control through chemical means; and
- Increase potential evaporation and extraction for irrigation will impact on water levels and long term security of supply.

As a consequence additional resources may need to be directed to preservation of the freshwater ecosystem in future and may need regular review to ensure adequacy.

Climate change may also exacerbate existing pressures on the values of the Gardens, requiring a review of existing management strategies including:

- Changes in rainfall patterns may mean that fertiliser application regimes in the Gardens are no longer appropriate;
- Water management - a decline in water availability within the Gardens may mean restrictions on water use within the Gardens. A decline in water availability in general may also mean that the cost of water rises and therefore the cost of maintaining the Gardens increases prohibitively.
- Strategies to control and minimise weeds and pests may no longer be appropriate. Under climate stressed conditions a number of factors will combine resulting in further risk of pest and weed infestations including:
  - southerly expansion of species range;
  - changes in seasonal rainfall;
  - heat and water stress, increasing plant vulnerability to pests; and
  - increased growth through increased photosynthetic activity resulting in lower nutritional value and greater pest activity.
- Current fire management strategies in the Gardens may not be adequate to reduce the risk of fire under climate change. The window available for prescribed burning may shift and narrow (Hennessy *et al*. 2005) directly impacting on the management of fuel loads on the surrounding areas. This will impact on ability to protect the collection from fire damage and to retain and manage naturally occurring vegetation to provide a buffer between the planted areas of the Gardens and the rest of the National Park.

The role of *ex situ* botanic gardens collections will become increasingly important as reserves of genetic material as climate change impacts on natural populations of plant species (pers comm. J Croft 2007). As a result there may be increased pressure on space in the Gardens for plant conservation and preservation, including those from the local region. This may result in increased demand and expanding use for the living collection, nursery and herbarium for preservation purposes. Land and resource constraints however will increase the importance and the need for cooperating with other regional institutions and may require expansion of the current area covered by the Gardens.

Increasing decision-making capacity by improving understanding

Management activities to mitigate existing pressures may need to be adapted or expanded under climate change. For example, the likelihood that pests, parasites and pathogens will spread southward, or become established once introduced, increases with climate warming (Pittock 2003). Intensification of management effort is likely to control and minimise weeds, pests and pathogens within the Gardens. In conjunction with the Booderee National Park, managers may need to consider which native species new to the area should be supported as part of a wider climate change adaptation programme.

There are several gaps in knowledge that may prevent management from adequately answering questions regarding resilience, climate change impacts and sustainable use of the Gardens. Gaps in knowledge include:

- The role the Gardens will be expected to play in the national effort to preserve and conserve native flora i.e. how many additional species may need to be managed within the Gardens. Water and land constraints may reduce the capacity of the Gardens to contribute to national efforts. In this instance a bioregional prioritisation process may be required;
- The role the Gardens may play in co-ordinating national effort in identifying the necessary funds to support an innovative co-ordinated national approach to the *ex situ* conservation of species and their genetic material; and
- A detailed analysis of the effects of climate change on the biology of the species within the Gardens;

Maintaining infrastructure and protocols to ensure visitor safety and enjoyment

An increase in the number of extreme fire danger days and days over 35°C will result in increase closure of the National Park and Gardens. Visitor restriction will therefore reduce the ability of managers to use the Gardens for educational purposes and may reduce visitor satisfaction.

Changing climatic conditions such as increased temperatures, increased fire risk and increased intensity of storm events may require additional expenditure on maintenance of public facilities including shading for visitors, seating and first aid facilities.

14 Norfolk Island Botanic Garden

14.1 Bioregional Setting

Norfolk Island is a remote island of volcanic origin located in the South Pacific Ocean at latitude 29 degrees 01' south, Longitude 167 degrees 56'east. The Territory of Norfolk Island includes Nepean and Phillip Islands (small, uninhabited islands that lie to the south of Norfolk Island), as well as numerous rocky islets dotted about Norfolk Island's coastline. Norfolk Island is approximately 1700km from Sydney, Australia and 1100km from Auckland, New Zealand. Prior to European settlement, much of the island was covered by sub-tropical rainforest (Environment Australia 2000).

Norfolk Island Botanic Garden (hereafter referred to as the Garden) is adjacent to the Norfolk Island National Park (refer to Chapter 9) which is managed separately by Parks Australia.

14.2 Management Arrangements

The Garden was declared jointly by the Norfolk Island and Commonwealth Governments in 1986 and originally comprised an area of 0.6 hectares. A further 4.9 ha of remnant rainforest was purchased and added to the Garden in 1993 (Environment Australia 2000).

Since declaration of the Garden it has been managed under the *National Parks and Wildlife Conservation Act (1975)* and subsequently under the *Environment Protection and Biodiversity Conservation Act (1999)*. It was declared to provide a place where specimens of Norfolk's unique flora could be conveniently seen and appreciated.

The Garden has been assigned to the IUCN Protected Area Category IV.

14.3 Climate

Norfolk Island experiences a sub-tropical climate influenced by the surrounding sea and the belt of high pressure. The belt of high pressure oscillates north and south over the island annually. Temperature ranges on Norfolk Island are small and humidity relatively high. The region experiences some rainfall, ranging from 75mm to 130mm per month (BoM 2007). Thunderstorms are most common during winter and spring, with the occasional hail storm accompanying thunderstorms in winter. Tropical cyclones are rare, but occasionally have an influence in the early months of the year.

14.4 Natural and Scientific Values

Living Collection

The Garden's goal is to develop a reference collection of the Island's flora, including representatives of every plant taxon native to Norfolk

Island. To achieve this it is necessary to have collections of both living and herbarium specimens.

The Garden also forms a minor water catchment for the Mission Road area of Norfolk Island and acts as a recharge area for local aquifers.

Established herbarium collection

The Garden's goal is to establish and maintain a comprehensive herbarium collection of Norfolk Island's flora, linked to the living collection of the Garden, for the purposes of conservation, study, research and education.

Parks Australia staff have compiled a reference collection of herbarium specimens of terrestrial plants native to Norfolk and Phillip Islands. The collection is housed at the Parks Australia office on Norfolk Island and can be accessed by members of the public on request.

Herbarium specimens of the Norfolk Island flora are also held in a number of botanical institutions including the ANBG in Canberra and the Royal Botanic Gardens at Kew, United Kingdom.

Bioprospecting is also a potential value within the Park and Gardens due to its high species diversity (pers comm. B.Watson).

Pressures on natural and scientific values

Pressures on the natural and scientific values of the Garden include:

- Introduced pest species – rats pose the biggest threat to living collections;
- Introduced weed competitors such as the cherry guava, *Psidium cattleianum*.
- The botanical garden is located in a cyclone prone area. Tropical cyclones and other extreme weather events have the potential to cause damage to plant species and habitat;
- Plant pathogens which have the potential to cause significant impacts on the living specimens within the Garden. Earth-moving equipment, mowers and other vehicles operating in the Garden are among the potential sources of pathogens. Of particular concern is the root rot fungus *Phellinus noxius*, already suspected of killing trees within the Garden; and
- The Herbarium collection housed in the Parks Australia Office is potentially vulnerable to water or human induced fire damage.

14.5 Recreational and Visitation Values

The Garden is a significant local recreational resource for both residents and visitors to Norfolk Island. Walking trails within the Garden are well used for exercise and for sightseeing. The Garden incorporates basic facilities including picnic areas, public toilets and seating areas. The intention is to keep these facilities at a minimum whilst meeting the needs of visitors to the Garden.

Education plays an important role in teaching local residents and visitors about the flora and history of Norfolk Island in particular. Although there is no visitor centre, information is available from the Parks Australia Office and via the Garden's notice board, a visitor guide and information leaflets.

Pressures on recreational and visitation values

- Limited staffing;
- Limited wheelchair access;
- There are no sources of potable water within the Garden; and
- Limited covered areas available for shelter from rain or extreme heat.

14.6 Current Management Approaches

Management activities in the Gardens are aimed at maintaining the water catchment values of the Garden and establishing and maintaining living collections and a comprehensive herbarium collection that are representative of Norfolk Island's flora for the purposes of conservation, study, research and education. This currently includes management of threatening processes such as fire and invasion by exotic plants, weed species and damage from pests, pathogens and feral animals.

Management activities also focus on encouraging scientific use consistent with the purposes and values of the Garden and providing a resource for scientists through access to the Garden's facilities and plant resources and provision of information and plant materials.

Management activities also provide for recreational opportunities for visitors and residents of Norfolk Island, including the maintenance of visitor facilities and provision of information to increase public awareness of nature conservation values of the Garden, inform people of features of interest, and promote appropriate behaviour.

14.7 Climate Change Scenarios

The high range global warming scenarios pertinent to the Gardens are presented in Table 14-1. It is noted that these scenarios are for NSW and therefore can be interpreted as an indication of change only. Uncertainty surrounding the projection scenarios is shown in brackets.

Table 14-1: Climate change scenarios for NSW (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor		Current (1975-2004)	2030 scenarios	2070 scenarios
Annual average temperature		Max 24.4°C, min 11.1°C	+1.3°C (±0.6°C)	+4.0°C (±1.7°C)
Annual average rainfall[23]		553mm	+4% (±11%)	+11% (±34%)
Seasonal average rainfall	Summer	168mm	+4% (±19%)	+11% (±57%)
	Autumn	139mm	+4% (±19%)	+11% (±57%)
	Winter	114mm	-7% (±15%)	-23% (±45%)
	Spring	132mm	-7% (±15%)	-23% (±45%)
Annual daily extreme rainfall[24]		N/A	+0% (±10%)	+10% (±5%)
Annual average potential solar radiation		N/A	-0.6% (±1.9%)	-1.9% (±5.7%)
Annual average potential evaporation		N/A	+6% (±4%)	+17% (±13%)
Annual average no. of hot days (>35°C)		3 days (Sydney)	+3 days	+15 days
CO_2 concentration		353ppm	+165ppm	+365ppm

A summary of the potential impacts of climate change on the values identified for the Garden is described below. Implications of climate change for management of the Garden are also discussed.

14.8 Summary of Potential Climate Change Impacts

Botanic gardens have had to be intensively managed in order to grow the widest possible range of plants in the living collections. In gardens, plants grow in very favourable conditions. They are usually propagated in controlled conditions, planted into carefully prepared ground and protected from pest and diseases and competing plants. Thus the elasticity of response to climate change is very much greater than in the natural environments. The factors important in determining climate change impacts will be plant hardiness to changing temperatures,

23 Uncertainty surrounding annual and seasonal rainfall projections in this region is high. Planning for these impacts will need to take into consideration the possibility that rainfall may increase or decrease.
24 1-in-40 year intensity, based on 2 climate models (Hennessy *et al*. 2004)

atmospheric CO_2, water availability and any resulting increase in invasions by plant pathogens, disease and weeds.

Change in rainfall patterns

Whilst a small increase in annual, summer and autumn average rainfall is projected, there is a large degree of uncertainty surrounding these figures i.e. in the order of ±34% for annual average rainfall and ±57% for summer and autumn and ±45% for winter and spring rainfall.

Prolonged drought conditions will place further constraints on water availability at the Gardens. Prolonged drought may also result in pressure from rats and other competitive pest species entering the Garden's for food and water.

Drought and other climate induced stresses may also increase the susceptibility of the living collections plants to diseases such as brown root rot (*Phellinus noxius).* In larger tree species, drought conditions will increase their susceptibility to borer attack (pers comm. B.Watson).

Changes to seasonal rainfall may have negative affects on species dependant on seasonal rainfall. These effects may be significant due to the limited water availability on the island (pers comm. B.Watson)

Any potential increase in high winds, intensity of storm events or extreme rainfall events will result in an increase in tree and branch damage in the living collection and damage (including water damage) to the Herbarium. Extreme events can have significant negative effects and may even lead to species loss. Closure of the Garden to visitors may also result.

Extreme rainfall events may also increase soil erosion and loss of nutrients through leaching, which will be exacerbated by an increase in seasonal average temperature as described above.

Increase in annual average temperatures and number of days over 35°C

Temperature levels play a key role in regulating the annual growth cycle of perennial plants. Currently spring is arriving 2-6 days earlier per decade and autumn two days later each decade. Precocious spring flowering, delayed leaf fall, extended lawn growth and unseasonal winter flowering are already commonplace and will increase in extent and frequency as climate changes.

Seasonal temperature increases will enhance biological activity of soil micro-organisms, leading to more rapid breakdown of soil organic matter and faster nutrient release. Increased availability of soluble soil nutrients will bring about faster and more vigorous plant growth; however, it will also increase the loss of soil nutrients through leaching.

Higher summer temperatures will increase water evaporation from leaves and the soil, lowering soil moisture content. A 3°C increase in soil temperature, (which may be experienced by 2070), can increase water loss by 30% and decrease soil moisture by 25%. If combined with substantially lower summer rainfall, plants will suffer from severe drought stress more frequently.

An increase in extreme temperature days may result in heat stress in plants in the living collection and Herbarium. Plants that are maintained in glasshouses within the Gardens will be particularly susceptible to stress unless shading and ventilation are provided.

Plants under heat and water stress (which will be further exacerbated through an increase in potential evaporation) will be more susceptible to weeds and pest species. Plant mortality is also anticipated where there are extreme temperature days in succession.

Warmer temperatures are also likely to favour a southwards advance of native pest species and an influx of pests, either by natural migration or accidental introduction.

An increase in annual average temperatures and the incidence of the number of hot days may affect visitor comfort and satisfaction.

Increase in carbon dioxide concentrations

An increase in temperatures and concentration of CO_2 may result in increased plant growth rates for some species in the living collection and herbarium; however these conditions may also favour grown of weeds such as the cherry guava (*Psidium cattleianum*) and the spread and increase in pest feeding activity.

Faster plant growth reduces leaf nutritive value and can increase pest feeding activity by 20-40 per cent (Bisgrove and Hadley 2002). Many insect pests transmit viral diseases, which will become more prevalent as pest infestations intensify and occur earlier in the year, when plants are more vulnerable.

14.9 Principal Management Implications

Managing to increase resilience of values

Management strategies to control weeds, insect and animal pests and pathogens are already in place; however, changing climatic conditions (such as increased carbon dioxide concentrations and temperature) may require a review and perhaps intensification of management effort to control and minimise these pressures. For example, more favourable conditions for germination and growth may increase the need for weeding, while slow growth in dry summers may reduce the effectiveness of glyphosate and hormone-based herbicides, which work best on plants that are growing rapidly. One likely consequence is that herbicide spraying may need to be conducted earlier in the year. Potential changes in plant growth and changes to rainfall variability may also require a review of fertiliser application in the Gardens.

Existing management strategies for fire may also not be adequate under climate change. The window available for prescribed burning may shift and narrow (Hennessy *et al*. 2005) directly impacting on the management of fuel loads on the surrounding areas. This will impact on ability to protect the collection from fire damage and to retain and manage naturally occurring vegetation to provide a buffer between the planted areas of the Garden and the rest of the National Park. Working with the neighbouring Park and land managers to manage fire and prevent the introduction and spread of pest species will become increasingly important.

Increased vulnerability of species within the Garden, Park and region in general may place additional pressures on the resources of the Garden. Ensuring viable freshwater supplies will be increasingly challenging and may require greater management effort and investment for example for irrigation.

Increasing decision-making capacity by improving understanding

Climate change may offer new opportunities to develop the living collection and Herbarium. Botanic gardens are in a key position to advance and disseminate knowledge on climate change and its effects.

Currently there are several knowledge gaps that require further research to increase decision-making capacity, including:

- Detailed understanding of the ecological processes operating on Norfolk Island;
- How certain species will respond to climate change including:
  - seasonality;
  - susceptibility to pests and diseases, including plant pathogens;
  - interactions with symbiotic soil fungi; and
  - beneficial micro-organisms.
- How species distributions outside the Gardens will change, including identification of vulnerable species that may require direct intervention by the Garden for propagation, conservation or preservation. This may include EPBC listed species and those susceptible to a shrink in range of distribution; and
- The implications of climate change on water availability at the Garden and catchment.

Maintaining infrastructure and protocols to ensure visitor safety

Current management strategies and visitor infrastructure may no longer be sufficient to ensure visitor safety, comfort and satisfaction under changing climatic conditions. For example:

- An increase in the number of extreme temperature days may affect recreational uses and visitor enjoyment of the Garden including increased closure of the Garden and National Park;
- It is also possible that conditions on Norfolk Island generally improve under milder climatic conditions and warmer summer months. This could lead to the growth of Norfolk Island as a tourist destination and increased demand for tourist facilities including the Garden. This is a scenario that management may also need to consider in their planning scenarios; and

- Increases in fire frequency and intensity and an increase in cyclonic activity and extreme weather will also place further pressures on Garden’s resources through increased maintenance costs from the replacement and upgrade of visitor infrastructure.

15 Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve

15.1 Current Management Arrangements

Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve (hereafter referred to as the "Reserves") are renowned for their high biological diversity with many different species of fish, corals, molluscs and other invertebrates. Both Reserves also provide significant habitat for an unusually high diversity and number of sea snakes, some of which are endemic to the region. Furthermore, the reserves support breeding and feeding habitats for sea turtles and dugongs.

The Reserves were established by the Commonwealth to protect their outstanding and representative marine ecosystems and to facilitate scientific research. Ashmore Reef National Nature Reserve was established on the 16th of August 1983 and Cartier Island Marine Reserve was proclaimed on the 21st of June 2000.

The Reserves were established by proclamations under the *National Parks and Wildlife Conservation Act 1975*, which was replaced by the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*) on the 16th of July 2000. The proclamations of the Reserves are continued by the *Environmental Reform (Consequential Provisions) Act 1999* (ER (CP) Act) as if they had been made under the *EPBC Act*, and as if the proclamations stated that the purposes for which the Reserves were declared were: the preservation of the area in its natural condition; and, the encouragement and regulation of the appropriate use, appreciation and enjoyment of the area by the public (Environment Australia 2002).

Ashmore Reef National Marine Reserve is listed under a number of international and national conventions and agreements. These are outlined in some detail below:

- Ashmore Reef National Nature Reserve recognised under the IUCN as an overall category 1a reserve comprising of 54,991 hectares of category 1a area and 3,346 hectares of category II area. Category 1a reserves are described as "Strict Nature Reserves – areas which should be significantly free of direct human intervention and capable of remaining so". Category II is described as a "National Park" and is a Natural area of land and/or sea, designated to exclude exploitation or occupation inimical to the purposes of designation of the area' (IUCN 1994). Furthermore, Ashmore Reef is also included in the IUCN list of Coral Reefs of International Significance;
- This Reserve is also recognised under the Memorandum of Understanding with Indonesia, under which traditional Indonesian fishers are allowed access to an area that includes the Reserve; and
- The Reserve is listed under the Wetlands (Ramsar) Convention.

Cartier Island Marine Reserve is also listed under a number of international and national conventions and agreements. These are outlined in some detail below:

- Cartier Island Marine Reserve is recognised under the IUCN as a category 1a reserve. Category 1a reserves are described as a "Strict Nature Reserves – areas which should be significantly free of direct human intervention and capable of remaining so" (IUCN 1994); and
- The Reserve is recognised under a Memorandum of Understanding with Indonesia, which allows traditional Indonesian fishers to access an area which includes the Reserve.

15.2 Bioregional Context

Ashmore Reef National Nature Reserve is located approximately 450 nautical miles west of Darwin, 330 nautical miles north of Broome and 60 nautical miles south of the Indonesian island of Roti. Ashmore Reef Nature Reserve has a total area of 58,337 hectares consisting of a number of habitats including two extensive lagoons, several channelled carbonate sand flats, shifting sand cays, extensive seagrass meadows, reef flats, and three vegetated islands which make up a combined terrestrial area of 112 hectares.

Cartier Island Marine Reserve is located approximately 35 nautical miles to the south-east of Ashmore Reef National Nature Reserve. This Reserve covers a total area of 17,237 hectares consisting of an un-vegetated sand cay and a mature reef flat with two shallow pools.

Both Reserve areas include the seabed and substrata to a depth of 1,000 metres.

15.3 Climate and Oceanography

Its location and range of habitats makes Ashmore Reef of great conservation significance, lying as it does in the path of the Indonesian throughflow. This is a westerly current transporting an immense volume of water from the Pacific Ocean, which passes along the northern coast of New Guinea and then moves down through the Indonesian archipelago and into the Indian Ocean (CSIRO 2002). Ashmore materially benefits from these low-salinity waters bathing the reef, through larval recruitment from reef systems to the north contributing to the maintenance of gene diversity. The reefal waters are also enriched by the South-east Trade winds, which generate a surface current from the Arafura and Timor Seas, thereby transporting marine organisms to Ashmore from eastern waters.

Both Reserves are located in the tropics where the climate is dry and annual evaporation is twice that of the annual precipitation. The majority of rainfall occurs during the relatively short summer monsoon period. Prolonged periods of rainfall are rare, and annual rainfall is 950mm. Monsoonal conditions dominate from December to May and cyclones are common with the region experiencing seven percent of the annual global cyclone total (Environment Australia 2002).

Westerly to north-westerly rain bearing winds occur from November to March, while dry south-easterly to easterly trade winds prevail from May until September. Transitional winds occur in between these periods where winds are light and unsteady from either the south-east or north-west.

Sea surface temperatures vary seasonally with the highest oceanic water temperature recorded at 31^{o}C. Lagoonal water has been recorded as high as 35.4 ^{o}C. Oceanic currents which affect the region include the Indonesian Through Flow, which carries warm low-saline water from the western Pacific Ocean into cooler, high nutrient, highly saline up-welling water of the Indian Ocean; and Leeuwin Current which originates in the region and flows southward down the Western Australian coastline, which is the only example of a west coast, southern flowing boundary current in the world. The interaction between these currents and the reefs of the Indo-Pacific play a significant role in the maintenance of coral reef and algal communities located further to the south.

15.4 Natural Values

The natural values of the Reserve include:

- Highest diversity and density of sea snakes in the world. Ashmore Reef National Nature Reserve in particular, has been estimated to provide habitat for 40,000 sea snakes from at least 13 species, representing the greatest number of sea snake species recorded for anywhere in the world (Guinea 1993);
- Supports the greatest number of reef building coral species of any reef area on the Western Australian coast (Veron 1993);
- Approximately 286 species of crustaceans have been recorded within the Reserves. These include 99 species of decapods, of which 40% are xanthoids (crabs) and 25% are paroroids (hermit crabs);
- Ashmore and Cartier reefs are known to support at least 433 mollusc species;
- The Reserves contain approximately 192 species of *Ecinoderms* of which 39 are crinoids (feather stars); 27 are asteroids (starfish); 45 are ophiuroids (brittle and basket stars); 25 are echinoids (sea urchins, heart urchins and sand dollars) and 45 are Holuthurians (trepand or sea cucumbers);
- The Ashmore Reef National Nature Reserve supports a number of terrestrial invertebrates including hermit crabs, 127 species of insects, 7 species of spider and one species of centipede, pseudoscorpian and millipede (Brown 1999);
- The Reserves play an important role in maintaining biodiversity in reef systems further south;
- A 1997 survey revealed that the total number of fish species recorded in Ashmore Reef National Nature Reserve was 709. This

indicates that this Reserve has the most diverse marine fish fauna of any region in Western Australia (Hutchins 1997);

- Nationally vulnerable species such as the green turtles (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys imbricata*) are found in both Reserves as well as the nationally endangered loggerhead turtles (*Caretta caretta*);
- The seagrass beds within Ashmore and Cartier Reserves provide a critical habitat for this dugong population (Whiting 1999);
- Ashmore Reef National Nature Reserve consists of both vegetated islands, which provide critical nesting habitat for many species, and unvegetated sand cays;
- The islands within the Ashmore Reserve support some of the most important seabird rookeries on the North West Shelf and provide a resting place for large numbers of migratory wading birds and shorebirds;
- The Ashmore Reef Reserve was designated a Ramsar Wetland of International Importance in October 2002;
- The Reserves as are listed feeding and resting sites under the Migratory Species (Bonn) Convention (26 of the 98 for Ashmore and 4 of the 98 listed Australian species for Cartier), the China – Australia Migratory Birds Agreement 38 of the 81 and listed species for Ashmore, and listed under the Japan – Australia Migratory Birds Agreement for 38 of the 76 listed species for Ashmore. Species included under these agreements are the sanderling (*Calidris alba*), large sand plover (*Charadrius leschenaultii*), black tailed godwit (*Limosa limosa*) and the marsh sandpiper (*Tringa stagnatilis*); and
- Under the *EPBC Act*, Ashmore Reef National Nature Reserve contains 109 listed fauna of which 1 is endangered, 2 are vulnerable, 46 are migratory and 60 are marine. There is no listed flora and a recovery plan is being implemented for marine turtles. The Reserve is also listed as Commonwealth Heritage under the *EPBC Act*. Species listed under the *EPBC Act* include the black noddy tern *Anous tenuirostris* and the green turtle *Chelonia mydas.* The Cartier Island Marine Reserve contains 23 listed fauna of which 1 is endangered, 1 is vulnerable, 4 are migratory and 17 are marine. There is no listed flora and 1 recovery plan has been implemented for marine turtles.

15.5 Socio-cultural Values

- Traditional Indonesian fishers have a rich history associated with the Reserves that dates back approximately three centuries. Recognition of this traditional fishing is incorporated into the Memorandum of Understanding (MOU) between Australia and Indonesia in 1974. Under these provisions, traditional fishers are permitted to take fish and certain sedentary species within the MOU box area, but not within the Reserve;
- Indonesian artefacts can also be found within the Reserves and can include ceramics, graves, ballast rocks and what could be a trepang cooking site (Clark 2000). Graves have been found on the

vegetated islands of Ashmore Reef National Nature Reserve. These cultural artefacts have been observed deteriorating through natural processes;

- Guano mining was known to occur within the region from about the 1850's until the 1891. There may be artefacts associated with this mining activity still remaining on the islands; and
- The Ann Millicent was a European vessel which was wrecked on Cartier Island on the 5th of January 1888. Another relic found within the Reserves includes the wreckage of a Second World War RAAF Beaufighter which was forced to undertake an emergency landing on Cartier Island.

15.6 Existing Pressures on Values

Potential risks to living resources may occur as a result of natural pressures and human activities.

Potential natural pressures include:

- Invasive species and the introduction of marine and terrestrial pests (e.g *Cenchrus* and *Pennisetum* species including buffel grass, *Cenchrus ciliaris* (Director of National Parks 2006);
- Natural processes of erosion and weathering will undoubtedly deteriorate the cultural artefacts present within the reserves. Reef destruction associated with increases in extreme weather events associated with climate change are likely to be a future pressure on these systems due to their long recovery times.
- Coral death caused by natural predators such as crown-of-thorns starfish and gastropod *Drupella cornis*.

Potential Human induced pressures include:

- Foreign fishing pressure is a major concern. As climate change begins to affect the livelihood opportunities for the communities of southern Indonesian islands (particularly Roti), the pressure will increase substantially and this is one of the major management challenges for this MPA;
- Traditional fishing including illegal and unsustainable practices have been recorded and are recognised as a significant direct and indirect threat to natural processes and biological diversity to the Reserves. Ashmore falls within the outer boundaries of at least three domestic fisheries managed by AFMA, but there is currently very little commercial interest in operating near Ashmore or Cartier;
- Target species for traditional fisheries include trochus, trepang and sharks, it is expected that the demand for these species will continue.
- Pollution from fishing operations including the release of sewage, hydrocarbons and litter / marine debris, particularly plastics and abandoned fishing nets, may come from human activities near shore and off shore;
- Unauthorised immigration and associated resource use and waste production.

15.7 Management Responses

In order to achieve the aims of the Reserve, management is currently implementing strategies focused on the following key areas:

- Minimise disturbances from visitors enforcing the restrictions on access and activities in the management plan;
- Continue to work cooperatively with governments and the fishing industry to protect the values of the Reserves;
- Conduct and facilitate research and monitoring that will increase knowledge of the natural and cultural values of the Reserves, provide information to enhance management, and measure management success; and
- Protect the Reserves from extractive and other forms of commercial activity.

15.8 Climate Change Scenarios

The high range global warming scenarios in Table 15-1 have been projected for the North West Australian region within which the Reserve is located. Due to the remote location of the Ashmore Reef and Cartier Island, these projections can be an indication of anticipated direction and degree of change only. CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in Table 15-2.

Table 15-1: Climate change scenarios for NWA (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor		Current (1975-2004)	2030 Scenarios	2070 Scenarios
Annual average temperature		Max 33.2 °C, min 20.2 °C	+1.3 °C (±0.6°C)	+4.0 °C (±1.7°C)
Sea level		0	+17cm	+50cm
Annual average Rainfall		702mm	-4% (±11%)	-11% (±34%)
Seasonal average rainfall	Summer	474mm	-4% (±11%)	-11% (±34%)
	Autumn	162mm	± 0% (±15%)	±0% (±45%)
	Winter	15mm	N/A	N/A
	Spring	52mm	N/A	N/A
Annual average potential evaporation		N/A	+4% (±3%)	+13% (±9%)
Annual average daily extreme wind-speed		N/A	+0.6% (±3.1%)	+ 1.9% (±9.4%)
CO_2 concentration		353ppm	+165ppm	+ 365ppm

Table 15-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C^
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m

Physical climate change indicators	Projected climate change impacts by 2070
pH	Decline in pH by 0.2 units

^ Ashmore Reef and Cartier Island are located outside of the biogeographic range of these projections. It is anticipated that the rate of warming experienced at the Park will be 20-30% below the global average (pers. comm. P Whetton CSIRO)

Tropical cyclones and winds are also expected to intensify under climate change (pers comm. P Whetton 2006).

A summary of the potential impacts of climate change on the values identified for the Reserve are described below. Implications of climate change on management are also discussed.

15.9 Summary of Potential Climate Change Impacts

The marine values of the Ashmore and Cartier Reserves are likely to be most vulnerable to increased sea surface temperatures and acidification of the ocean. This unique site will also be impacted by changes to ocean currents, wind patterns and seasonal influences for the Indian Ocean and the Indonesian flow through. A summary of the climate change impacts on the values of the Reserves are described below:

Indonesian Throughflow

Ocean currents and the characteristics of the marine environment are arguably the most important factors in considering climate change impacts on the Ashmore and Cartier Reserves. In particular, the dominant flow in this region is the Indonesian Throughflow which is a system of currents that transport water between the oceans through the maze of straits and passages in the Indonesian Archipelago. The Indonesion Throughflow carries warm, low saline water from the Western Pacific Ocean into cooler, high nutrient, highly saline up welling water of the Indian Ocean (CSIRO 2002).

The Throughflow is one of the primary links or ‘chokepoints’ in the global exchange of water and heat between the major ocean basins. On-going monitoring and modeling of changes in the Throughflow will determine the changing influences of this current and the associated biological impacts.

Sea temperature warming

Australia coastal waters are undergoing warming and are projected to warm by 1-2°C over the next 3 decades and by 2-3°C by 2070 (Hobday *et al*. 2006a). Recent increases in sea temperature have started to exceed the stress tolerance of marine life. In the case of coral reefs, this has meant an increasing frequency and intensity of coral bleaching. This would be particularly true for the shallow water lagoon areas which are potentially the most vulnerable to coral bleaching. Negative impacts on other marine life (such as sea snakes) are also becoming evident.

Ocean pH and carbonate ion concentrations

Almost half of CO_2 that has entered the atmosphere has entered the ocean, where it has combined with water to drive a gentle acidification of the world's marine waters. Given that coral reefs represent a balance between calcification and erosion, it would appear that atmospheric CO_2 concentrations that exceed 500ppm will severely compromise the ability of corals to maintain the reef structures and communities that they build against the forces of physical and biological erosion.

Tropical cyclones

The intensity and frequency of tropical cyclones is expected to increase in northern Australia. The significance on these changes on the reserves is uncertain. It is anticipated that increases in ocean temperature and acidity will increase the susceptibility of coral reefs to the destructive effects of tropical cyclones. These impacts may be exacerbated by reduced coral growth and calcification.

Loss of biodiversity

There is little evidence that coral reefs will be able to experience the environmental changes surrounding them without undergoing major changes in their structure, abundance and community composition (Hoegh-Guldberg 2005). The actual changes are difficult to predict and require ongoing monitoring of reef biology in conjunction with direct ocean monitoring of the surface ocean waters and their interaction with the atmosphere.

Graham *et al* (2006) investigated the impacts of coral bleaching and mortality on fish populations and demonstrated that impacts included local extinctions, reduced taxonomic distinctiveness and species richness, and a loss of species within key functional groups of reef fish. Wilson *et al*. (2006) have also shown that fish diversity is directly affected by the loss of corals. Using data from Pacific and Indian studies, these authors found that fish populations are highly sensitive to changes in coral cover with 62% of fish species declining in abundance within 3 years of disturbances that resulted in greater than a 10% decrease in coral cover.

Species invasion, increased competition and disease outbreaks

One of the most likely outcomes of climate change on Australia's marine ecosystems is the prospect of species migrating to higher latitudes. In the case of Ashmore and Cartier reserves this would mean species migrating from Indonesian waters and reef systems into the reserve and some species from the reserve moving to more southerly reef systems. How species move will depend very much on their mobility, the rate of climate change and the availability of suitable habitat for new populations to become established. Inevitably this will result in competition over limited resources and invasive species may out compete local reef species. Managing this will require close monitoring to understand the impact of invasive species over time.

15.10 Principal Management Implications

Managing to increase resilience by reducing human impacts

Whilst the reserves will be increasingly stressed by climatic change it is imperative that efforts to minimise human threats and impacts are maximised. It will be important to monitor and enforce the control of potentially illegal fishing operations and landings on the reserves' islands. The low recovery times associated with these systems means that human impacts may be most destructive after extreme weather patterns associated with climate change. This highlights the importance of continuing the current, strict management of seasonal human activity in these reserves.

Coral communities in the reserve have suffered from a mass mortality event which is thought to have been a bleaching event in 2003. As a consequence there is still lower coverage and diversity of species within the reserve. It is therefore critical that resources are focused on protecting the reef from other stresses such as marine pollution, commercial fisheries and anchoring, in order to promote the recovery of the coral communities.

Capacity to monitor and enforce marine activities and fishing will require regular review, particularly as circumstances change which affect the livelihood of fishing communities. Illegal fishing activities are expected to rise and this will exert pressure on existing resources to enforce the law and protect the natural assets of the Reserve.

Increase decision-making capacity by improving understanding

The major role of marine parks designed to protect warm water corals will be to find ways to reduce species loss, accommodate changes in species composition and to respond to challenges posed by invading species and disease. Given the scale and rapidity of the changes, early rather than later preparation for the changes and challenges is clearly an imperative. In the first instance the management implication is to fill outstanding gaps in knowledge in order to facilitate informed decision making.

Currently there are several gaps in knowledge that may prevent Reserve managers to adequately answer questions regarding resilience, climate change scenarios and sustainable use of the Reserve. Increasing understanding in these areas will in effect increase their decision making capacity. Gaps in knowledge include:

- Knowledge of reef ecosystems and their adaptive capacity to changed environmental conditions, particularly temperature and pH;
- Specific climate change projections for marine environments are lacking, such information will over time refine decision making in response to climate change.

- Knowledge of the role of ocean currents in the sustainability of coral reef systems for example the role of the Indonesian Flow Through and the effect on nutrient supply, reef colonisation, species distribution and population dynamics, introduction of invasive species and temperature.
- The interaction of marine species, communities and ecosystem processes including how primary and secondary productivity will change in response to climate change.

More frequent monitoring of coral condition and indicators of potential coral bleaching may be required to facilitate on-going informed decision making.

Given the pace of climate change the frequency of updates to the management plan may not be adequate.

In the short term (prior to 2020) significant risks to coral reef ecosystems have been identified. In order to manage these risks current levels of staffing and funding may not be appropriate.

Maintaining infrastructure and protocols to ensure visitor safety

An increase in the likelihood of severe storm events or destabilisation of coral reefs (from the combined effects of increased ocean acidity, increased sea surface temperatures and severe storm events) may present issues for visitor safety. Current management strategies may need to be revised to take the risks of climate change into account.

16 Coringa Herald National Nature Reserve & Lihou Reef National Nature Reserve

16.1 Current Management Arrangements

The existence of the Coral Sea Islands has been documented since the early 1800's. During the 1960's three scientific parties visited and assessed the conservation status of the islands and reefs. This resulted in the eventual declaration of the reserves on the 16th of August 1982 by the relevant government departments.

Both Coringa-Herald and Lihou Reef National Nature Reserves (collectively referred to as the "Reserves") are listed as category 1a under the IUCN. The IUCN describes this category as a "Strict Nature Reserve – an area which should be significantly free of direct human intervention and capable of remaining so" (IUCN 1994).

The Reserves are also part of the National Representative System of Marine Protected Areas (NRSMPA) which has been set up to protect marine areas that represent all major ecological regions and the communities of plants and animals they contain.

16.2 Bioregional Context

The Reserves are located within the Coral Sea Islands Territory to the east of the Great Barrier Reef Marine Park. Together, they make up the Coral Sea National Nature Reserves. The Reserves are located in a remote oceanic environment on the Coral Sea Plateau, which is separated from the Great Barrier Reef by an area of deep water known as the Queensland Trough.

Coringa-Herald National Nature Reserve covers approximately 885,250 hectares while Lihou Reef National Nature Reserve takes up 843,670. They are separated by approximately 100km of open ocean waters. The Reserves contain extensive reef systems covering up to 300 hectares. This includes 24 sandy islets and cays that have developed on the shallow selves of the Coral Sea Plateau. As well as protecting the water and seabed, the Reserves also protect the subsoil and reefs to a depth of 1,000 metres below the seabed.

Primarily, the Reserves were established to maintain ecological processes and systems, and to protect their habitats and biodiversity from pressures associated with human activity. A secondary objective of the Reserves is to encourage research and monitoring and to allow for appropriate recreational activities which are consistent with the primary objective.

16.3 Climate and Oceanography

The tropical location and the oceanic influence to the Reserves means there is little variation in daily or annual temperature (ANPWS 1989a, b).

Mean daily temperatures for the two hottest months range from a minimum of 25.3°C for December and 25.6°C for January to a maximum of 30.7°C for both months. The mean daily minimum temperature for the coldest month of August is 21.9°C, whilst the maximum is 26.4°C (DEH 2001).

Mean annual rainfall at Willis Islet (approximately 50km north-west of Coringa-Herald National Nature Reserve) is 1,094mm, with 68% of rainfall falling between January and April (DEH 2001).

Wind speed and direction have a critical influence on sediment transport dynamics, cay location on reefs, and the distribution and growth of flora. From March to November, the prevailing winds over the Coral Sea tend to be from the south-east, while the north-west monsoon prevails from December to February (DEH 2001)

16.4 Natural Values

- The Reserves support a diverse range of marine algae, sponges, soft and hard corals, crustaceans, molluscs, starfish, sea urchins, sea cucumbers, and fish;
- The *Pisonia grandis* forest ecosystem occurs on two islets within the Coringa-Herald National Nature Reserve and has intrinsic conservation status as it is an important habitat for nesting seabirds;
- The green turtle (*Chelonia mydas*) breeds in the Reserves and a number of species of dolphins and whales are known to occur in the area;
- The Reserves include a number of marine habitats including front (windward) reef slopes; exposed reef crest/reef rim; reef flat, back (leeward) reef crest; back reef slope, reef shoals and inter reef channels;
- Cetaceans likely to occur in the area include humpback whales *Megaptera novaeangliae*, sperm whales, *Physeter macrocephalus*, spinner dolphins, *Stenella longirostris*, striped dolphins, *S. coeruleoalba*, spotted dolphins, *S. attenuata*, common dolphins, *Delphinus delphis*, bottlenose dolphins, *Tursiops truncatus*, and Risso's dolphins, *Grampus griseus*;
- Scientific surveys have revealed that 14 seabird species use the Reserves specifically for breeding. It has also been found that these seabird colonies may have great significance to the overall ecological balance of the Coral Sea Region; and
- A total of 17 of the 28 species of birds recorded from Coringa-Herald NNR and 16 of the 24 species recorded from Lihou Reef NNR are listed in the JAMBA and CAMBA agreements (DEH 2001).

Coringa-Herald National Nature Reserve is a feeding and resting site for species listed under the following key conventions and agreements:

- Migratory Species (Bonn) Convention for 8 listed species, including the Green turtle (*Chelonia mydas*);

- China – Australia Migratory Birds Agreement for 14 listed species and the Japan – Australia Migratory Birds Agreement for 15 listed species. Such species include the wedge-tailed shearwater (*Puffinus pacificus*), red-footed booby (*Sula sula*), great frigatebird (*Fregata minor*), lesser golden plover (*Pluvialis dominica*) and the bridled tern (*Sterna anaethetus*);
- EPBC listed fauna species including 2 endangered, 8 vulnerable, 16 migratory and 51 marine; and
- *EPBC Act* recovery plans to be implemented for marine turtles and the great white shark (*Carcharodon carcharias*).

Lihou Reef National Nature Reserve is listed under the following key conventions and agreements:

- Migratory Species (Bonn) Convention for 6 listed species;
- China – Australia Migratory Birds Agreement for 12 listed species and the Japan – Australia Migratory Birds Agreement for 15 listed species. Such species include the great knot (*Calidris tenuirostris*), little wimbrel (*Numenius phaeopus*), great frigatebird *(Fregata minor*), little tern (*Sterna albifrons*) and the common noddy (*Anous stolidus*);
- EPBC listed for fauna species including 2 endangered, 8 vulnerable, 17 migratory and 51 marine; and
- *EPBC Act* recovery plans to be implemented for the green turtle *Chelonia mydas a*nd the great white shark (*Carcharodon carcharias*).

16.5 Socio–cultural Values

There are a number of shipwrecks within the Reserves which have considerable cultural value. On Lihou Reef, there are a several well-documented wrecks including the *Elizabeth* (1892), the S.S. *Queen Cristina* (1899) and the *Kyten Maru* (1982). Additionally, a number of post-1900 wreck structures are visible on Lihou Reef although they have not yet been identified. Coringa-Herald National Nature Reserve is home to one known historic shipwreck. This is the *Coringa Packet,* which was wrecked off Chilcott isle in 1845.

Other significant cultural values within the Reserve include the relics of guano mining which may date back to the late 1800's and the remains of two beach rock slab constructions found in 1991 which are thought to resemble Chinese graves.

16.6 Economic Values

A number of monitoring programmes and scientific studies are conducted by DEWHA to obtain information on seabirds, vegetation, green turtle populations, insect outbreaks, marine debris and other human disturbances. These studies have significantly contributed to the national and international significance of the Reserves and their continuation remains a high priority (DEH 2001).

Organised dive tours are currently the only commercial activities permitted in the Reserves; however, due to their remote location, the number of visitors to these Reserves still remains relatively low.

All fishing is prohibited within the Reserves but commercial fishing is regularly practiced within their vicinity. In June 2000, the Coral Sea fishery had 13 permit holder endorsed to fish within the vicinity of the Reserves (DEH 2001). Main methods of fishing include finfish trawling, crustacean trawl, dropline and demersal longlining, hand collection and aquarium fish collection.

The reserve is 1a therefore no current oil and gas extraction or exploration is permitted within the Reserves; however there may be a possibility that these activities become feasible in the future.

16.7 Existing Pressures on Values

Potential pressures to living resources may occur as a result of natural pressures and human activities:

Potential natural pressures include:

- Impacts from tropical cyclones and warming of ocean temperatures particularly in shallow lagoon areas;
- Accidental or deliberate introduction of exotic species has the potential to disturb or damage the unspoilt wildlife resources and ecosystems of the area. Known introduced species in the Reserves includes the black rat *Rattus rattus,* which was thought to prey on seabird eggs and nestlings and the dominant, invasive ant, *Tetramorium bicarinatum*;
- Coral death caused by natural predators such as crown-of-thorns starfish and gastropod *Drupella cornis*;
- Scale insects *Pulvinaria urbicola,* which can extensively damage and even destroy *Pisona* forest. Impacts from the pest, leaf scale, which can suck life-giving sap, killing a *Pisonia grandis* forest as occurred historically on SW Coringa Island and more recently on NE Herald Island; and
- The Hawkmoth is a significant pest to the Pisona forest.

Potential human-induced pressures include:

- Solid wastes potentially discarded illegally from passing ships, commercial vessels and research vessels. Such waste can often pose as hazards to marine fauna (through ingestion and entanglement) as well as to other vessels and humans;
- Oil spills and other liquid waste can pose a potential risk to flora and fauna within the Reserves. Release of sewage from boats can reduce water quality and may have the localised effect of increasing nutrient levels resulting in a negative impact to the marine environment;
- Anchor damage to coral reefs and the sea floor from visiting vessels;

- Although diving activity in the Reserves is relatively low, there is still potential for divers to damage fragile corals and other organisms through deliberate or accidental contact;
- Human activity will always have the potential to adversely affect wildlife behaviour and habitat. Seabird breeding and foraging zones and turtle nesting activities are susceptible to negative impacts resulting from human activity. Activities which can potentially have adverse effects include approaching and handling wildlife, trampling of vegetation, nests/burrows and coral reefs, light from anchored boats, noise and fire;
- Harvesting and collection of wildlife and wildlife products;
- Both commercial and recreational fishing are prohibited within the Reserves, however, external fishing activities outside of the reserves may potentially impact upon biological diversity within the reserve.
- Research activities may adversely impact on wildlife and their habitats through site marking and manipulation, and over collection of wildlife and wildlife products.

16.8 Management Responses

In order to achieve the aims of the Reserve, management is currently implementing strategies focused on the following key areas:

- Protecting the natural and cultural values of the Reserves from the adverse impacts of tourist and recreational visitation;
- Allowing limited use of the Reserves for passive tourism and recreational activities that are consistent with the strategic objectives for the Reserves;
- Protecting the Reserves from commercial fishing;
- Conducting and encouraging research and monitoring that will increase knowledge of the natural and cultural environments of the Reserves, provide information to enhance management, and measure management success;
- Ensuring that research activities are appropriate and will not adversely impact on the conservation values of the Reserves;
- Protecting the natural and cultural values of the Reserves from environmental impacts that may result from the establishment, operation, and maintenance of facilities and installations.

16.9 Climate Change Scenarios

The high range global warming scenarios in Table 16-1 have been projected for the North East Queensland region. No scenarios exist for the Coral Sea specifically; the following can only therefore be used as an indication of anticipated direction and degree of change only. CSIRO have also projected changes to the physical and chemical characteristics of Australia’s marine realm by 2070 as shown in Table 16-2 .

Table 16-1: Climate change scenarios for NEQ (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor		Current (1975-2004)	2030 Scenarios	2070 Scenarios
Annual average temperature		Max 33.2 °C, min 20.2 °C	+1.3 °C (±0.6°C)	+4.0 °C (±1.7°C)
Average sea level		0	+17cm	+50cm
Annual average rainfall		702mm	-4% (±11%)	-11% (±34%)
Seasonal average rainfall	Summer	474mm	+4% (±11%)	+11% (±34%)
	Autumn	162mm	-7% (±15%)	-23% (±45%)
	Winter	15mm	N/A	N/A
	Spring	52mm	0% (±22%)	0% (±68%)
Annual average potential evaporation		N/A	+4% (±4%)	+11% (±11%)
Average daily extreme wind-speed		N/A	+0% (±2.5%)	+ 0% (±7.5%)
CO_2 concentration		353ppm	+165ppm	+ 365ppm

Table 16-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C
Temperature at 500m depth	Warming of 0.5-1°C
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface winds	Increase of 0-1ms^{-1} surface winds
Surface currents	Decline in strength of surface currents of between 0-1.2ms^{-1}
pH	Decline in pH by 0.2 units

Tropical cyclones and winds are also expected to intensify under climate change (pers comm. *P Whetton 2006*).

A summary of the potential impacts of climate change on the values identified for the Reserve are described below. Implications of climate change on management are also discussed.

16.10 Summary of Potential Climate Change Impacts

The values of Coringa- Herald National Nature Reserve and the Lihou Reef National Nature Reserve are threatened by a number of challenges associated with climate change as follows:

Changes to water quality and circulation

The Park is most vulnerable to increases in atmospheric CO_2 concentrations and consequent increases in sea surface temperatures, increased ocean acidity and potential changes to the East Australian Current generally considered to be caused by Antarctic ozone depletion (Cai and Cowan 2007). Ocean acidification can potentially tip the balance from coral calcification to erosion; atmospheric levels above 500ppm will severely reduce coral viability. Levels above 600ppm will severely compromise the ability of corals to maintain themselves against the forces of physical and biological erosion (Hobday *et al.* 2006a).

Changes in sea level and storm Intensity

The Reserves are likely to be most vulnerable to increases in atmospheric CO_2 concentrations and ocean acidity, increases in sea surface temperatures, sea level rise as a consequence of thermal expansion and increased intensity of cyclones. All of these factors will impact upon the ecological processes and systems, habitats and biodiversity within the reserves. These are the primary values or drivers for the establishment of the two reserve areas.

Increases in sea level within the Reserve (projected 50cm sea level rise by 2070) may lead to a loss of foraging and roosting habitats found on the 24 sandy islets and cays located within the reserves. The greatest threat to seabirds is likely to come from climate induced changes of food resources in their critical habitats (Hobday *et al* 2006a). Many seabirds feed on small pelagic fish and zooplankton and are therefore sensitive to changes at lower trophic levels. Some seabirds may be able to rapidly shift their distributions depending on restrictions to habitat requirements at particular life stages such as availability of nursery areas, feeding grounds or breeding grounds.

Increased competition, disease and pest outbreaks

Species may also shift southwards into and out of the Reserves as temperatures warm and the EAC strengthens. However, the Reserve's Coral communities and thereby other species are relatively isolated so the likelihood of recruitment from external sources is minimal. This highlights the fact that the reserve is potentially vulnerable and less resilient to change than other reserves with good connectivity. It is possible that some species able to adapt to shallower waters would move over time to the Great Barrier Reef. These species may already be present on the Great Barrier Reef or maybe new to this environment and therefore impact upon the ecological balance within this marine habitat.

Loss of biodiversity and increased rates of extinction

The coral reef communities support a diverse suite of marine fauna including fish, crustaceans, molluscs and echinoderms. Climate change, namely through increased CO_2 concentrations and increased ocean acidity, combined with increased sea surface temperatures related to a strengthening of the southward flow of the East Australia Current may result in further coral bleaching and repeated bleaching eventually leading to coral death.

The coral reefs represent essential habitat, feeding grounds, and nursery areas and therefore any reduction in coral cover will also threaten the diverse communities they support.

Refuge and feeding ground for green turtles

Climate change may impact on green turtles directly through warming and indirectly through impacts on food resources. Warming is likely to be a major climate change threat to marine turtles as all stages of life history are strongly influenced by temperature; for example a small increase in temperature may bias the sex ratio of hatchlings towards females. The greatest threat to turtles is likely to come from climate-induced changes of food resources in their critical habitats (Hobday *et al*. 2006a).

Scientific research opportunities

If coral cover is further reduced as a consequence of algal growth and coral bleaching through climate change, current research programmes may be compromised. Climate change may also result in loss of endemic species currently unknown to science.

Protected shipwrecks and associated relics

Sea level rise and increased storm/cyclone intensity will accelerate erosive processes on shipwrecks and associated artefacts.

16.11 Principal Management Implications

Managing to increase resilience

Whilst climate change is likely to have an affect on the values of the marine inshore environment, fringing coral reef, beaches and subterranean habitats, efforts to protect these values may be limited to management of non-climate stressors such as minimising marine pollution, managing tourism operations and enforcing restrictions on commercial fishing.

The capacity of managers to monitor and enforce marine activities and fishing will require regular review, particularly as circumstances change which affect the livelihood of fishing communities.

Accelerated deterioration of shipwrecks in the Reserve through climate change will impede efforts to protect and maintain their historical and cultural significance, as well as efforts to improve knowledge of the Reserve's cultural heritage.

Increasing decision making capacity by improving understanding

Habitat loss, coral bleaching and coral death may reduce opportunities for scientific research and also for tourism and visitor satisfaction. However, it may also provide an opportunity to examine the effects of climate change and even distinguish climate change effects from those of fisheries and other disturbances. Opportunities will exist to monitor and research colonisation of the reserves by species from northerly areas and also to liaise with the Great Barrier Reef Marine Park Authority in relation to any cross colonisation between these areas.

Currently there are several gaps in knowledge that may prevent Park management from adequately answering questions regarding resilience, climate change scenarios and sustainable use of the Park. Increasing understanding in these areas will in effect increase decision making capacity of Park managers. Gaps in knowledge include:

- The ability of marine turtle and seabird populations to adapt to loss of habitat and food sources, including availability of habitat and food further south
- Turtle dispersion and population connectivity in and around the Park
- Species likely to migrate in and out of the Park as a result of an anticipated southward shift in species distribution under climate change.

Current management objectives include undertaking research to increase knowledge of the distribution, abundance and status of the flora and fauna, and of the ecological processes of the reserves. This type of research will enable species most at risk from climate change to be identified and current management to be revised as appropriate.

Whilst the Reserve should continue to be managed to contribute to the long term ecological viability of marine and terrestrial systems; their current role may change significantly. Understanding the new role of these reserves within this framework will be an important implication for management to respond to.

More frequent monitoring of coral condition and indicators of potential coral bleaching may be required to facilitate on-going informed decision making.

Given the pace of climate change the frequency of updates to the management plan may not be adequate.

In the short term (prior to 2020) significant risks to coral reef ecosystems have been identified. In order to manage these risks current levels of staffing and funding may not be appropriate.

Maintaining infrastructure and protocols to ensure visitor safety

Increasing efforts may be required to ensure the safety of visitors to the Reserves, including researchers and Park managers. Regular review of safety risk assessments, contingency plans and communication strategies and risk control measures will be imperative.

17 Elizabeth and Middleton Reefs Marine National Nature Reserve

17.1 Current Management Arrangements

Elizabeth and Middleton Reefs Marine National Nature Reserve (hereafter referred to as the “Reserve”) was declared in 1987 under the *National Parks and Wildlife Conservation Act 1975*. The Reserve continues in existence as a Commonwealth reserve under the *EPBC Act*. One of the main reasons for the reservation of Elizabeth and Middleton reefs was to protect the diverse assemblage of marine species including a number of species endemic to these reefs.

The Reserve has been listed as World Conservation Union (IUCN) category Ia: a northern ‘Sanctuary Zone’ around and to the south of Middleton Reef to be managed as a ‘strict nature reserve’ for research and monitoring as well as appropriate passive use by the public. The reserve has also been listed as IUCN category II: the southern ‘Habitat Protection Zone’ around Elizabeth Reef, to be managed as a ‘National Park’ for research and monitoring, appropriate use by the public including recreational fishing under permit. It has also been included in the List of Wetlands of International Importance under the Ramsar Convention. The area of reef wetland within the Reserve is estimated to be 8,800 ha (5,100 ha Elizabeth Reef and 3,700 ha at Middleton Reef). Wetland areas within the site are situated at, and several metres below, mean sea level (Director of National Parks 2006).

The Reserve is part of the National Reserve System of Marine Protected Areas (NRSMPA), which aims to protect representative samples of all Australia’s marine environments in all Australian jurisdictions for the protection of marine biodiversity and ecological processes, and the sustainable use of marine resources through the principles and goals of ecologically sustainable development.

The Reserve is located in a transition zone between tropical and temperate seas and covers an area of 1,880 km^2 and is divided into two protection zones: a Sanctuary Zone (Middleton Reef) and a Habitat Protection Zone (Elizabeth Reef) both of which are within Commonwealth waters (Director of National Parks 2006).

The nearest Commonwealth MPA, Lord Howe Island Marine Park, is approximately 150km to the south. Lord Howe Marine Park adjoins a NSW parks established in the coastal waters of NSW Lord Howe Island and Elizabeth and Middleton Reefs are connected in terms of ocean dynamics and shared species and ecological characteristics. The Reserve protects the values of World Heritage Listed Lord Howe Island because these islands are all connected in terms of ocean dynamics and shared species and ecological characteristics.

17.2 Bioregional Context

The Reserve is located in the northern Tasman Sea, 630km east of Coffs Harbour, NSW and 690km east-south-east of Brisbane, Queensland.

The Reefs are peaks of volcanic seamounts separated by 50 km of deep ocean, which together form part of the of the Lord Howe Island volcanic chain. Though more than 20 volcanic peaks are known in the Tasman Sea, only Lord Howe Island and Elizabeth and Middleton Reefs reach the sea surface presently.

Elizabeth Reef is a platform coral reef roughly oval in shape and approximately 5.5 km long by 8.2 km wide. Middleton Reef is a platform coral reef that is roughly kidney shaped, approximately 8.9km by 6.3 km. Its lagoon is structurally complex with areas of relatively deep water. Isolated patch reefs with a high percentage of fragile, living corals occur at the western end of the lagoon. Together with Lord Howe Island, Middleton Reef and Elizabeth Reef comprise the world's most southern coral reefs (Director of National Parks 2006).

17.3 Climate and Oceanography

There are no rainfall data for the site, but data at Lord Howe Island (150 km to the south) may indicate conditions at Elizabeth and Middleton Reefs with monthly averages from 108 mm in February to 184 mm in July. Air temperatures range from a maximum of 25°C in summer to minimum of 14°C in winter (Director of National Parks 2006).

The monthly tidal maxima range from 1.8 to 2.6 m and minima range from 0 to 0.2 m. Tides at the reef are modified by local wind and currents and surface seawater temperatures vary seasonally between 20 to 25°C (Jaensch *et al*. 2002). In summer, the reefs receive warm tropical water from the East Australian Current, which sustains reef growth as a consequence of the carbonate saturation state of this warm versus cold water. In winter, cooler water from the Southern Ocean reaches the Reefs. The unique assemblages of tropical, subtropical, and temperate species at these reefs result from this particular balance of tropical and temperate currents.

The Reefs lie at latitudes within the southern-most zone of influence of destructive tropical cyclones.

17.4 Natural Values

The natural values of the Reserve include:

- Hotspot of biological diversity in the region including 324 fish (pers comm. P.Anderson), 122 species of corals, 122 species of crustacean, 240 species of mollusc and 74 of echinoderm (including sea cucumbers) and 18 taxa of algal flora
- Open-ocean platform reefs representing the most southerly occurrence of these reefs in the world

- Feeding and roosting areas for numerous migratory marine species, including several migratory bird species listed under the Bonn Convention and the Japan-Australia and China-Australia Migratory Birds Agreements (JAMBA and CAMBA)
- Important foraging area for marine turtles including green turtles (*Chelonia mydas* listed under the *EPBC Act* 1999
- unique assemblage of ecosystems not represented in other marine protected areas
- The isolated oceanic environment with associated faunal assemblages considered unique within Australian waters including the Galapagos shark (*Carcharhinus galapagensis)*. The presence of these sharks in the Reserve is very significant as it is unlikely to be present at other Australian reef systems (excluding Lord Howe Island)
- endemic species including corals, three mollusc species and seven possible fish and marine species with restricted south-west Pacific distribution.
- southernmost habitat for the Queensland giant groper (*Epinephelus lanceolatus*) and is one of the last remaining sites in Australian waters that remains a major population centre for the protected black cod (*Epinephelus daemelii*).
- EPBC listed species including 13 vulnerable (including the green turtle, *Chelonia mydas*), 16 migratory (including the common noddy, *Anous stolidus* and wedge-tailed shearwater, *Puffinus pacificus*) and 15 marine fauna species (including the tasselled pipefish, *Halicampus brocki* and the Lord Howe pipefish, *Cosmocampus howensis*)
- 8 listed species - Migratory Species (Bonn) Convention (including the Campbell Albatross, *Thalassarche impavida,* Gibson's Albatross, *Diomedea gibsoni* and the Shy Albatross, *Thalassarche cauta*)
- 6 listed species - Japan-Australia Migratory Birds Agreement (including the Ruddy Turnstone, *Arenaria intrepres* and the Wandering Albatross, *Diomedea exulans*)
- 3 listed species - China-Australia Migratory Birds Agreements (these include the sooty shearwater, *puffinis griseua,* the ruddy turnstone, *Arenaria intrepres* and the common noddy, *Anous stolidus*).

The reefs can be divided into three major habitats: outer exposed reef slope, which below 30m drops off rapidly into deeper water; reef crest, which is exposed at high tide; and shallow protected lagoon with well developed patch reefs. Coral communities, sandy lagoons and algal meadows form the dominant structural components and ecological features of the site. Seagrass (*Halophila ovalis*) has a small patchy distribution on the sheltered sandy lagoons at both Reefs.

17.5 Socio-cultural Values

The Reserve contributes to the conservation of Australian maritime heritage. The Reefs are located near a number of historical shipping routes to and from Sydney, Newcastle and Brisbane. Shipwrecks on the reef platforms span most of the period of Australian history since European settlement, making the area of considerable marine archaeological significance. At least 30 ships are thought to have been wrecked on the Reefs, which some more recent wrecks being visible and prominent features of the landscape. All wrecks that are more than 75 years old are protected under the Historic Shipwrecks Act 1976, together with their associated relics. A full list of the wrecks can be found in the Elizabeth and Middleton Reefs Marine National Nature Reserve Management Plan 2006-2013. The wreck, Fuku Maru, on Middleton Reef supports a small breeding colony of terns that would not otherwise occur at the site and has also been used as a food cache and shelter for shipwreck survivors.

Elizabeth and Middleton Reefs have long been regarded by Lord Howe Islanders as important to island culture resulting in a degree of stewardship over the reefs.

17.6 Economic Values

The Reserve is regularly visited by those on ocean yacht voyages, as well as by residents from nearby Lord Howe Island for recreational purposes including fishing. Given the remoteness and location of the Reserve, visitation has not been high and is not anticipated to change in the near future.

Commercial activities within the Reserve are largely restricted to commercial tours. At present, there are few visitors to the Reserve and there is one commercial tour permit in operation. Commercial fishing and commercial fishing charters are not permitted within the Reserve. Surrounding areas support commercial, demersal long-line fisheries based on Blue-eye Trevalla (*Hyperglyphe antarctica*) and Rosy Job Fish (*Aprion virescens*) to which may depend on the reef system.

The Reefs have been visited by a number of scientific expeditions; however due to the remote location and lack of permanent dry land, research opportunities are limited. Scientific observations are undertaken during management patrols.

17.7 Existing Pressures on Values

Potential risks to living resources may occur as a result of natural pressures and human activities:

Potential natural pressures include:

- invasive species (including crown-of-thorns starfish), recent surveys have shown very little evidence of crown of thorns starfish activity;

however they have been quite common and widespread on these reefs in the past;

- pressures from natural disasters such as tropical storms and cyclones and coral bleaching events from increased sea water temperatures. A survey undertaken in 2003 by the Australian Institute of Marine Science found the Reserve to be generally in good health with no bleaching (Director of National Parks 2006).

Potential human induced pressures include:

- illegal fishing in the sanctuary zone and over fishing in the habitat zone;
- recreational fishing, which is permitted at Elizabeth Reef but not at Middleton Reef. The legal or illegal taking of significant numbers of fish and other marine organisms has the potential to adversely affect fish and invertebrate populations on the reefs. Australian commercial fishing vessels regularly visit the Reserve seeking protected anchorage; however all commercial fishing is prohibited;
- divers inadvertently damaging coral through touch and fin damage and research activities;
- damage to or removal of habitat as a consequence of anchoring and illegal fishing activities, resulting in impacts on marine fauna, a decline in fish populations and deterioration of the aesthetic attributes of the reserve (including shipwrecks);
- pollution in the form of oil, marine debris and sewage can result from a number of sources including boating and recreation within the Reserve, from ships in transit and from shipwrecks;
- introduced pests from ballast water, ballast water release is one of the main vectors for the translocation of non-indigenous marine organisms around the world and is a significant risk to the integrity of the Reserve (Director of National Parks 2006);

17.8 Management Responses

In order to achieve the aims of the Reserve, management is currently focused on the following key areas:

- protecting and conserving physical habitat in its natural condition, and to conserve populations of all native species, particularly commercially valuable species vulnerable to population decline such as beche-de-mer (sea cucumber) and black cod;
- maintaining the Reserve's fish and invertebrates populations as well as other native species populations in a natural condition while allowing for restricted forms of recreational fishing;
- ensuring commercial activities are undertaken in a way that does not diminish the experience of other visitors while the natural and cultural values of the reserve are maintained;
- improving knowledge of the Reserve's natural and cultural heritage, as well as current uses and threats.

17.9 Climate Change Scenarios

The high range global warming scenarios in Table 17-1 have been projected for the New South Wales region. CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in Table 17-2

Table 17-1: Climate change scenarios for NSW (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor	Current (1975-2004)	2030 Scenarios	2070 Scenarios
Average sea level	0	+ 17cm	+ 50cm
CO_2 concentration	353ppm	+165ppm	+365ppm

Table 17-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C
Temperature at 500m depth	Warming of 0.5-1°C
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface winds	Increase of 0-1ms^{-1} surface winds
Surface currents	Decline in strength of surface currents of between 0-1.2ms^{-1}
pH	Decline in pH by 0.2 units

A summary of the potential impacts of climate change on the values identified for the Reserve are described below. Implications of climate change on management of the Reserve are also discussed.

17.10 Summary of Potential Climate Change Impacts

The Reserve is likely to be most vulnerable to increases in atmospheric CO_2 concentrations and ocean acidity, increases in sea surface temperatures, sea level rise and increased intensity of cyclones. The key climate change impacts on the Reserve are described below:

Changes to water quality and circulation

These reefs exist at the edge of the saturation states of aragonite (a form of bio-available calcium carbonate) in ocean water. Additional stresses such as increased ocean temperature and acidity might therefore tip the balance of reef growth towards a net dissolution or otherwise serve to impact these special biological assemblages adversely. Greater intensities and frequencies of storms will also increase these impacts and could act in conjunction with other changes as well.

Changes to sea levels and storm intensity

Increases in sea level within the Reserve may lead to a loss of foraging and roosting habitats for some seabirds. More specifically, Middleton Reef provides semi protected anchorage and valuable shelter in bad weather for recreational and commercial vessels. Currently access to the reefs is restricted due to shallowness of lagoons; however, by 2070 sea level rise may increase access at Middleton Reef.

Loss of biodiversity and increased rates of extinction

The coral reef communities at Elizabeth and Middleton Reefs support a diverse and somewhat endemic suite of marine fauna including fish, crustaceans, molluscs and echinoderms. Climate change, namely through increased CO_2 concentrations and increased ocean acidity, combined with increased sea surface temperatures related to a strengthening of the southward flow of the East Australia Current may result in coral bleaching.

The coral reefs represent essential fish habitat, feeding grounds, and nursery areas and therefore any disappearance in coral cover will also threaten the diverse communities they support. The Reserve contains a unique assemblage of tropical species at, or near, the southern limits of their distribution, and subtropical species that are rare or absent from tropical reefs. Populations of endemic or regionally significant species may also decline where these species are ‘bounded to the south’, by for example, lack of available habitat or abundance of prey species. This may be compounded by competition for resources from species entering the Reserve from northern areas.

Climate change is likely to alter the abundance and distribution of migratory marine seabirds. Warming will expand or shift distributions of seabirds southwards and impact on the reproductive success of species such as the wedge-tailed shearwater as warming reduces prey availability.

Climate change may impact on green turtles directly through warming and indirectly through impacts on food resources. Warming is likely to be a major climate change threat to marine turtles as all stages of life history are strongly influenced by temperature; for example a small increase in temperature may bias the sex ratio of hatchlings towards females. Whilst the Reserve does not provide sufficient sand habitat for Green turtles to nest; a bias in the sex ratio may reduce the abundance of turtles found in the Reserve. The greatest threat to turtles is likely to come from climate-induced changes of food resources in their critical habitats (Hobday *et al*. 2006a). Green turtles forage on seagrasses, which are found at both Elizabeth and Middleton Reefs. Increased intensity of storms and cyclones, increased UV radiation and sea level rise may lead to significant erosion, damage or loss of seagrass in the Reserve.

Research opportunities are limited due to the remote location. Research is currently being undertaken into Black Cod populations and coral cover. Climate change may also result in loss of endemic species currently unknown to science.

The Reserve is often visited by residents from Lord Howe Island for recreational fishing which is permitted in the Habitat Protection Zone around Elizabeth Reef. Increases in temperature will drive benthic and demersal fish species southwards, resulting in changes to the abundance, distribution and composition of fish species in the Reserve. Disappearance of coral cover is also likely to contribute to these effects. Changes in abundance of particular species will have flow on effects to recreational fishing if change is seen in species targeted for this purpose.

Increased competition, disease and pest outbreaks

Species may also shift southwards into and out of the Reserve as temperatures warm and the EAC strengthens. This can assist with colonisation of the reef, but can also introduce invasive species. The risk with these reefs is their isolation and the low prospect of colonisation from reef systems to the north;

The greatest threat to seabirds is likely to come from climate induced changes of food resources in their critical habitats (Hobday *et al.* 2006a). Many seabirds feed on small pelagic fish and zooplankton and are therefore sensitive to changes at lower trophic levels. Some seabirds may be able to rapidly shift their distributions depending on restrictions to habitat requirements at particular life stages such as availability of nursery areas, feeding grounds or breeding grounds.

The greatest threat to the Black cod is likely to come from climate-induced changes to the coral reefs where it dwells.

17.11 Principal Management Implications

Managing to increase resilience

By 2070, climate change is likely to have considerable impacts on the physical habitat in the Reserve and on the distribution, abundance and composition of marine species within it. Climate change is therefore likely to considerably reduce the ability of protected area managers to protect and conserve physical habitat in its natural condition, and to conserve populations of all native species.

Climate change in this Reserve may have implications on the seabird populations which utilise this area for breeding, foraging and migration. Key management areas may include the protection of food sources (such as fish stocks) and roosting areas.

Habitat loss, coral bleaching and coral death may negatively affect visitor satisfaction and reduce recreational fishing opportunities through reduced ecosystem function.

Accelerated deterioration of the shipwrecks will impede efforts to protect and maintain the historical and cultural significance of shipwrecks in the Reserve and efforts to improve knowledge of the Reserve's cultural heritage.

Capacity to monitor and enforce marine activities and fishing will require regular review, particularly as circumstances change which affect the livelihood of fishing communities. Illegal fishing activities are expected to rise and this will exert pressure on existing resources to enforce the law and protect the natural assets of the Reserve.

Increasing decision-making capacity by improving understanding

Currently there are several gaps in knowledge that may prevent Marine Park managers from adequately answering questions regarding resilience, climate change scenarios and sustainable use of the Reserve. Increasing understanding in these areas will in effect increase their decision making capacity. Gaps in knowledge include:

- Species likely to enter the Reserve from more northerly areas, and the potential impacts these species will have on existing values
- Understanding of human pressures through commercial fishing in the vicinity of the Reserve.
- Species may migrate south and therefore be lost from the Reserve
- Co-operative research opportunities with Lord Howe Marine Park, in particular in recognition of potential species movement between Reserves
- Opportunities to monitor the effects of climate change at the Reserve and distinguish climate change effects from those of fisheries and other disturbances
- Baseline information - significant gaps in knowledge exist that could be filled through comprehensive surveys.

More frequent monitoring of coral condition and indicators of potential coral bleaching may be required to facilitate on-going informed decision making.

Maintaining infrastructure and protocols to ensure visitor safety

Existing strategies to ensure visitor safety (including researchers and Park management staff) may no longer be appropriate under changing climatic conditions at the Reserve, in particular increases in storm intensity and sea level. Safety risk assessments, contingency plans, communication strategies and risk control measures may require regular review.

18 Great Australian Bight Marine Park

18.1 Current Management Arrangements

The Great Australian Bight Marine Reserve (Commonwealth Waters) (hereafter referred to as the “Reserve”) was first proclaimed on 17 April 1998 under the *National Parks and Wildlife Conservation Act 1975*. On 4 November 2004, the proclamation was amended so that changes could be made to the boundary description to take into account current mapping practices. Minor technical problems and errors were also corrected.

The Reserve was proclaimed to protect the endangered southern right whale and Australian sea lion (*Neophoca cinerea*) and was established to complement the adjacent State marine reserve, which includes the sanctuary and conservation zones for the southern right whale (*Eubalaena australis*). The State Marine Reserve was declared for the protection of calving waters for the whale species and populations of the Australian sea-lion. Other protected species are also found in the region, such as the great white shark *(Carcharodon carcharias*) and several albatross species (refer to Chapter 18.4 for further detail).

The Reserve was also proclaimed to protect a benthic environment. This area of seafloor is known for its high level of endemic invertebrate species. The Reserve was the first to include an area specifically designed to be a representative region and as an early model for sustainable use management in a protected marine area (DEH 2005).

The Reserve is made up of two adjoining marine reserves established by both the South Australian and Australian governments and extends from State (Coastal) Waters into Commonwealth Waters, covering an area of around 19 700 square kilometres. It has a Marine Mammal Protection Zone and a Benthic Protection Zone and is one of Australia’s largest protected marine areas.

The Reserve forms part of Australia’s National Representative System of Marine Protected Areas, which aims to contribute to the long-term ecological viability of marine and estuarine systems, to maintain ecological processes and systems, and to protect Australia's biological diversity at all levels.

18.2 Bioregional Context

The Reserve is situated adjacent to the south-west coast of South Australia as shown in Error! Reference source not found.. It encompasses the waters and seabed and the subsoil beneath the seabed to a depth of 1000 metres. The Reserve extends from the Head of the Bight, in which these coastal areas are the most important breeding grounds in Australia as well as one of the most important, discrete breeding locations in the world for the southern right whale. The Reserve also protects an area of the continental shelf well known for its highly diverse marine and benthic communities and contains the largest representative sample of the southern continental margin of Australia (DEH 2005).

18.3 Climate and Oceanography

The Great Australian Bight experiences seasonal variation controlled by the position of the subtropical ridge of high pressure (BoM 2007). From November to around April, this ridge is located below the coastline, above the Great Australian Bight, with high pressure systems moving eastward. Cold fronts associated with the southern low pressure system meet the high pressure ridge and sometimes result in rainfall. The most prevalent winds blow from an easterly direction. In summer, thunderstorms may develop due to the convergence of warm moist tropical air. In the colder months (May to October), the subtropical ridge migrates north and prevalent winds come from the northwest to southwest. Frontal systems associated with the depressions travelling eastward have a high significance in determining the weather off the southern coast of South Australia.

Two major ocean currents influence the Great Australian Bight region. The first is the Leeuwin Current, which originates from the warm tropical waters of the Indian Ocean. It passes from west to east during winter and can affect the seafloor environment due to its low salinity and vertical uniformity (DEH 2005). The second significant ocean current is the Flinders Current, which flows westward all year round and from the gyre south of the South Australian coastline.

18.4 Natural Values

The Reserve's natural values include the following:

- Critical Habitat for Endangered Species including southern right whale (*Eubalaena australis*) and Australian Sea-lion (*Neophoca cinerea*);
- The Reserve supports a number of species listed under international agreements such as Bonn, CAMBA and JAMBA. The Reserve also support EPBC listed species including:
  - Seven mammal species including the endangered southern right whale (*Eubalaena australis*) and blue whale (*Balaenoptera musculus*) and the vulnerable humpback whale (*Megaptera novaengliae*); sei whale (*Balaenoptera borealis*); fin whale (*Balaenoptera physalus*); Australian sea lion (*Neophoca cinerea*) and sub-antarctic fur seal (*Arctocephalus tropicalis*); .
  - One fish species - the vulnerable great white shark (*Carcharodon carcharias*);
  - One marine turtle species - the vulnerable leatherback turtle (*Dermochelys coriacea*); and
  - Thirty one migratory species and fifty seven marine listed seabirds including endangered southern giant petrel (*Macronectes giganteus*); amsterdam albatross (*Diomedea amsterdamensis*) tristan albatross (*Diomedea dabbenena*) and

the northern royal albatross (*Diomedea sanfordi*) and the vulnerable blue petrel (*Thalassarche melanophris*); soft-plumaged petrel (*Pterodroma mollis*); northern giant petrel (*Macronectes halli*); royal albatross (*Diomedea epomophora*); gibson's albatross (*Diomedea gibsoni*); sooty albatross (*Phoebetria fusca*); shy albatross (*Thalassarche cauta*); campbell albatross (*Thalassarche impavida*); wandering albatross (*Diomedea exulans*);grey-headed albatross (*Thalassarche chrysostoma*) and black-browed albatross (*Thalassarche melanophris*).

- Unique continental shelf benthic region of high diversity with specific species assemblages. A number of species of high scientific value exist in the region including sponges, bryozoans and undiscovered species.

18.5 Socio-cultural Values

The Reserve boasts one of Australia's best whale watching sites from the Head of the Bight. Many tourists are drawn to the Great Australian Bight to observe the winter gatherings of the southern right whale in its pristine environment. Fishing and boating activities can still take place, but are regulated by the Management Plan.

18.6 Economic Values

The Great Australian Bight supports six Commonwealth fisheries and six major State fisheries. The Reserve is an important fisheries region particularly for the southern bluefin tuna along with southern and eastern scalefish and sharks.

18.7 Existing Pressures on Values

Potential risks to living resources may occur as a result of natural pressures and human activities.

Potential natural pressures include:

- Changes in ocean currents leading to changes in water temperature;
- Climate models predict decreases in mixed layer depth and increasing stratification in response to warming for large regions of the global ocean, including most Australian waters. This will result in reduced nutrient transport to the surface layer over vast areas of the pelagic zone with repercussions for phytoplankton production (Hobday *et al.* 2006a); and
- Ecological changes as a consequence of range extension, with the introduction of invasive species into the Reserve.

Potential Human-induced pressures include:

- Fishing and trawling activities both current and historic;
- Pollution and marine debris;

- Tourism / human disturbances;
- Introduced species carried by human activities within the Reserve; and
- Mining operations -the resource most likely to be mined in the Reserve is petroleum, in forms of oil and gas. Petroleum exploration in the area has involved seismic testing as well as proposals for core sampling (i.e. drilling into the 'protected' ocean floor).

18.8 Management Responses

In order to achieve the aims of the Reserve, management is currently implementing strategies focused on the following key areas:

- Development and implementation of species recovery plans for example, for the southern right whale, great white shark, marine turtles, albatross and giant petrels;
- Minimising human disturbances to habitats considered important to the survival of species of high conservation significance, particularly the southern right whale and the Australian sea-lion;
- Minimising human disturbances to the seabed in the Reserve in order to contribute towards the protection of the benthic habitat and associated ecological communities and seabed sediments characteristic of the Reserve;
- Restricting access to the Reserve consistent with protecting the conservation values of the Reserve;
- Supporting and encouraging on-going scientific study consistent with protecting the conservation values of the Reserve; and
- Promoting educational resources to enhance public and user awareness of the Reserve's values.

18.9 Climate Change Scenarios

The high range global warming scenarios pertinent to the Reserve are shown in Table 18-1. CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in Table 18-2.

Table 18-1: Climate change scenarios for Great Australian Bight (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor	Current (1975-2004)	2030 Scenarios	2070 Scenarios
Average sea level	0	+17cm	+50cm
CO_2 concentration	353ppm	+165ppm	+365ppm

Table 18-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C
Temperature at 500m depth	Warming of 0.5-1°C
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface winds	Increase of 0-1ms^{-1} surface winds
Surface currents	Decline in strength of surface currents of between 0-1.2ms^{-1}
pH	Decline in pH by 0.2 units

A summary of the potential impacts of climate change on the Reserve's values are described below. Implications of climate change on management of the Reserve are also discussed.

18.10 Summary of Potential Climate Change Impacts

The values of the Reserve are exposed to a number of challenges associated with climate change as follows.

Changes to water quality and circulation

The Reserve is likely to be most vulnerable to increases in atmospheric CO_2 concentrations and associated changes in ocean circulation and hence productivity. This could potentially impact on southern right whale populations, breeding success and food availability.

Increases in atmospheric CO_2 levels will make the ocean more acidic. Increasing acidity adversely affects many organisms that use calcium carbonate for their skeletons and shells, including corals, molluscs and some phytoplankton species.

The large changes in the sea-surface temperatures will likely have a strong effect on the ranges of many fish species and assemblages in this region which will be seen through a tendency for shifts in species distributions poleward and towards newly appropriate thermo-habitats and shifted food resources (Hobday *et al*. 2006a).

More specifically, increasing sea surface temperature may result in a shift in phytoplankton community composition towards warm-water species, reductions in the abundance of the existing phytoplankton flora and changes in the timing of phytoplankton. Phytoplankton is the primary source of organic material and energy in oceanic food webs.

In general, climate model simulations of climate change predict oceanic warming; an increase in oceanic stratification; changes in circulation and convective overturning; and changes in cloud cover and sea ice and thus light supply to the surface ocean. All these will cause significant and sometimes dramatic alterations in marine ecosystems (Hobday *et al*. 2006a).

Changes to storm intensity

Increasing storm intensity in the reserve has the potential to disrupt on-going research and monitoring programs. These programs are vital to providing sufficient information on the ecology of the reserve to build resilience to human induced pressures. Examples of research in the area include the ongoing monitoring of southern right whale numbers and the interactions of sea lions with fishing vessels (pers comm. P.Anderson).

Loss of biodiversity and increased rates of extinction

Changes to phytoplankton in the region of the Reserve are likely to have significant consequences for the diverse benthic communities of the Reserve and commercially valuable species that it supports. Studies have projected that the expected increases in Australian ocean temperatures would cause a 35% overall economic decline of Australian fisheries by 2070 and that temperate Australian fisheries will be more vulnerable than tropical ones (Hobday *et al*. 2006a).

Warming will not only affect surface waters, but will also penetrate deep into the ocean, warming waters down to 500m and beyond. The depth of the mixed depth layer affects sea surface temperature, the supply of light and nutrients to phytoplankton, and phytoplankton sinking losses. Mixing depth therefore strongly affects phytoplankton production and abundance in surface waters and deeper. A shallowing of the mixed layer may therefore affect phytoplankton production and community structure in the entire water column.

Increased competition, disease and pest outbreaks

Changes in ocean currents, temperatures and stratification will lead to increasing competition over limited resources. New species to the reserve may be introduced as part of natural range extension in response to climate change. Introduced species may create stressful conditions under which the existing fauna and flora may be at heightened risk to disease and vulnerable to pest outbreaks.

18.11 Principal Management Implications

Managing to increase resilience

Currently the Reserve facilitates a multi use approach to management and this exerts a range of pressures on marine life. Management focus must remain on minimising these external stresses and consequently building the resilience of the Reserve to negative affects from climate change. In particular, more information is needed to adequately assess the current impact of both commercial fisheries and of mining activities within the Reserve.

Increasing decision-making capacity by improving knowledge

Conservation and management efforts within the Reserve are currently focused on a few species of major significance. A greater understanding of the overall ecology of the Reserve would support on-going informed decision making aimed at maintaining conservation values. This would require regular review of capacity and resources allocated to improving knowledge of the ecological diversity of the Reserve and the fundamental ocean characteristics that support this biological diversity.

Significant scientific monitoring and research is required before the Reserve is sufficiently well understood, both to manage the existing biological assets and then to consider the additional threats posed by climate change.

This Reserve (due to its southerly location) may provide an early warning sign for climate change affects such as changes to ocean productivity. This information may have far reaching impacts on other MPAs and on the viability of regional commercial fisheries. Regular strategic Government reviews of the relative importance of marine monitoring data for building resilience to climate change would support the appropriate allocation of funds to monitoring and research efforts within the Reserve.

Further research and monitoring of nutrient availability in the Reserve and surrounding waters, measured through phytoplankton response may provide an on-going measure of ecosystem health and vulnerability.

The long term implications for the Reserve are dependant on primary ocean characteristics, including current patterns, temperatures and nutrient availability. Much of this knowledge required to inform decisions on management of the reserve will be gathered by third parties. A report by the Centre for Resource and Environmental Studies has suggested the development of a centralised database for information sharing between reserve managers (CRES 2006). Such a concept could be extended to further centralise ocean research and enhance data availability on primary ocean characteristics and thereby improve information exchange between research scientists, oceanographers and those responsible for MPAs.

19 Heard Island and McDonald Island Marine Reserve

19.1 Current Management Arrangements

The Heard Island and McDonald Islands Marine Reserve (hereafter referred to as the Reserve) was proclaimed on the 16th October 2002. The Reserve is managed by the Australian Antarctic Division of the Department of the Environmental and Water, under delegation from the Director of National Parks, in accordance with the Reserve Management Plan 2005.

The Reserve forms part of Australia's National Representative System of Marine Protected Areas, which aims to contribute to the long-term ecological viability of marine and estuarine systems, to maintain ecological processes and systems, and to protect Australia's biological diversity at all levels. The Reserve is of outstanding national and international conservation significance and the following national and international conventions agreements are relevant to the Reserve:

- Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention);
- Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention);
- Convention on the Conservation of Antarctic Marine Living Resources;
- Agreement on the Conservation of Albatrosses and Petrels;
- Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention);
- Agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds and Birds in Danger of Extinction and their Environment (JAMBA);
- Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and Birds and their Environment (CAMBA);
- Treaty between the Government of Australia and the Government of the French Republic on Cooperation in the Maritime Areas Adjacent to the French Southern and Antarctic Territories, Heard Island and the McDonald Islands;
- Directory of Important Wetlands in Australia;
- Register of the National Estate; and
- National Heritage List.

19.2 Bioregional Context

The Australian Territory of Heard Island and McDonald Islands (HIMI) lies in a remote location near the meeting-point of sub Antarctic surface waters and colder Antarctic surface waters. HIMI is an external territory of Australia in the Indian Ocean sector of the Southern Ocean at around 53° 05' S and 73° 30' E (AAD, 2005). It lies about 1500 km north of Antarctica and over 4000 km south-west of Australia. Heard Island is around 43 kilometres long, dominated by a heavily glaciated circular volcano called 'Big Ben'. The McDonald Islands, approximately 40 km to the west, have also recently experienced change due to volcanic activity.

The Reserve is Australia's second largest marine protected area with full protection from fishing, after the Great Barrier Reef. It covers an area of around 6.5 million hectares. The Reserve includes the islands and the surrounding territorial waters (12 nautical miles), plus additional marine areas that extend in parts to the Exclusive Economic Zone boundary.

There is no local human population at HIMI. The area's extreme isolation and severe climate have also meant that visitational human access has been minimal. Since the sealing period of the mid-late 1800s, human activities have had little negative effect on the Reserve. Thus the Reserve remains one of the world's most pristine regions.

19.3 Climate and Oceanography

The climate of Heard Island and McDonald Island region is strongly influenced by its mid-latitude location in the Southern Ocean, south of the Antarctic Polar Front and in a zone of strong and persistent westerly winds (known as the furious fifties) associated with deep low-pressure systems. The islands exhibit low seasonal and daily temperatures in the region, frequent precipitation, and strong winds along with persistent and generally low cloud cover due to their maritime setting (AAD 2005).

The local climate on Heard Island is significantly influenced by its perennial ice cover and mountainous nature, particularly the orographic effects of Big Ben (a massive volcanic cone between 18 and 20km in diameter that rises to a height of 2745m) on precipitation, snow accumulation and cloud cover. On the other hand, the relatively low lying McDonald Islands are free of permanent ice and, while windy, do not experience the highly changeable conditions of Heard Island (AAD 2005).

19.4 Natural Values

The waters surrounding the islands provide important benthic habitats that support unique marine species. The Reserve also contains important terrestrial and marine breeding areas for fish, seabird and seal species such as the southern giant petrel, *Macronectes giganteus* and southern elephant seal, *Migrounga leonina*. The waters surrounding the islands also provide valuable foraging grounds for land-based marine predators such as king penguins (*Aptenodytes patagonicus*), macaroni penguins

(*Eudyptes chrysolophus*), black-browed albatross (*Diomeda melanophrys*), antarctic fur seal (*Arctocephalus gazelle*) and the leopard seal (*Hydrurga leptonyx*).

Specific natural values of the Reserve include:

- World heritage listed for outstanding universal natural heritage values;
- The islands contain outstanding examples of physical and biological processes continuing in an essentially undisturbed environment;
- The islands are also the only major sub Antarctic island group free of human introduced species and with negligible modification by humans. It provides a classic example of a sub Antarctic island group with low species diversity and large populations of certain species;
- Distinctive natural geographical features;
- The region displays ongoing geomorphic processes such as the role of crustal plates and the formation of ocean basins and continents;
- Unique benthic habitat for vulnerable marine species;
- Foraging grounds for threatened species such as birds and seals under the *EPBC Act* – one endangered, 10 vulnerable, 14 migratory and 51 marine listed fauna species including the grey headed albatross (*Tahlassarche chrysostoma*) and the southern elephant seal (*Mirounga leonina*);
- Migratory Species (Bonn) Convention for 12 of 98 listed Australian species including the greenshank (*Tringa nebularia*), the southern right whale (*Balaena australis*) and the dusky dolphin (*Lagenorhynchus obscurus*);
- China- Australia Migratory Birds Agreement for 1 of 81 listed species (the greenshank, *Tringa nebularia*);
- Japan-Australia Migratory Birds Agreement for 4 of 76 listed species including the greenshank (*Tringa nebularia*), the south polar skua (*Catharacta maccormicki),* the wandering albatross (*Diomeda exulans*) and the Wilson's storm petrel (*Oceanites oceanicus*); and
- Some areas of the HIMI exhibit significant wetland features and processes and also provide habitat for a number of wetland species. The Reserve has been rated as the most important Commonwealth-managed wetland when assessed against criteria for wetlands of international importance. Consideration is also being given to nominating the Territory as a wetland of international importance under Ramsar criteria.

(Source: AAD 2005)

19.5 Socio-cultural Values

The socio-cultural values of the Reserve include:

- Evidence of sealing activities on Heard Island in the mid- to late-1800s is still present. These include stone platforms made from cobbles, surrounded by seal wallows where working activities took place. The ruins of huts built from a range of materials are found on most sealing beaches;
- A number of shipwrecks have been lost or wrecked at Heard Island during the sealing period. No specific locations of wrecked ships are known but shipwreck material has been recorded at Walrus Beach, Skua Beach and the northern beach at Spit Bay. These remains and any others from shipwrecks over 75 years old are automatically classified as historic shipwrecks under the *Historic Shipwrecks Act 1976*;
- Heard Island contains significant cultural relics and heritage sites from the first Australian National Antarctic Research Expeditions in the late 19^{th} and early 20^{th} centuries; and
- The Reserve constitutes a uniquely appropriate location for conducting scientific research into global warming, environmental change and its consequences, due to a combination of the islands' position south of the Antarctic Polar Frontal Zone (APFZ), the presence of permanent ice caps and retreating glaciers, the simple vascular flora, and vegetation communities free from the confounding influences of introduced herbivores.

(Source: AAD 2005)

19.6 Existing Pressures on Values

Potential risks to the values of the Reserve may occur as a result of natural pressures and human activities.

Potential natural pressures include:

- Natural processes such as volcanism, coastal erosion, severe storms and glacial deposition and retreat, severe storms, natural arrival and establishment of new species and increasing, decreasing or relocated wildlife populations have to potential to exert pressures on the natural values of the Reserve;
- Specifically, natural disturbance to ice-free areas, and the creation of new ice-free areas, through general weathering, coastal erosion landslips, glacial retreat or wildlife trampling, can result in the loss of cultural heritage sites and also the favours the establishment of new species, including non native species; and
- The current increasing population of fur seals and king penguins may result in increased pressures through trampling of vegetation, eutrophication of waterbodies, competition with other wildlife for breeding sites, disturbance to seabird nesting sites and impacts on the surrounding marine ecosystem through increased competition for food sources.

Potential human-induced pressures include:

- Human introduction and spread of invasive species Introduction of pest species via ships ballast water and on clothing, equipment etc. There are currently no known alien species on McDonald Island and only four known introduced terrestrial species on Heard Island. These include the vascular plant *Poa annua,* the thrip *Apterothrips apteris,* the mite *Tyrophagus putrescentiae,* and the worm *Dendrodrilus rubidus*;
- Human induced wildlife and physical disturbance. This disturbance can occur through the intentional catching and manipulation of animals, and disturbance of natural habitat from human activity related to research, tourism and shipping; and
- Terrestrial and marine pollution. Marine pollution can take the form of fuels and oil spills, sewage or wastewater discharge and the introduction of anthropogenic marine debris. Terrestrial pollution, whilst minimal, can have a negative impact on the natural values and comes in the form of human waste, litter and grey water.

19.7 Management Responses

The Reserve Management Plan identifies climate change as a key issue for the Reserve, both as a driver of change to environmental values and as a driver for research to understand the consequences of climate warming. The management plan details a range of research and monitoring priorities which acknowledge the significant costs and logistical difficulties with accessing the Reserve. These priorities are detailed to better understand climate change effects, and provide a range of practical management actions. For example, the management plan includes provisions to achieve the following aims:

- Conducting and supporting research in the Reserve, including that which:
  - will contribute to the effective management of the Reserve and the surrounding region;
  - will contribute to the national and international conservation initiatives, including requirements to report on the state of the Reserve; and
  - is of intrinsic benefit to science and humanity provided it does not adversely impact on, or put at risk, the Reserve’s values.
- Protecting the native flora and fauna of the Reserve by managing human activities to minimise or avoid disturbance; and
- Preventing the human introduction of alien species or disease and responding to reports of such events to minimise impacts on the Reserve’s values.

19.8 Climate Change Scenarios

There are no specific climate change scenarios or projections for the Reserve; however, Table 19-1 shows Australian regional scenarios that can be applied. CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in Table 19-2.

Table 19-1: Australian regional climate change scenarios that can be applied to Heard and McDonald Islands (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor	Current (1975-2004)	2030 Scenarios	2070 Scenarios
Average sea level	0	+17cm	+50cm
CO_2 concentration	353ppm	+165ppm	+365ppm

Table 19-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*. 2006a)

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C
Temperature at 500m depth	Warming of 0.5-1°C
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface winds	Increase of 0-1ms^{-1} surface winds
Surface currents	Decline in strength of surface currents of between 0-1.2ms^{-1}
pH	Decline in pH by 0.2 units

A summary of the potential impacts of climate change on the values identified for the Reserve are described below. Implications of climate change on management of the Reserve are also discussed.

19.9 Summary of Potential Climate Change Impacts

Despite gaps in specific climate change projections for this region the above indicators provide a guide to projected change.

Increased air and surface water temperature

Considerable evidence of climate change already exists for Heard Island, particularly as a consequence of temperature change. A one degree increase in annual average temperature has been observed since 1948. As a consequence glacial retreat has been recorded, including the formation of lagoons and freshwater lakes, as well as newly exposed land areas for colonisation by local flora and fauna. The recession and intermittent advance of glaciers on the islands correlates well with changes in sea surface temperatures and air temperatures (AAD 2005).

The combination of rapid glacial recession and climate warming on Heard Island has resulted in the production of one of the most rapidly changing physical settings in the sub Antarctic. The resulting increase in ice-free areas has resulted in marked changes in the structure and composition of vegetation communities on Heard Island. This has the potential to further change the structures and distribution of the wider ecological community. Whilst native species will generally colonise these newly exposed areas, this also provides an opportunity for colonisation by non-native species. One example is *Poa annua* a cosmopolitan grass native to Europe and the only recorded non-native plant species on Heard Island, which has shown increases in density and abundance since it was first recorded on the island in 1987 (AAD 2005).

Changes in air and sea surface temperatures can result in changes in species range and distribution. This is likely to increase the probability of alien species becoming established in the Reserve and may also enhance the impacts of alien species that have become established (AAD 2005).

Climate impacts on long-lived benthic invertebrate species such as sponges and some calcareous species, some of which have decadal and perhaps century-long life spans, are unknown.

Changes to food availability

Climate change, through increased sea surface temperatures and changes to current activity may alter the abundance of food stocks, with repercussions for all marine life including fish, seabirds and top marine predators such as marine mammals. Krill and pteropods (a type of mollusc) are considered to be keystone species, organisms which very many predators such as some species of whale (i.e. Killer whale, *Orcinus orca*) and seals (i.e. the New Zealand, Antarctic and Sub Antarctic fur seals, *Arctocephalus fosteri, Arctocephalus gazelle* and *Arctocephalus tropicalis*) depend. Antarctic krill (*Euphausia superba*) stocks in the Southern Ocean have declined since the 1970s possibly due to a contraction in the extent of the sea-ice due to warmer ocean temperatures. The potential for a further decline in population is a likely scenario under the influence of continued global warming (CRES 2006).

The implications of declining ocean productivity will be far reaching and current staffing and resources to monitor the effects may not be adequate. Areas for on-going investment of resources and research efforts might include:

- Measurement and monitoring of ocean productivity in the southern oceans;
- The impacts of declining ocean productivity on atmospheric carbon dioxide concentrations;
- The impacts of declining ocean productivity on sustainable commercial fish catch;

- Impacts on the behaviour and migration patterns of marine mammals.

Sea level rise

Sea level rise and the impacts of storm surges will result in inundation and erosion of coastal land and will impact on terrestrial habitat. Combined with other climatic factors such as rising temperatures, sea level rise will contribute to changing the composition of ecological communities.

Changes to breeding and migration patterns

Shifts in the timing of Antarctic seabird breeding and peak migration dates have already been observed. Climate change is also likely to cause altered reproductive success and loss of nesting and feeding habitats. The timing and abundance of populations of seabirds in the Marine Park is therefore likely to change.

19.10 Principal Management Implications

The principal management implications do not change current practice outlined in the recently produced management plan for this hugely important Reserve.

Managing to increase resilience

- It is likely that the Reserve will receive continuing visitation due to its scientific value, including for climate change studies. The strict controls detailed in the management plan will therefore need to be maintained at a high standard; and
- The existing vulnerable species and habitats within the Reserve are likely to change as a consequence of climate change, requiring ongoing monitoring as practical with available budgets and resources.

Increasing decision-making capacity by improving understanding

In light of the pace of climate change and considering latent effects upon ocean systems the importance of undertaking scientific study within the Reserve is paramount. The Reserve presents unique opportunities to research and monitor the impacts of climate change on relatively undisturbed ecosystems and to specifically study the ecological implications of significant climate induced changes such as glacial retreat and declining ocean productivity. Lessons leant through monitoring and research at Heard and McDonald Islands may provide valuable information for the conservation of other Commonwealth Protected Areas.

Current knowledge gaps for the Reserve include, but may not be limited to, the following:

- The identification of species particularly at risk is unknown. Research to identify these species will inform strategies to preserve species including ex-situ preservation options. In this instance, further research will be needed into suitable locations for terrestrial and marine species; and
- Due to costs and logistical restrictions on access, Reserve managers will be increasingly reliant on data provided by satellite imagery / remote sensing for monitoring and responding to climate change impacts on the reserve. Investment and capacity available to utilise such resources is currently unknown.

The following research and monitoring priorities to address knowledge gaps relating to climate change effects are identified in the management plan:

- Comprehensive surveys of indigenous species to provide baseline information against which to compare human introduced or otherwise newly colonized terrestrial, freshwater and marine species;
- Monitoring of the area and extent of newly deglaciated land and decrease in ice covered land, including the colonisation of this land by plants and animals;
- Long term climate monitoring and knowledge of the Reserves biodiversity and its response to current conditions and climate change; and
- Long term changes to the coastline, glacial landscape and other features of the Reserve.

Maintaining infrastructure and protocols to ensure visitor safety

- The Marine Park will potentially be exposed to more severe weather events including intense storm activity that could compromise safety and communications. As a consequence of rapid change in climate, safety protocols and procedures will need to be reviewed regularly to ensure that they are appropriate and the risks have been fully considered; and
- The infrastructure available to support visitation should be reviewed based on the identified climate change projections. This should include consideration of jetties and moorings, shelters and accommodation.

20 Lord Howe Island Marine Park (Commonwealth Waters)

20.1 Current Management Arrangements

Lord Howe Island Marine Park (hereafter referred to as the Marine Park) was proclaimed on the 21 June 2000 under the *National Parks and Wildlife Conservation Act 1975.*

The Lord Howe Island Group, which includes Lord Howe Island, the Admiralty Islands, Muttonbird Island, Blackburn Island, Gower Island and Balls Pyramid, was inscribed on the World Heritage List in 1982. The listing of Lord Howe Island as a World Heritage Property was based on its superlative natural phenomena, exceptional natural beauty and aesthetic importance and the importance and significance of its natural habitats for in-situ conservation of biological diversity. The NSW State Water component of the Marine Park extends to 3 nautical miles (nms) around Lord Howe Island and Ball's Pyramid. The Commonwealth component extends from 3nms to 12nms roughly corresponding to the 1800 metre depth contour at its outer limit.

Lord Howe is of particular significance for its unique environment with many species at their southerly range.

20.2 Bioregional Context

Lord Howe Island is located in the south-west Pacific Ocean, approximately 760km north-east of Sydney at 31^{o} 30 S, 159^{o} 05 E. The island is 11 kilometres long and 2.8 kilometres wide at its widest point.

There are clear interface and interactions between the Commonwealth and NSW Waters of Lord Howe Island Marine Park. However, there is some debate as to whether Lord Howe Island reefs are reliant on replenishment of larvae from the Great Barrier Reef or from local brooding corals (CRES 2006).

Within the State National Park sits Lord Howe Island, the eroded remnant of a large shield volcano. A series of eruptions followed by erosion processes began about 6.9 million years ago. This was followed by another period of volcanic activity 6.3 million years ago. The Island sits atop a large undersea shelf which is many times larger than the Island itself. All of the offshore Islands in the Lord Howe Island group are basalt.

20.3 Climate and Oceanography

Lord Howe Island is particularly exposed to weather extremes. During summer, winds are predominantly from the east and northeast and may exceed 30 kilometres an hour (km/h) (17 knots), while winter winds are normally from the south-west and commonly exceed 40 km/h (22 knots). Gales, with winds in excess of 34 knots, can be expected on an average of 3 days per month during winter. Other strong winds occur, on average, between 4 and 7 days per month throughout the year (Lord Howe Island Board, 1985). Lord Howe Island and surrounding waters are also subject to major storm events and occasional cyclonic activity.

The maritime setting ensures little diurnal or annual variation in temperature, with summer temperatures ranging from 17–25ºC and winter temperatures from 14–18ºC. Water temperatures vary from 17ºC in winter to 25ºC in late summer (Hutton 1986). The average rainfall is 1586 mm, most of which falls in winter. The average number of rain days for the year is 190. Humidity is moderate to high at about 70–77 per cent.

Lord Howe Island has its own microclimate. This is brought about by the confluence of a number of factors. The first is Mount Gower which stands at 28,750 ft (875 m). The second is the East Australian Current (EAC) which brings warm water from the New Hebrides, stabilising the year round water temperature (while feeding the local corals with nutrients).

During summer months the high pressure cells are well to the south of Lord Howe and fresh easterly winds predominate. Periodic influx of moist tropical air occurs, making for still, humid conditions. Tropical cyclones do not occur at the latitude of Lord Howe. During winter months the high pressure cells are located about the latitude of the Island. There is a progression of these cells from west to east, with a cold front between adjacent cells.

20.4 Natural Values

The natural values of the Marine Park include:

- High species abundance and diversity, especially in the sea mount areas;
- Rare example of a transitional algal and coral reef;
- The world’s southernmost locality exhibiting a well-developed barrier coral reef community and associated lagoon (Allen *et al*. 1976);
- Potential for finding little or unknown species due to deep water ecosystems;
- Feeding and resting site for listed seabirds and migratory shorebirds; and
- Occurrence of rare and potentially threatened species.

20.5 Economic Values

The economic values of the Marine Park include:

- Recreational diving and fishing supported by commercial charters;
- Commercial fishing; and

- Commercial diving.

20.6 Existing Pressures on Values

Potential risks to the values of the Marine Park may occur as a result of natural pressures and human activities.

Potential natural pressures include:

- Modification of the East Australian Current due to climate resulting in introduced species and alterations to the natural environment; and
- Coral death cause by natural predators such as crown-of-thorns starfish (*Acanthaster planci*).

Potential human-induced pressures include:

- Unsustainable harvesting of species;
- Introduction of exotic species via ballast water and coastal shipping movements between domestic ports;
- Pollution in the form of oil, marine debris and sewage can result from a number of sources including boating and recreation within the Reserve, from ships in transit and from shipwrecks;
- Environmental damage caused by human activity.

20.7 Management Responses

In order to achieve the aims of the Marine Park, management is currently implementing strategies focused on the following key areas:

- To protect, promote awareness and provide a framework for the conservation values associated with marine biological diversity, marine habitats and marine ecological and geological processes associated with the Lord Howe Island seamount and its marine environs;
- To provide a management and planning process that will allow the community to maintain their involvement in the protection of the marine environment that is central to the traditions and lifestyle of the Island community; and
- To add a representative sample of the Lord Howe Island marine environs (habitats, species and ecological processes) to the National Representative System of Marine Protected Areas.

20.8 Climate Change Scenarios

The high range global warming scenarios pertinent to the Marine Park are shown in Table 20-1. CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in Table 20-2.

Table 20-1: Climate change scenarios for NSW (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor	Current (1975-2004)	2030 Scenarios	2070 Scenarios
Average sea level	0	+17cm	+50cm
CO_2 concentration	353ppm	+165ppm	+365ppm

Table 20-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C
Temperature at 500m depth	Warming of 0.5-1°C
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface winds	Increase of 0-1ms^{-1} surface winds
Surface currents	Decline in strength of surface currents of between 0-1.2ms^{-1}
pH	Decline in pH by 0.2 units

A summary of the potential impacts of climate change on the values identified for the Marine Park are described below. Implications of climate change on management of the Reserve are also discussed.

20.9 Summary of Potential Climate Change Impacts

The values of the Lord Howe Marine Park are exposed to a number of challenges associated with climate change as follows:

Changes to water quality and circulation

- The Park is most vulnerable to increases in atmospheric CO_2 concentrations and consequent increases in sea surface temperatures, increased ocean acidity and potential changes to the East Australian Current;
- Ocean acidification can potentially tip the balance from coral calcification to erosion; atmospheric levels above 500ppm will severely reduce coral viability. Levels above 600ppm will severely compromise the ability of corals to maintain themselves against the forces of physical and biological erosion (Hobday *et al.* 2006a); and
- To date, there are no studies that have examined the sensitivity of cold water coral reef systems to CO_2 induced ocean acidification. However, it is expected that calcification of cold corals are likely to be affected in the same way, or more so, as calcifying organisms at lower latitudes. Current modelling predictions suggest that cold water coral reef systems are likely to face extinction if aragonite saturations levels continue to decline. Thus, not only is the ocean-wide decrease in the aragonite saturation level likely to decrease cold-water coral calcification, large areas of the oceans may also become completely uninhabitable for cold-water corals as the impacts of increased CO_2 are felt.

Changes to sea levels and storm intensity

- The combined impacts of ocean warming, ocean acidification, sea level rise and increased intensity of cyclones are likely to contribute to the degradation of coral reef habitat. Climate change will also cause a loss or shift of species out of the Park and a shift of species into the Park from northern waters.

Loss of biodiversity and increased rates of extinction

- A 2°C warming will potentially lead to annual bleaching of corals and regular large-scale mortality events, and a shift of fish species either to deeper / cooler waters or to more southerly waters. Dependant on frequency of bleaching events - a succession of devastating mass coral-bleaching events would compromise ability of coral to recover;
- Changes to the composition of the Park's biodiversity are likely to develop, potentially adding further pressure on endemic species. The Park contains a unique assemblage of tropical species at, or near, the southern limits of their distribution, and subtropical species that are rare or absent from tropical reefs. Populations of endemic or regionally significant species may also decline where these species are bounded to the south, by for example, lack of available habitat or abundance of prey species. This may be compounded by competition for resources from species entering the Park from northern areas;
- The biodiversity of calcareous shell species including echinoderms and molluscs may reduce as increasing acidity threatens the integrity of the calcium carbonate shelled organisms. Further

monitoring and research efforts are necessary to clarify whether this is the case and whether there are opportunities for mitigation; and

- Some temperate fish species are likely to shift to deeper waters where temperatures are cooler, again resulting in competition for both habitat and food sources.

Increased competition, disease and pest outbreaks

- Recent research indicates that warmer species may have a better adaptive advantage over the cooler species in response to rising sea surface temperatures, an indication that rising sea surface temperatures are promoting the recruitment of tropical coral species. Further work is required to substantiate these claims (CRES 2006).

20.10 Principal Management Implications

Managing to increase resilience

By 2070, climate change is likely to have significant impacts on the physical habitat in the Park and on the distribution, abundance and composition of marine species within it. Climate change is therefore likely to significantly reduce the ability to protect and conserve physical habitat in its natural condition, and to conserve populations of all native species. The elimination or mitigation of non climate related stresses including commercial fishing impacts and marine pollution impacts from the islands and marine operations will therefore become a priority for Marine Park managers.

Additional pressures from climate change may impede the long term ability to maintain existing conservation values.

Capacity to monitor and enforce marine activities and fishing will require regular review, particularly as circumstances change which affect the livelihood of fishing communities. Illegal fishing activities are expected to rise and this will exert pressure on existing resources to enforce the law and protect the natural assets of the Reserve.

Increasing decision-making capacity by increasing understanding

Loss of species abundance and diversity will significantly impede the gathering of knowledge of the natural values of the Park as well as the current threats on those species. Many species will potentially be lost before they are scientifically documented and along with them the understanding of their role in the ecosystem and any potential human benefits.

Currently there are several gaps in knowledge that may prevent Marine Park managers from adequately answering questions regarding resilience, climate change scenarios and sustainable use of the Marine

Park. Increasing understanding in these areas will in effect increase their decision making capacity. Gaps in knowledge include:

- Strategies to increase resilience of seabirds to climate change such as strategies to protect food sources and roosting areas;
- The integrity of habitat within the Park depends on the status of existing water currents, ocean surface water temperatures and ocean acidity. Further study of these relationships to the Park biodiversity values is necessary to understand the complex interactions that exist and to identify biological indicators of change;
- Lord Howe Island provides a unique opportunity to study fish migratory patterns in response to climate and changes in sea water temperatures. Preliminary work has shown that there has been a moderate change in fish migration over the last few years and on-going research is under way to verify if there is a link to climate change. The relationship between fish migration along the Eastern Australian Current (EAC) and changes in sea surface temperature is currently being investigated by Dr David Booth and his colleagues at University of Technology, Sydney (UTS);
- High resolution mapping of marine fish species distribution in some locations has been used in the past for developing risk assessment management strategies and could be expanded. High resolution mapping could assist in the development of a climate change risk assessment management programme for marine life around Lord Howe Island (CRES 2006);
- The effects of recreational fishing management effectiveness are largely unknown. This information would be valuable in climate change risk assessments for vulnerable species;
- There is currently no regular monitoring of pH and temperature at a range of depths within the seamount areas of the reef system. This data may in the future support new technologies that could maintain the required environmental conditions to support the reef;
- A comprehensive survey and risk assessment of marine pests currently impacting upon the Park is needed in order to develop a future climate change management plan;
- Generally it appears that knowledge relating to the recruitment and reproduction of temperate coral species is limited. Similarly for marine invertebrates, very little is known about the biology of smaller-sized taxa or those species that inhabit the deeper water. The importance of the East Australian Current to the structure and diversity of biological communities at Lord Howe and the potential impacts arising as a consequence of changes to this current also requires further monitoring to support management efforts; and
- A better understanding of the extent of genetic diversity amongst endemic fish species may provide some insight into the capacity of some species to adapt to environmental change.

Maintaining infrastructure and protocols to ensure visitor safety

Habitat loss, coral bleaching and coral death may reduce visitor satisfaction and reduce recreational fishing opportunities through reduced ecosystem function. An increase in the likelihood of severe storm events or destabilisation of coral reefs (from the combined effects of increased ocean acidity, increased sea surface temperatures and severe storm events) may also present issues for visitor safety. Current management strategies may need to be revised to take the risks of climate change into account.

21 Macquarie Island Marine Park

21.1 Current Management Arrangements

The Macquarie Island Marine Park was proclaimed on the 27th of October 1999 under the *National Parks and Wildlife Conservation Act 1975* (NPWC Act) to protect the unique and vulnerable marine ecosystems of the south eastern portion of the Macquarie Island Region. The NPWC Act was replaced by the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*) on the 16th of July 2000. In 1997 Macquarie Island and waters within a 12 nautical mile radius were inscribed on the World Heritage List on the basis of its outstanding natural values (Parks and Wildlife Service, Tasmania 2006). The existing Management Plan expires in 2008.

21.2 Bioregional Context

Macquarie Island is located in the Southern Ocean approximately 1500 kilometres south-south-east of Tasmania. The terrestrial environment and the surrounding waters out to three nautical miles are located in the Macquarie Island Marine Reserve (State Waters). Macquarie Island Marine Park (Commonwealth Waters) (hereafter referred to as the Marine Park) extends from 3 nautical miles zones around each of the exposed outcrops (Macquarie Island, Bishop and Clerk Islets, and Judge and Clerk Islets) to the edge of the Australian Exclusive Economic Zone (EEZ).

The Marine Park is divided into a central Highly Protected Zone situated between two highly regulated Habitat/Species Management Zones (Environment Australia 2001).

The Macquarie Island region has unique bio-geographical characteristics and an unusual geological make-up. It is the only known location where oceanic crust from a normal mid ocean ridge (the Macquarie Ridge) has been lifted above sea level in a major oceanic basin (Director of National Parks 2006).

21.3 Climate and Oceanography

The Macquarie Island region experiences a sub Antarctic wet and windy climate with a small variation in temperature both seasonally and diurnally. Also characteristic, are the persistent, strong prevailing west to north-westerly winds. Mean daily maximum temperatures range between 8.8°C in January and 4.9°C in July. Mean daily minima range from 5.3°C in January and February to 1.5°C in June. The highest temperature on record is 14.4°C, recorded in December 1984 and the lowest on record is -9.4 C, recorded in July 2003 (BOM 2007).

Humidity in the region is typically over 85% and can be over 95% up to one third of the time. The mean value of 87% is the highest for any Australian observing station and is due to air rushing over a vast expanse of ice free, wind swept sea (BOM 2007).

Macquarie Island lies just to the north of an oceanic boundary, the Antarctic Polar Frontal Zone or Antarctic Convergence, where cold polar water to the south meets the warmer sub Antarctic water to the north (DEW, Australian Antarctic Division 2006). The Macquarie Ridge, of which Macquarie Island is a part, is one of the world's great oceanic ridges. Its overall north-south orientation causes it to act as a major barrier to the Atlantic Circumpolar Current. This is the Earth's largest and most important oceanic current and flow eastward about the Antarctic landmass. The Current's spatial variation is largely affected by seasonal dynamics and impacts on the balance of oceanic and atmospheric heat and chemical exchange. This in turn has an effect on the southern hemisphere's climatic budget (Environment Australia 2001).

21.4 Natural Values

The natural values of the Marine Park include:

- A variety of large-scale benthic habitats;
- Species under local or global threat (under the IUCN criteria) including the royal penguin *(Eudyptes schlegeli*), blue petrel *(Halobaena caerulea*), Hooker's sea lion (*Phocarctos hookeri)* and Southern elephant seal (*Mirounga leonine*);
- Feeding and migratory areas for marine mammals including species considered nationally significant under the *EPBC act 1999.* Such species include the Weddell seal (*Leptonychotes weddelli*), the killer whale (*Orcinus orca)*and the minke whale (*Balaenoptera acutorostrata*);
- Feeding and migratory areas for 38 species of seabirds including species of national significance under the *EPBC act 1999* and of international significance under the Bonn, CAMBA and JAMBA agreements. Such species include the wandering albatross (*Diomedea exulans),* sooty shearwater (*Puffinus griseus)* and the Black-browed albatross (*Diomedea melanophris)*;
- Highly productive marine areas;
- Habitat and foraging grounds for seal populations. The Marine Park is unique in that it provides the only habitat where New Zealand fur seals (*Arctocephalus forsteri*), Antarctic fur seals (*A. gazelle*) and subantarctic fur seals (*A. tropicalis)* coexist and interbreed. All three species are protected under the *EPBC Act*;
- Killer whales (*Orcinus orca)* are the most commonly sighted whale species, particularly during September to January; and
- The Marine Park represents a substantial portion of the known feeding ground for breeding royal penguins (*Eudyptes schlegeli*) from a small colony on the north-east coast of Macquarie Island. The royal penguins are endemic to Macquarie Island and are considered a vulnerable species under IUCN criteria (Environment Australia, 2001).

21.5 Socio-cultural Values

The socio-cultural values of the Marine Park include:

- The Marine Park is of global significance for science and education (Environment Australia 2001);
- The undisturbed nature of the habitats in the Marine Park provides a valuable resource for research, surveys and monitoring to enhance knowledge of deep-water benthic ecosystems, marine mammal and seabird ecology, and the linkages between benthic and pelagic environments in an area of unusual oceanographic character (Environment Australia 2001);
- The Australian Government Antarctic Division (AGAD) maintains a research station year round on Macquarie Island with several studies into the activities of marine mammals and seabirds; and
- Specific research centre for Patagonian toothfish fishery.

21.6 Existing Pressures on Values

Potential risks to the values of the Marine Park may occur as a result of natural pressures and human activities.

Potential natural pressures include:

- Declining food sources to sustain sea bird populations;
- Increasing competition for resources;
- Invasive species, i.e. Rabbits and rodents on the island;
- Rise in surface ocean water temperatures;
- Increasing frequency and intensity of storms; and
- Increasing ocean stratification and declines in ocean productivity.

Potential human-induced pressures include:

- Commercial fishing activities outside of the Marine Park;
- Future mineral and petroleum exploration and extraction activities;
- Research and tourism activities on Macquarie Island;
- Marine pollution and debris (pers comm. H.Sullivan);
- Tourism in the Southern Ocean and Antarctic region has become increasingly popular with increased interest in conservation values and easier access to these areas; and
- Introduction of pests through ballast water associated with shipping.

21.7 Management Responses

In order to achieve the aims of the Marine Park, management is currently implementing strategies focused on the following key areas:

- Protecting pelagic species and the benthic communities from direct human disturbance;

- Protecting the habitats of threatened species, migratory and foraging marine mammals and seabirds, and benthic and pelagic fauna that depend on the area;
- Promoting scientific research and environmental monitoring as primary activities associated with sustainable resource management and use; and
- Ensuring that research activities have a minimal environmental impact on the conservation values of the Marine Park.

21.8 Climate Change Scenarios

The high range global warming scenarios for the Tasmanian region are shown in Table 21-1. Uncertainty surrounding the projections is shown in brackets. Due to the remote location of Macquarie from the Tasmanian region, these scenarios can be an indication of anticipated direction and degree of change only. CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in Table 21-2.

Table 21-1: Climate change scenarios for Tasmanian region (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

<table>
<tr><th colspan="2">Climate change factor</th><th>Current (1975-2004)</th><th>2030 Scenarios</th><th>2070 Scenarios</th></tr>
<tr><td colspan="2">Annual Average sea level</td><td>0cm</td><td>+17cm</td><td>+50cm</td></tr>
<tr><td colspan="2">Annual average rainfall[25]</td><td>1131mm</td><td>+4% (±11%)</td><td>+11% (±34%)</td></tr>
<tr><td rowspan="4">Seasonal average rainfall</td><td>Summer</td><td>206mm</td><td>-7% (±15%)</td><td>-23% (±45%)</td></tr>
<tr><td>Autumn</td><td>262mm</td><td>+0% (±15%)</td><td>+0% (±45%)</td></tr>
<tr><td>Winter</td><td>358mm</td><td>+4% (±11%)</td><td>+11% (±34%)</td></tr>
<tr><td>Spring</td><td>304mm</td><td>-4% (±11%)</td><td>-11% (±34%)</td></tr>
<tr><td colspan="2">CO_2 concentration</td><td>353ppm</td><td>+165ppm</td><td>+365ppm</td></tr>
</table>

Table 21-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C^
Temperature at 500m depth	Warming of 0.5-1°C
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface currents	Decline in strength of surface currents of between 0-1.2ms^{-1}
pH	Decline in pH by 0.2 units

^ Macquarie Island is located outside of the biogeographic context of these projections. It is anticipated that the rate of warming experienced in the region of the Marine Park will be half or less of the global average (*pers. comm. P Whetton CSIRO*)

25 Uncertainty surrounding annual and seasonal rainfall projections in this region is high. Planning for these impacts will need to take into consideration the possibility that rainfall may increase or decrease.

A summary of the potential impacts of climate change on the values identified for the Marine Park are described below. Implications of climate change on management of the Marine Park are also discussed.

21.9 Summary of Potential Climate Change Impacts

The values of the Marine Park are likely to be most vulnerable to increases in temperature of the sea surface and water at depth, greater stratification and shallowing of the mixed layer and associated changes to food availability. The key climate change impacts on the Marine Park are described below:

Changes to food availability

Climate change, through increased sea surface temperatures and changes to current activity may alter the abundance of food stocks, with repercussions for all marine life including fish, seabirds and top marine predators such as marine mammals. Krill and pteropods (a type of mollusc) are considered to be keystone species, organisms which very many predators such as some species of whale (i.e. killer whale, *Orcinus orca*) and seals (i.e. the New Zealand, Antarctic and Sub Antarctic fur seals, *Arctocephalus fosteri, Arctocephalus gazelle* and *Arctocephalus tropicalis*) depend. Antarctic krill (*Euphausia superba*) stocks in the Southern Ocean have declined since the 1970s possibly due to a contraction in the extent of the sea-ice due to warmer ocean temperatures. The potential for a further decline in population is a likely scenario under the influence of continued global warming (Loeb *et al.* 1997). Changes to food availability associated with climate change are likely to impact on the following species:

- Penguins are a highly specialised group of birds that rely on a relative abundance of prey for their survival and reproductive success. Changes in sea surface temperatures and a shortfall in food resources could be a contributing factor leading to the decline of some penguin populations (i.e. Rockhopper penguins, *Eudyptes chrysocome*) in the Sub-Antarctic region (Cunningham and Moors 1994; Guinard *et al.* 1998); and
- Since the 1960s, southern elephant seal (*Mirounga leonine*) numbers have declined at a rate of 1.2% per year and in 2002 it was estimated that population numbers had declined to less than 50% of the original population of the 1950s (Parks and Wildlife Service, 2003). The decline is thought to be due to a change in the abundance or availability of food brought about by shifts between two climatic systems, namely the Antarctic Circumpolar Wave (ACW) and El Niño Southern Oscillation (ENSO) cycle (McMahon *et al* 2005, Murphy and Reid 2001). ENSO influences the extent of sea-ice retreat (Kwok and Comiso 2002) which in turn can affect the survival and recruitment of krill (Loeb *et al* 1997) and ENSO activity can also influence the sex ratio of southern elephant seals (Vergani *et al* 2004). Further climate change may contribute to a continuing decline in numbers.

The capacity for these species to adapt to changes in climate and food availability may depend on the species' ability to forage for food over greater distances. There will also be additional pressures on migratory species and marine mammals that nest or breed on Macquarie Island which will be susceptible to sea level rise, increases in atmospheric temperatures, changes to rainfall patterns and increased incidence of disease or invasion by exotic flora and fauna (i.e. rabbit and rodent populations).

Increased threat of disease

Two species of albatross, the wandering albatross (*Diomedea exulans*) and grey-headed albatross (*Thalassarche chrysostoma*) have been listed under the *EPBC Act* as vulnerable to extinction. Currently, fishing activities pose the greatest threat to the survival of these birds rather than from climate change. However, it has been reported that the spread of avian cholera in albatross and large petrel populations could become a greater threat with further increases in global warming (Weimerskirch, 2004).

Changes to breeding and migration patterns

Shifts in the timing of Antarctic seabird breeding and peak migration dates have already been observed. Climate change is also likely to cause altered reproductive success and loss of nesting and feeding habitats. The timing and abundance of populations of seabirds in the Marine Park is therefore likely to change.

Changes to benthic habitat and species

Aragonite is the only form of calcium carbonate readily available in the Southern Ocean for calcareous species such as molluscs. As atmospheric CO_2 levels increase, the depth of the aragonite saturation horizon will decrease with projections that the entire Southern Ocean could become under saturated by 2100 (Hobday *et a*l. 2006a). As a result calcareous shell species may not be able to maintain shell integrity in a more acidic ocean reducing the overall biodiversity of these species. Warming will not only affect surface waters, but will also penetrate deep into the ocean, warming waters down to 500m and beyond. Warming may see some populations of benthic and demersal species decline where ranges are bounded to the south. This may have significant implications for the benthic ecosystem of the Marine Park; potentially causing the extinction of species that may or may not yet be known to science.

21.10 Principal Management Implications

Managing to increase resilience by reducing human impacts

- Direct human disturbance may reduce the resilience of pelagic species, benthic communities, the threatened species, migratory and foraging marine mammals and seabirds to climate change. Some of these species are likely to be extremely slow to recover from disturbance. Protecting these species and communities from disturbance will therefore become a priority;

- Climate change is likely to place additional pressure on habitat and species within the Marine Park. Existing strategies to protect habitats and species from pollution, marine debris, invasion by exotic species and disease and research activities will remain essential to build resilience to the impacts of climate change;
- Marine debris surveys and collection will be increasingly important to build resilience to the impacts of climate change;
- Pest eradication programs on Macquarie Island will have increasing significance and will be an important means of building resilience for fauna that frequent both the terrestrial and marine environment of Macquarie Island;
- Seabirds such as albatross spend considerable amount of time in waters that are outside of the MPA and are therefore particularly susceptible to commercial fishing. Best practice commercial fishing operations in the vicinity of the Marine Park will become a priority assisting to minimise seabird mortality and building ecosystem resilience to climate change; and

Increasing decision-making capacity by improving understanding

Climate change is likely to place additional pressures on the marine environment, in particular through changes to food availability and associated impacts on higher trophic levels. Scientific research and environmental monitoring of key indicators of climate change will be increasingly important in order to build resilience. Particular knowledge gaps include, but may not be limited to, the following:

- Currently, no baseline data exists for species presence and abundance in the Marine Park.
- Whilst the potential impacts on terrestrial biodiversity on Macquarie Island have been investigated to some degree, little material is available on the potential impacts of climate change on the marine environment around the Island;
- The interaction between rising sea surface temperatures, sheet ice contraction and food supply requires further investigation. The interactions between ENSO activity rising temperatures and changes in food supply are also largely unknown.

The risks posed by climate change may have implications for the content of threatened species recovery plans for southern right whale (*Eubalaena australis*); sub Antarctic fur seal (*Arctocephalus tropicalis*) and southern elephant seal (*Mirounda leonine*);

Climate change, through increases in sea surface temperatures and associated alterations to food availability may impact on the biological values of the Park. Existing management strategies and recovery plans will require regular update (annually or every two years) to incorporate these potential impacts.

The risks posed by climate change may have implications for the content of threatened species recovery plan for albatross (*Diomeda* spp and *Thalassarche* spp.) giant petrels (*Macronectes* spp.) and other seabird species.

Maintaining infrastructure and protocols to ensure visitor safety

- The Marine Park will potentially be exposed to more severe weather events including intense storm activity that could compromise safety and communications. As a consequence of rapid change in climate, safety protocols and procedures will need to be reviewed regularly to ensure that they are appropriate and the risks have been fully considered; and
- The infrastructure available to support visitation should be reviewed based on the identified climate change projections. This should include consideration of jetties and moorings, shelters and accommodation.

22 Mermaid Reef Marine National Nature Reserve

22.1 Current Management Arrangements

The Mermaid Reef Marine National Nature Reserve (hereafter referred to as “the Reserve”) was declared in 1991 for the primary purposes of protecting the diverse and abundant marine life; and encouraging sustainable recreational use of the area.

The Reserve is managed through service level agreements between the Director of National Parks and the Western Australian Department of Environment and Conservation and also with the Western Australian Department of Fisheries. These agencies cooperate in implementing management activities, such as routine monitoring and liaising with commercial tour operators. Coastwatch provides aerial surveillance of the reserve and WA Fisheries provides surface patrols.

The first management plan expired on 16 May 2007. A draft of the second plan is due to be released for public comment in mid 2007. Until the second plan takes effect, the Reserve will be managed through an approvals process in a manner consistent with its status as an IUCN Category Ia protected area.

22.2 Bioregional Context

Mermaid Reef is located at 17°06' south, 119°38' east. It is the most northerly of the three reefs in the Rowley Shoals. The reef is totally submerged at high tide and therefore falls under Commonwealth jurisdiction. The Reserve encompasses an area of 53,987 hectares within the Provincial Bioregion #3 (Northwest Transition) according to the Benthic Marine Bioregionalisation of Australia’s Exclusive Economic Zone (Heap *et al*. 2005). Within the Northwest Transition, Mermaid Reef is one of the only three pinnacles surrounded by reef. Clerke Reef and Imperieuse Reef, the two southerly reefs, have permanent sand cays above the high water mark. Together they were incorporated into the Rowley Shoals Marine Park, declared under Western Australian legislation on 25 May 1990.

The three reefs of the Rowley Shoals have been described as the most morphologically perfect examples of shelf-edge reefs occurring in Australian waters. Fauna surveys show that Mermaid Reef and the other Rowley Shoals reefs harbour a rich and diverse fauna that is regionally important including species not occurring elsewhere in Western Australia, some endemics and others at the limit of their known distribution. Fauna in the reef show strong affinities with reefs of the Indonesian Region and are more closely allied to these reefs than to the inshore reefs of Western Australia. The coral communities are one of the special values of Mermaid Reef.

Approximately 100-200 visitors enter the Reserve each year, including tourists and commercial tour operators, scientists, photographers and journalists.

The significance of the Reserve can be defined in terms of its natural, cultural and economic values as well as its contribution to global conservation, as identified below.

22.3 Climate and Oceanography

The climate at Mermaid reef is arid-tropical, where rainfall is restricted to short monsoon periods. Cyclones typically form in between January-April. The area experiences an average of 25 rain days per annum. Most precipitation occurs in the December-March monsoonal period and from epitropical storms in late autumn-early winter.

The currents affecting the Rowley Shoals are important in determining water characteristics such as temperature and clarity and also influence the dispersal and mixing of sediment, biota and pollutants to and within the reefs. The Leeuwin current affects the Rowley Shoals during the months of February to June when it flows from the north-east to the south-west. Regional surface currents flow southwards from approximately February to June and northwards from approximately July to February. The seasonal reversal of surface circulation around mid July corresponds with a weakening of the Leeuwin current in the north-west region, (AIMS 2007).

The Rowley Shoals experience a semi-diurnal (twice daily) tidal cycle with a spring range of about 4.5 metres. Tidal range in the lagoons is reduced due to the emergent reef rim which impounds water within the lagoons. This also explains the lack of both a localised surf zone and well defined algal reef crest or boulder zone (UNEP/IUCN 1988). Mean sea surface temperatures in the Rowley Shoals area vary from about 25°C in winter to a peak of about 30°C in March and April (Holloway and Nye 1985). The prevailing swells are from the south-west and this causes formation of wider reef flats on the western margins of each shoal.

22.4 Natural Values

The natural values of the Reserve include:

- High species diversity and abundance, including the EPBC listed species such as the vulnerable green turtle (*Chelonia mydas).*
- Pristine water quality;
- Feeding and resting site for CAMBA and JAMBA listed seabirds and migratory shorebirds. Sighted listed species include the ruddy turnstone (*Arenaria intrepres),* white tailed tropic bird (*Phaethon lepturus),* brown booby *(Sula leucogaster*), least frigate bird (*Fregata ariel*), eastern reef egret (*Egretta sacra*), white-bellied sea eagle (*Haliaeetus leucogaster*), eastern curlew (*Numenius madagascariensis*), red-necked Stint (*Calidris ruficollis*), pacific golden plover (*Pluvalils fulva*), large sand plover (*Charadrius leschenaultia*), sanderling (*Calidris alba)* and the little tern (*Sterna albifrons*).
- Behaviour of wildlife unaffected by human activity;

- Coral formations;
- Geomorphological significance; and
- Low incidence of pests and diseases.

22.5 Socio-cultural Values

The socio-cultural values of the Reserve include:

- Shipwreck of the *Lively*, located on the western side of Mermaid Reef, which is protected under the *Historic Shipwrecks Act 1976* as being of historic significance;
- Remote natural ambience;
- Long-established scientific study site for monitoring fish and corals by AIMS, and the WA Museum;
- Comparative scientific study site with similar reefs in the region including those in the Mov box
- Educational ecotourism site; and
- Uniqueness as diving location.

22.6 Economic Values

The economic values of the Reserve include:

- Recreational diving and bird watching supported by commercial charters;
- Potential for biodiscovery ventures.

22.7 Existing Pressures on Values

Potential risks to the values of the Reserve may occur as a result of natural pressures and human activities.

Potential natural pressures include:

- Climate events such as tropical cyclones, increased water temperatures; and
- Coral death caused by natural predators such as crown-of-thorns starfish and gastropod *Drupella cornis*.

Potential human-induced pressures include:

- Anchor damage to the sea floor from visiting vessels;
- Damage to corals as a result of diving activities and reef walking;
- Illegal fishing causing reduction in fish populations;
- Visitors feeding large fish resulting in unnatural behaviour;
- Collection of fauna such as clams and holothurians;
- Pollution from boats or other activities;
- Overcrowding in the area during peak tourism seasons;

- Collection of artefacts from the shipwreck; and
- Mining or petroleum exploration and production in close proximity to the Reserve.

22.8 Management Responses

In order to achieve the aims of the Reserve, management is currently implementing strategies focused on the following key areas:

- Reducing risks to water quality by restricting the type and location of discharge allowed by visiting vessels;
- Minimising disturbances to natural and cultural values from visitors by designing and enforcing appropriate education, restrictions on access and activities (including installation and maintenance of moorings) in mid 2007;
- Improving decision-making capacity by increasing understanding of natural systems and human interactions with those systems by implementing a research and monitoring program; and
- Establishing and maintaining surveillance and response capacity by managing service level agreements with other relevant agencies.

22.9 Climate Change Scenarios

The high range global warming scenarios in Table 22-1 have been projected for the North West Australian region within which the Reserve is located. CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in

Table 22-2.

Table 22-1: Climate change scenarios for NWA (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor	Current (1975-2004)	2030 Scenarios	2070 Scenarios
Sea level	0	+17cm	+50cm
CO_2 concentration	353ppm	+165ppm	+365ppm

Table 22-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}

Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface winds	Increase of 0-1ms^{-1} surface winds
Surface currents	Decline in strength of surface currents of between 0-1.2ms^{-1}
pH	Decline in pH by 0.2 units

A summary of the potential impacts of climate change on the values identified for the Reserve are described below. Implications of climate change on management of the Reserve are also discussed.

22.10 Summary of Potential Climate Change Impacts

Climate change has the potential to significantly degrade or alter the values that underpin the status of the Reserve which will be exposed to several new threats according to climate projections for the region. New threats include increased acidification of waters resulting from an increase in atmospheric carbon dioxide concentrations; increased sea surface temperatures and increased solar radiation. Atmospheric CO_2 concentrations may rise to 528ppm by 2030 and 718ppm by 2070, and surface temperatures may increase by 1-2°C by 2070. This will create conditions that result in frequent coral bleaching and potentially coral death. These impacts will be compounded by an increasing intensity and frequency of storms and also sea level rise. These multiple pressures will interact with or exacerbate secondary threats, such as invasive species. The Reserve has significant geological, ecological, commercial, recreational and cultural values which vary in their resilience to these climate change impacts.

Changes to water quality and circulation

Currents play a major role in determining local conditions and the flow of propagules between reefs and coastal areas. The Leeuwin current flows down the west coast of Australia and has a large influence on the ecosystems that exist along this coast. Changes in this current will be important and will affect the distribution and abundance of marine life around the Australian coastline (Hobday *et al.* 2006a).

Rising CO_2 levels in the atmosphere leads to an increase in CO_2 being directly absorbed by the oceans and a consequent rise in ocean acidification. This can result in an associated reduction in the calcification rate of a range of marine organisms as diverse as microalgae (*coccolithophores*), molluscs (*pteropods*) and corals. This reduction in calcification could adversely impact calcifying organisms such as corals, shell fish and some species of phytoplankton, thus having severe biological and ecological consequences in reef systems (CRES 2006).

Coastal waters in Australia are warming rapidly and temperatures are projected to increase by 2-5^{o}C by 2100 (IPCC 2001). Further recent increases in sea temperatures have started to exceed the stress tolerance of marine life. For coral reefs, this translates to an increase in the frequency and intensity of coral bleaching events (Hoegh-Guldberg 1999). Coral reefs in Australia are at particular risk of rising sea temperatures as most systems currently sit 1°C below the threshold at which bleaching is triggered. Furthermore, there is currently no evidence of adaptation in terms of an upward movement of this threshold. Given the current projected future rates of warming, it is likely that coral bleaching and mortality will significantly increase in the coming decades (Hoegh-Guldberg 1999, 2004).

Changes to sea levels and storm intensity

Studies have highlighted the potential influence of climate change on storm intensity and frequency. Although storm frequency is not expected to increase significantly, there are projections that show that the intensity of storms may increase due to increases sea surface temperature (CSIRO 2002). The prospect of increased storm intensity near the Reserve would have large effects on the structure and integrity of coral reefs.

Loss of biodiversity and increased rates of extinction

There is little evidence that coral reefs will be able to experience the environmental changes surrounding them without undergoing major changes in structure, abundance and community composition (Hoegh-Guldberg 2004). Coral reef systems such as Mermaid Reef provide habitat for many species at high levels of diversity. More importantly, these systems are highly interconnected and dependant on the processes that occur within them.

Many organisms may be highly susceptible given that factors such as the density of mates in an area or the need for highly involved species-species interactions can be critical for reproductive success. In these cases, reductions in coral cover may have major impacts on their reproductive success leading to local or global extinction (Hoegh-Guldberg 2004).

Climate change impacts are known to affect a number of species and may result in their extinction or adaptation in a number of ways. For example for species in the Reserve such as the green turtle (*Chelonia mydas*), the impacts of climate change can be felt in both nesting and foraging behaviour. Green turtles are known to forage on sea grass beds in the lagoons of this Reserve. Increased intensity of storms and cyclones, increased UV radiation and sea level rise may lead to significant erosion, damage or loss of seagrass beds, thus affecting green turtle mortality rates in this area. Increased temperature also has the impact of altering reproduction cycles in these and other temperature dependant species (TDS) as small increases in temperature can have the effect of altering the sex ratio of hatchlings towards an increased number of females.

Increased competition, disease and pest outbreaks

One most likely outcomes of climate change on Australia's marine ecosystems is the prospect of species migrating to higher latitudes. These changes have already begun to occur in a large number of terrestrial and now marine populations (Parmesan and Yohe 2003). How species move will depend very much on their mobility, the rate of climate change and the availability of suitable habitat at higher latitudes for new populations to become established. We currently know very little about how marine populations in Australian waters are shifting; however, projected increases in sea surface temperatures over the next 30 to 70 years sets up the possibility for the migration of northern populations, in the southern locations as they warm. Currently, very little is known about how these changes will transpire as new community assemblages are established.

It is clear that climate change will place the reserve ecosystems under increasing stress over the next two to three decades. The major issues as discussed above are the changes in sea temperature and acidity with a series of other related climate factors that may have minor to major implications over longer time frames. All of these factors lead to significant movements in the environmental envelope that coral reefs and their many dependent species have evolved to exist within.

These changes will almost certainly mean reductions in biodiversity and changes in community composition, as well as increased species extinction, ecological phase changes, reef framework deterioration, range shifts, species invasion and disease outbreaks.

22.11 Principal Management Implications

Managing to increase resilience by reducing human impacts

The major role of marine parks designed to protect warm water corals will be to find ways to reduced species loss, accommodate changes in species composition and to respond to challenges posed by invading species and disease. Given the scale and rapidity of these changes, early preparation is imperative.

Existing management approaches with regards to rehabilitation plans, documentation of species and management strategies may not be appropriate under worst case climate change scenarios. Stricter controls on human activities may be necessary to build the resilience of values to the affects of climate change. Of particular importance will be monitoring potentially illegal fishing operations, marine pollution, anchoring, marine littering, visitation and recreational activities including access to commercial operators.

Capacity to monitor and enforce marine activities and fishing will require regular review, particularly as circumstances change which affect the livelihood of fishing communities. Illegal fishing activities are expected to rise and this will exert pressure on existing resources to enforce the law and protect the natural assets of the Reserve.

Increasing decision-making capacity by improving understanding

Currently there are several gaps in knowledge that may prevent Reserve managers to adequately answer questions regarding resilience, climate change scenarios and sustainable use of the Reserve. Increasing understanding in these areas will in effect increase their decision making capacity. Gaps in knowledge include:

- Knowledge of reef ecosystems and their adaptive capacity to changed environmental conditions, particularly temperature and pH;
- Specific climate change projections for marine environments are lacking, such information will over time refine decision making in response to climate change.
- Knowledge of the role of ocean currents in the sustainability of coral reef systems for example the role of the Leeuwin Current and its effects on nutrient supply, reef colonisation, introduction of invasive species and temperature.

Continued regular and frequent monitoring of coral condition and indicators of potential coral bleaching may be required to facilitate on-going informed decision making.

Given the pace of climate change the frequency of updates to the management plan may not be adequate.

Maintaining infrastructure and protocols to ensure visitor safety

An increase in the likelihood of severe storm events or destabilisation of coral reefs (from the combined effects of increased ocean acidity, increased sea surface temperatures and severe storm events) may present issues for visitor safety. Current management strategies may need to be revised to take the risks of climate change into account.

23 Ningaloo Marine Park (Commonwealth Waters)

23.1 Current Management Arrangements

Ningaloo Marine Park (Commonwealth Waters) (hereafter known as the Marine Park) was declared by proclamation under the *National Parks and Wildlife Conservation Act 1975* (NPWC Act) on 7 May 1987 and amended in 1992. The Marine Park (Commonwealth Waters) is managed predominantly for conservation, recreation, science and education.

The Marine Park has also been listed as:

- World Conservation Union (IUCN) category II – National Park (Commonwealth Waters)
- IUCN list of coral reefs of international significance (UNEP/IUCN, 1988) (Ningaloo Reef) (State Waters).
- Register of the National Estate (Commonwealth and State Waters)

The Reserve is part of the National Representative System of Marine Protected Areas, which aims to establish and manage a comprehensive, adequate and representative system of marine protected areas and to contribute to the long-term ecological viability of marine systems, to maintain ecological processes and to protect Australia's biological diversity at all levels (Environment Australia 2002).

The Marine Park can be considered to be located in an overlap area between the tropical and temperate biogeographic regions of Western Australia, with a mix of mainly tropical and fewer temperate species. For example, the shallow portions of the Commonwealth waters of the west coast of North West Cape have a predominantly tropical biota with a small proportion of temperate species. Superimposed on the tropical and temperate components of the fauna is a small element of shallow water species that are endemic to Western Australia.

The Marine Park is a part of the Interim Marine and Coastal Regionalisation for Australia IMCRA, an ecosystem-based regionalisation scheme in which marine and coastal regions with distinct biological and physical characteristics were delineated throughout Australia. Most of the Marine Park falls within the Ningaloo Bioregion, which is described as an area of great complexity with a species-rich coral reef community (Environment Australia 2002).

23.2 Bioregional Context

The Marine Park is located along the coast of Western Australia, extending 260km south from just below the Tropic of Capricorn. The Marine Park consists of Ningaloo Marine Park (Commonwealth Waters) and Ningaloo Marine Park (State Waters). The Marine Park encompasses representative habitats of a large marine ecosystem from the shoreline to the edge of the continental slope. The three major habitats represented within the Commonwealth waters component are the open waters and the seabeds of the continental slope and continental shelf. Representation of the remaining shallow water habitats including Ningaloo Reef, one of the longest fringing barrier reefs in the world, is confined to the State waters component. Only Ningaloo Marine Park (Commonwealth Waters) (hereafter referred to as the Marine Park) is considered here.

The Marine Park extends seaward from the limit of the coastal waters of Western Australia a further three to nine nautical miles and covers 2326 km^2. The Commonwealth waters component excludes two areas covered by Petroleum Exploration Licences.

23.3 Climate and Oceanography

The climate of the Marine Park and its hinterland is arid-tropical, characterised by low rainfall and high evaporation rates, relatively high temperatures and seasonal tropical cyclones. Extreme rainfall events are frequently associated with the passage of tropical cyclones and these may result in monthly falls that exceed the annual average rainfall.

The region generally experiences a cyclone impact around every two years with a severe cyclone impact likely every 25 years. Southern parts of the Marine Park are slightly less influenced by cyclonic activity than the north. Winds associated with tropical cyclones that pass through the region may exceed 200km/h and rainfall events exceeding 200mm in a 24-hour period have been recorded.

Summers are hot and winters mild. In February and March (the two hottest months) the mean daily maximum and minimum temperatures are 33.6°C and 23.5°C respectively. In winter the daily mean temperatures is 22.9°C and mean minimum is 14.6°C in July, the coolest month. Temperatures offshore are generally less extreme, reflecting the moderating influence of the ocean. Regional sea surface temperatures range from 26-31°C in summer and 19-24°C in winter decreasing southwards (Environment Australia 2002).

Two major oceanic currents affect the Marine Park - the southward flowing Leeuwin Current and the Northward flowing Ningaloo Current. The Leeuwin Current is important in that it is a warm, relatively low salinity, low nutrient, southward flowing current. This contrasts with the cool, northward flowing currents which occur off the west coasts of South America and southern Africa. The Leeuwin current transports tropical marine species southward and brings warm enough water for such species to persist in what would otherwise be temperate conditions (Environment Australia 2002).

A northward flowing wind-driven current, termed the Ningaloo Current, passes inshore of the reef during the spring to mid-autumn period. This current runs counter to the southward flowing Leeuwin, which occurs seaward of the reef at the shelf break. Northward winds are believed to drive water along the coast, leading to the upwelling of cooler waters from beneath the Leeuwin Current. Studies suggest that the Ningaloo Current determines the dispersal of coral larvae following the autumn mass spawning and plays an important role in retaining planktonic biomass within the Ningaloo ecosystem.

The Leeuwin and Ningaloo currents transport tropical organisms into the Marine Park, modifying conditions (warming) such that they are suitable for the tropical organisms' survival (Leeuwin Current) and recirculating nutrients within the system (Ningaloo Current), such that an essentially low nutrient system is able to sustain relatively high productivity.

23.4 Natural Values

The natural values of the Marine Park include:

- High water quality which supports marine communities and habitats
- Diverse marine communities and assemblages including benthic, demersal and pelagic species of invertebrates and fish;
- the whale shark (*Rhincodon typus*), the largest fish in the world, reaching lengths of more than 12m, occur in both tropical and temperate waters and they aggregate in the waters of the Marine Park during late March to early June. This aggregation behaviour is known to occur in only a few places in the world. Whale sharks are listed by IUCN as vulnerable and as a listed migratory species under the *EPBC Act*.
- The Commonwealth waters are significant for tuna migration and potentially for juvenile southern bluefin tuna;
- Large sharks, such as the oceanic white-tipped shark (*Carcharhinus longimanus*), and grey reef shark (*Carcharhinus amblyrhynchos*), and manta rays (*Manta birostris*) occur in deep water outside the reef and are likely to be found in Commonwealth waters.
- Supports a wide diversity of marine mammals including dugongs *(Dugong dugon),* humpback whales *(Megaptera novaeangliae),* blue whales (*Balaenoptera musculus*) and numerous species of dolphin.
- Supports a wide diversity of marine reptiles including sea snakes and marine turtles. Four species of marine turtle are known to occur in the Marine Park. These are the hawksbill (*Eretmochelys imbricata*), flatback (*Natator depressus*), green (*Chelonia mydas*), and loggerhead turtles (*Caretta caretta*).
- About 30 species of seabirds are reported to occur on the coastal islands, mainland coastline and offshore waters in the region (Ningaloo Marine Park Management Plan, 2002);
- EPBC listed species including 4 endangered, 12 vulnerable, 17 migratory and 59 marine fauna species. Endangered species include the blue whale (*Balaenoptera musculus), s*outhern right whale (*Eubalaena australis)* and the loggerhead turtle (*Caretta caretta).* Vulnerable species include the whale shark (*Rhincodon typus),* fin whale (*Balaenoptera physalis)* and the green turtle (*Chelonia mydas).*
- 12 listed species - Migratory Species (Bonn) Convention. Species under this convention include the blue whale (*Balaenoptera musculus),* green turtle (*Chelonia mydas*), humpback whale

(*Megaptera novangliae),* the dugong (*Dugong dugon),* and the osprey (*Pandion haliaetus).*

- 9 listed species - Japan-Australia Migratory Birds Agreement. Species under this agreement include the wedge-tailed shearwater (*Puffinus pacificus),* flesh-footed shearwater (*Puffinus carneipes)*, and Wilsons's storm petrel (*Pelagodrama marinus).*
- 9 listed species - China-Australia Migratory Birds Agreement. Species covered in this agreement include the eastern reef egret (*Egreta sacra),* the white bellied sea eagle (*Haliaeetus leucogaster),* Caspian tern (*Sterna caspia)* and the lesser crested tern (*Sterna bengalensis).*

23.5 Socio-cultural Values

The socio-cultural values of the Marine Park include:

- long association of Aboriginal people to the area;
- extensive area for scientific study;
- supports environmental education through eco-tourism.

23.6 Economic Values

The economic values of the Marine Park include:

- The Marine Park is a key tourist destination with over 80,000 visitors to the region per annum. Most tourist activities take place in the State Waters; however, approximately 25% of recreational fishing activity including charter tours occurs in the Commonwealth waters.
- the Marine Park provides for research opportunities in a number of fields including:
- biological and habitat surveys including, whale shark population and migration studies, humpback whale migration pattern studies and coral biology studies;
- oceanographic studies, in particular of the Leeuwin Current and more recently the Ningaloo Current, and their implications for species distribution and population dynamics within the Marine Park;

23.7 Existing Pressures on Values

Potential risks to living resources may occur as a result of natural pressures and human activities:

Potential natural pressures include:

- Both terrestrial and marine introduced species exert pressures on the biological values. Fox predation on green turtle and loggerhead turtle eggs on beaches in the state component of the Marine Park affect populations of turtles that forage in the Commonwealth waters and exotic organisms arrive on the hulls of yachts while in port or in lagoons such as Ningaloo.

- Alterations of natural perturbations and biological interactions due to climate change impacts can also influence overall biological values of Ningaloo Marine Park. Increase in tropical cyclone intensity and changes in food web structure are two examples. These natural effects can act in synergy with the exotic stressors discussed above to degrade the biological values of the Marine Park more readily than might be expected

Potential human induced pressures include:

- Pollution from a variety of sources presents one of the major threats to the values of Ningaloo Marine Park. Sources may be either land based or sea-based and include silt laden run off and contaminants from coastal developments after periods of heavy rainfall; fuel and oils discharges including oil spills from shipping and recreational vessels; flotsam and jetsam from recreational and commercial uses (e.g. large shipping containers during storms, plastic bags and fishing lines) and sewage from shore and vessels. The potential effects of pollution include reduction in the water quality which may especially negatively affect coral reefs and associated flora and fauna; entanglement of birds, fish and marine mammals and ingestion of marine debris, e.g. plastics, possibly causing death; collision of marine fauna with large flotsam; and potentially large-scale mortality of fauna and flora and damage to habitats from an oil or chemical spill.
- There are currently no permits for commercial fishing in the Commonwealth waters of Ningaloo Marine Park; however, commercial fisheries operate in the vicinity and within the state park and include the Western Tuna and Billfish Fishery (long-line fishing) and the Western Deepwater Trawl Fishery, which has a small overlap with the boundary of the Commonwealth waters of the Marine Park.
- While tourism has positive effects on the Marine Park in the form of increased awareness among visitors and the community, it also adversely affects the biological values of the Marine Park. These effects include disturbance of large marine fauna such as whales; impacts relating to recreational fishing and increased litter and pollution.
- Whilst drilling for petroleum exploration and production is not permitted in either the Commonwealth or State waters of Ningaloo Marine Park, offshore exploration activities take place to the west and north-west of the Marine Park and a number of exploration wells are located in areas adjacent to the Marine Park. Possible negative effects of this use include accidental discharge of substances (for example, oil, gas or fuel); emission of high-energy, low-frequency noise during seismic surveys (potentially causing stress and mortality of cetaceans and large migratory fish); discharge of drilling fluids and cuttings; and rig and supply vessel anchors, which disturb bottom sediment and reef structures.

23.8 Management Responses

In order to achieve the aims of the Reserve, management is currently implementing strategies focused on the following areas:

- Managing human activities to ensure that the abundance and species diversity of marine communities and ecosystem processes in the Commonwealth waters are not adversely affected;
- Promoting the maintenance of the high water quality required to sustain the marine communities and habitats of Ningaloo Marine Park;
- Negotiating complementary management regimes between relevant Government bodies to co-ordinate management efforts;
- Supporting involvement of Aboriginal people in management of Commonwealth waters as appropriate;
- Monitoring and managing the current and potential impacts of commercial fishing on the ecological values of the Commonwealth waters;
- Preventing adverse impacts on the physical, ecological, social and cultural values of the Commonwealth waters from petroleum or mining activities in the vicinity of Ningaloo Marine Park;
- Facilitating recreational fishing in the Commonwealth waters consistent with the conservation of the values of the Marine Park;
- Providing for the operation of low impact commercial tourism activities which add to the recreational and educational experience of Marine Park users;
- Supporting research that will improve knowledge of the values of the Marine Park and inform its management.

23.9 Climate Change Scenarios

The high range global warming scenarios in Table 23-1 have been projected for the Mid Western Australia region. CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in Table 23-2.

Table 23-1: Climate change scenarios for Mid Western Australia region (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor		Current (1975-2004)	2030 Scenarios	2070 Scenarios
Annual average temperature		Max 30.0°C, min 16.7°C	+1.7°C ± 0.6°C	+5.1°C ± 1.7°C
Average sea level		0	+17cm	+50cm
Annual average rainfall		286mm	-7% ± 15%	-23% ± 45%
Seasonal average rainfall	Summer	115mm	-4% ± 19%	-11% ± 57%
	Autumn	87mm	-4% ± 11%	-11% ± 34%
	Winter	66mm	-7% ± 15%	-23% ± 45%
	Spring	18mm	N/A	N/A
Annual average potential evaporation		N/A	+4% ± 4%	+11% ± 11%
Annual average relative humidity		36%	-1.1% ± 1.9%	-3.4% ± 5.7%
Annual daily extreme wind-speed		N/A	-1.2% ± 3.7%	-3.8% ± 11.3%
CO_2 concentration		353ppm	+165ppm	+365ppm

Table 23-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C
Temperature at 500m depth	Warming of 0.5-1°C
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface winds	Increase of 0-1ms^{-1} surface winds

Physical climate change indicators	Projected climate change impacts by 2070
Surface currents	Decline in strength of surface currents of between 0-1.2ms^{-1}
pH	Decline in pH by 0.2 units

A summary of the potential impacts of climate change on the values identified for the Marine Park are described below. Implications of climate change on management of the Marine Park are also discussed.

23.10 Summary of Potential Climate Change Impacts

The Marine Park is likely to be most vulnerable to increases in atmospheric CO_2 concentrations (and associated acidification of the ocean), increases in sea surface temperatures (1-2°C by 2070), and increased intensity of storms and cyclones. To a lesser extent, decreased rainfall (-23% by 2070) and sea level rise (50cm by 2070) will also have negative affects. Because there is a high degree of ecological interaction between the Commonwealth and State components of the Marine Park it is important to consider the impacts of climate change in State Waters, e.g. threats to the ecosystem services provided by Ningaloo Reef, when examining implications for Commonwealth Waters.

Changes to water quality and circulation

Nutrient availability, temperature and stratification of the surface ocean are key determinants of phytoplankton abundance, community composition, and production. Increasing sea surface temperatures and any strengthening of the Leeuwin Current will drive phytoplankton and zooplankton species southwards and earlier timing of the peak in production is also predicted.

Changes in water column primary production will alter abundances, community interactions, and benthic-pelagic coupling, potentially reducing pelagic fish abundance in the Marine Park including species of tuna, billfish, and sharks. The ranges of many pelagic species are expected to expand to the south as the ocean warms thereby changing assemblages of marine species. In addition, the general intensification of stratification may reduce the productivity of pelagic fish on the broader scale (Hobday *et al*. 2006c).

Acidification of the ocean may impair the ability of species with calcareous shells such as echinoderms, crustaceans, and molluscs (including pteropods) to maintain shell integrity resulting in reductions of the overall abundance and biodiversity of these species. The projected surface ocean warming would also result in a more stratified ocean (with less mixing of layers) and therefore a reduced supply of nutrients to the upper ocean. Overall, these impacts will result in a decline of primary (phytoplankton) and secondary (zooplankton) productivity which may drastically impact most marine life throughout the water column as changes in particular phyto- and zooplankton species abundance reverberates throughout the food web.

Changes to sea levels and storm intensity

Increased storm/cyclone intensity and sea level rise will cause damage to the reef. Other effects of climate change including acidification of the oceans and also human activity will reduce the stability of the reef, amplify the damage done by storm and cyclone events, and impair the reefs' capacity to recover from high wave forces. Damage to Ningaloo Reef may reduce its ability to function as a fish nursery and foraging ground including for hawksbill turtles, which prey on sponges and other invertebrates around coral reefs (Hobday *et al*. 2006a).

Reduced coral cover may also reduce protection of the coastal environment from wave erosion and storm surges. This coupled with sea level rise and intense rainfall from storm and cyclone events will negatively affect nesting habitat of green and loggerhead turtles in the Marine Park (State Waters) thereby affecting the abundance and distribution of these turtles in Commonwealth Waters. Both species are listed under the *EPBC Act*. Threats to nesting habitat and reproductive success include inundation of nests, drowning of embryos within eggs, and erosion of sand dunes exposing the egg clutches to the elements and to native and introduced predators such as foxes. Losses of nesting beaches may be substantial for a small rise in sea level and therefore significant impacts may be seen by 2070 with a + 50cm rise projected.

Loss of biodiversity and increased rates of extinction

Alterations of primary productivity driven by changes in mixed layer depth will impact on food availability for turtles in the open oceans and may result in range shifts and changes in their abundance. Whilst increased temperatures may extend ranges of turtles restricted to tropical and subtropical waters further south, green turtles and hawksbills are likely to be restricted by food availability.

Changes to primary and secondary productivity are likely to be significant for higher tropic level species, (Shuraleff II, G. 2000) Timing of production may also significantly affect the Whale Shark which aggregate in the waters of the Marine Park during late March to early June. This aggregation behaviour is only known to occur in a few places in the world. Cetaceans such as the humpback whale may also be vulnerable to decreases in productivity and changes in the patterns of prey distribution and availability.

Coral bleaching and reduced rates of calcification are likely as a result with reduced growth and survival of reef-building corals, coral death, reduced coral cover, and increased algal dominance on Ningaloo Reef. If reefs lose the coral genera and species that support the numerous coral-dependent organisms, many other organisms will almost certainly become extinct (Howden *et al*. 2003).

The abundance and distribution of many marine species will be influenced by increases in temperature and sea surface temperature. Three biological groups in particular may be affected:

- Sea turtles will likely be adversely affected by temperature changes, as all stages of marine turtle life history are influenced strongly by temperature (Hobday *et al.* 2006c). In particular, gender of embryos is determined by ambient nest temperatures and small increases in temperature may strongly bias the sex ratio of hatchlings towards females. This will have potentially significant effects on the long term distribution and abundance of green and hawksbill turtles in the Marine Park, which nest on the beaches.
- *Marine fish:* Warming will expand or shift distributions of marine species southwards including benthic and demersal fish, pelagic fish species, and seabirds. Where populations are bounded to the south, some populations may decline.
- *Seabirds:* As temperatures warm, shifts in the timing of peak breeding season is anticipated in seabirds. In addition, breeding success is related to sea surface temperatures in some Australian seabirds including the wedge-tailed shearwater *Puffinus pacificus* (Hobday *et al.* 2006c). Both these factors may change the timing of the distribution and abundance of seabirds in the Marine Park.

23.11 Principal Management Implications

Managing to increase resilience

The marine life of the Marine Park is currently affected by non-climate related stressors such as over fishing, disturbance of species and habitats, pollution and stress from petroleum activities in the region. The ecological effects of these stressors will potentially serve to reduce the resilience of marine species, communities and ecosystems to climate changes and vice versa.

Existing strategies with regards to managing these stressors may not be appropriate under worst case climate change scenarios. Stricter controls on human activities, including review of existing and potential sanctuary or “no take” zones, may be necessary to build the resilience of values, including pelagic fish, seabirds and turtles, to the affects of climate change. Of particular importance will be monitoring fishing, marine pollution and anchoring.

Capacity to monitor and enforce marine activities and fishing will require regular review, particularly as circumstances change which affect the livelihood of fishing communities. Illegal fishing activities are expected to rise and this will exert pressure on existing resources to enforce the law and protect the natural assets of the Reserve.

Increasing decision-making capacity by improving understanding

Currently there are several gaps in knowledge that may prevent Reserve managers to adequately answer questions regarding resilience, climate change scenarios and sustainable use of the Reserve. Increasing understanding in these areas will in effect increase their decision making capacity. Gaps in knowledge include:

- Knowledge of reef ecosystems and their adaptive capacity to changed environmental conditions, particularly temperature and pH;
- Specific climate change projections for marine environments are lacking, such information will over time refine decision making in response to climate change.
- Knowledge of the role of ocean currents in the sustainability of coral reef systems for example the role of the Leeuwin currents and the effect on nutrient supply, reef colonisation, species distribution and population dynamics, introduction of invasive species and temperature.
- The interaction of marine species, communities and ecosystem processes including how primary and secondary productivity will change in response to climate change.

Ongoing monitoring of coral condition and indicators of potential coral bleaching may be required to facilitate on-going informed decision making.

Given the pace of climate change the frequency of updates to the management plan may not be adequate.

In the short term (prior to 2020) significant risks to coral reef ecosystems have been identified. In order to manage these risks current levels of staffing and funding may not be appropriate.

Maintaining infrastructure and protocols to ensure visitor safety

An increase in the likelihood of severe storm events or destabilisation of coral reefs (from the combined effects of increased ocean acidity, increased sea surface temperatures and severe storm events) may present issues for visitor safety and satisfaction. Current management strategies may need to be revised to take the risks of climate change into account.

24 Solitary Islands Marine Reserve (Commonwealth Waters)

24.1 Current Management Arrangements

The Commonwealth Solitary Islands Marine Reserve (hereafter referred to as the “Reserve”) was proclaimed on the 3rd March 1993 under the *National Parks and Wildlife Conservation Act 1975* (NPWC Act). It encompasses the waters, seabed and subsoil beneath the seabed to a depth of 1000 metres. The NSW Solitary Islands Marine Park was declared in 1998 under the *Marine Parks Act 1997* (NSW). Previous to this, it was a marine reserve, declared in 1991 under the *Fisheries and Oyster Farms Act 1935.*

The Reserve is home to a number of species that are listed as endangered or vulnerable under Commonwealth legislation or international agreements (see Chapter 24.4 for further detail). Furthermore, both the Reserve and Park were listed on the Register of the National Estate in 1995 for outstanding marine biodiversity; mixture of communities; diversity of coral, algal and fish species; abundance of various species of anemone and clownfish; little penguin and muttonbird species and overall diversity and beauty (Director of National Parks 2006).

The Reserve is zoned into the following three management areas:

Sanctuary Zone: The management zone extends in a radius of 500 metre around the centre of Pimpernel Rock, a submerged pinnacle that provides important habitat for the vulnerable grey nurse shark *Carcharias taurus*, marine turtles, and schools of pelagic fish. This zone has a high level of protection for the single sample of pinnacle reef habitat, its biologically diverse ecosystems, ecological processes and associated marine species. This area is regarded as a “no take” zone, in which activities that may harm marine life or interfere with or damage habitat will be prohibited without a permit.

Habitat Protection Zone: This zone has been designed to protect a representative sample of the whole reef complex, including soft substrate sediments and subtidal reef habitats, deep water biotic communities and predator-prey assemblages, mammals and seabirds. The zone extends southward from the northern boundary of the Park and Reserve to the latitude in line with One Tree headland. The zone provides for ecologically sustainable recreational and commercial activities that are consistent with the strategic objectives of the Reserve. Activities such as demersal trawling, purse seining, coral collecting, and petroleum and mineral exploration and development will not be allowed.

General Use Zone: This zone comprises the remaining area of the Reserve and provides for the continuation of all ecologically sustainable activities currently undertaken within the Reserve, in conjunction with appropriate management measures to maintain its biological diversity and other natural values.

24.2 Bioregional Context

The Solitary Islands region covers a large section of the waters off the north coast of New South Wales. The NSW Solitary Islands Marine Park extends from the mean high water mark out to the three nautical mile limit of the coastal waters of New South Wales from Coffs Harbour north to Sandon River on the mid-north coast of NSW. The Reserve adjoins the seaward boundary of the Park and extends to the 50 metre depth contour. The Park has an area 710 square kilometres with the Reserve covering a further 160 square kilometres.

The region is an area of great conservation significance with a wide range of habitats including the adjacent littoral/intertidal ecosystems, coral-fringed islands and rocky outcrops, soft substrate sediments, subtidal reefs, pinnacles, and open ocean ecosystems. Furthermore, the Reserve is located in a mixing zone between tropical and temperate environments. Many species in the area are at, or close to, their southern and northern geographical extents.

24.3 Climate and Oceanography

Climate in the region is subtropical with mean air temperature ranging from 13.7°C to 23.2°C. Warm, humid conditions prevail in the summer months when the easterly trade winds blow from January to March. The winter months are predominantly cooler and drier. Average annual precipitation for the area is 1,700mm, with the majority of rain falling between December and May.

Water temperatures in the Reserve and the Park ranged between 16.5°C to 26.6°C from 1992 to 1994. Daily variations are minimal during the cooler months of April to November. During the summer months, these variations can increase to 4°C for a single day and 7.4°C over a two day period. Water temperatures can fall below the coral reef formation minimum of 18oC for more than 20 days in an average year.

The East Australian Current acts as a major influence within the Region and carries a mixture of tropical and subtropical waters from the Coral Sea, Great Barrier Reef region, and southern Queensland into the more temperate area of the NSW continental shelf before separating from the coast between the Solitary Islands and Smokey Cape. This current overlaps with the colder northward flowing inshore current and results in a complex mixture of marine species populations which can include species ranging from the Great Barrier Reef to Tasmania.

24.4 Natural Values

The Solitary Islands support wide species diversity and abundance and represents an important transitional region between tropical and subtropical area, with many species at the limit of their range extension. The Reserve's natural values include the following:

- The Reserve includes three main habitat types; subtidal reefs, soft substrate sediments and the open ocean;

- High species diversity including approximately ninety species of coral, (which accounts for about a quarter of the species recorded in the Great Barrier Reef) algal and fish species including anemone and clownfish (*Amphiprion latezonatus*) and raptor species including the osprey (*Pandion haliaetus*) and the white-bellied sea eagle (*Haliaeetus leucogaster*) which are of conservation significance in Commonwealth marine areas;

The Reserve supports a number of EPBC listed species including:

- three mammal species including the endangered southern right whale (*Eubalaena australis*) and blue whale (*Balaenoptera musculus*) and the vulnerable humpback whale (*Megaptera novaengliae*). dugong (*Dugong dugon*) have been occasionally sighted in the Reserve. This species is protected internationally through listings on the Convention on International Trade in Endangered Species (CITES) and the Bonn Convention.
- three marine turtle species including the vulnerable green turtle (*Chelonia mydas*), leatherback turtle (*Dermochelys coriacea*) and hawksbill turtle (*Eretmochelys imbricate*)
- thirty eight species migratory and marine listed seabirds are found within the Reserve including the endangered southern giant petrel (*Macronectes giganteus*) and Gould's petrel (*Halobaena caerulea*) and the vulnerable blue petrel (*Halobaena caerulea*) and black-browed albatross (*Thalassarche melanophris*); and
- the vulnerable southern elephant seal (*Mirounga leonina*).

The Reserve also supports other threatened fish species including the giant Queensland groper, the bleekers devil fish (*Paraplesiops bleekeri*) and the black cod (*Ephinephilus daemilii*) (which is also regionally endemic) and the grey nurse shark (*Charcharius taurus*) which aggregates around Pimpernel Rock.

24.5 Socio-cultural Values

The Solitary Islands region is of importance to the Goorie people. To date no native title applications have been made to areas within the Reserve.

Fifteen shipwrecks are known to have occurred in the region between 1833 and 1976 although none, as yet, have been located within the Reserve.

The Reserve and Park are used for a number of research activities including marine education in regional schools and scientific research conducted by local Universities. The Reserve is of particular interest to marine researchers due to its tropical/temperate ecotone, which results in very high biodiversity. Ecological processes such as recruitment, extinction, and physical and biotic limiting factors can be studied to good effect within the region. In addition, the area remains an important site climate change research and El Niño Southern Oscillation events.

24.6 Economic Values

The economic values of the Reserve include the following:

- Commercial fishers operate in the Solitary Islands Marine Park and Reserve; and
- The Reserve provides many values in terms of recreational activities including whale and dolphin watching, scuba diving, spear fishing, line fishing, boating and yacht racing.

24.7 Existing Pressures on Values

Potential risks to living resources may occur as a result of natural pressures and human activities.

Potential natural pressures include:

- Impacts from coastal water runoff of high nutrient laden waters;
- Impacts of invasive species from areas to the north as a consequence of warming waters; and
- Loss of species that exist at the extremity of their range as a result of changing climatic conditions.

Potential human-induced pressures include:

- Marine pollution arising from coastal development, sewage effluent disposal, storm water runoff and agricultural practices as well as effluent and litter from vessels all may have a detrimental effect on the quality of the marine environment within the Reserve;
- Boat traffic and human disturbance to marine mammals;
- Introduction of exotic species via ballast water and coastal shipping movements between domestic ports;
- Boat anchors from commercial and private vessels can be a significant source of physical damage to coral communities. The repeated use of anchors may also have cumulative impacts upon subtidal reef ecosystems;
- Pimpernel Rock rates as one of the top five dive locations along the NSW coastline. Divers may deliberately or accidentally contribute to the physical damage of coral reef and its inhabitants. Diving activities may negatively impact on grey nurse shark behaviour if interaction with the species increases;
- All fishing methods have the potential to place pressures on the subtidal reefs, associated ecosystems and can disturb predator-prey relationships, stocks and biological community structure. Commercial hook and line fishing is an effective fishing method used to catch large amounts of resident demersal and pelagic fish species. This technique can result in accidental catch of non target species such as grey nurse sharks; and
- Commercial trawling adjacent to the boundary of the Reserve may have indirect impacts on the Reserve's benthos, including

sedimentation impacts on the Reserve, potentially smothering benthic communities.

24.8 Management Responses

In order to achieve the aims of the Reserve, management is currently implementing strategies focused on the following key areas:

- Building resilience of benthic ecosystems, ecological processes and the environmentally sensitive structure of Pimpernel Rock and surrounding subtidal reefs to human impacts;
- Facilitating the recovery of grey nurse sharks in ways consistent with recovery plan actions that apply to key aggregation sites in marine protected areas;
- Protecting a representative sample of whole reef complex, including soft substrates and deeper water habitats and biotic communities;
- Ensuring that commercial fishing activities in the Reserve are ecologically sustainable and consistent with the strategic objectives of the Reserve;
- Developing performance measures and non intrusive research and monitoring programmes to provide information on the effectiveness of zoning and other management measures; and
- Ensuring that activities such as scuba diving, scientific research, commercial and recreational fishing are sustainable and compatible with the protection of habitats and biotic communities and other strategic objectives of the Reserve.

24.9 Climate Change Scenarios

The high range global warming scenarios pertinent to the Reserve are shown in Table 24-1. CSIRO have also projected changes to the physical and chemical characteristics of Australia's marine realm by 2070 as shown in Table 24-2.

Table 24-1: Climate change scenarios for NSW (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor	Current (1975-2004)	2030 Scenarios	2070 Scenarios
Average sea level	0	+17cm	+50cm
CO_2 concentration	353ppm	+165ppm	+365ppm

Table 24-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C

Temperature at 500m depth	Warming of 0.5-1°C
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface winds	Increase of 0-1ms^{-1} surface winds
Surface currents	Decline in strength of surface currents of between 0-1.2ms^{-1}
pH	Decline in pH by 0.2 units

A summary of the potential affects of climate change on the Reserve are described below. Implications of climate change on management of the Reserve are also discussed.

24.10 Summary of Potential Climate Change Impacts

The values of the Reserve are threatened by a number of challenges associated with climate change.

Changes to water quality and circulation

Species range shifts both southwards and northwards into and out of the Reserve as temperatures warm and the EAC strengthens. Changes in abundance of particular species will have flow on effects to their prey and predators. Invasive species may become dominant within the Reserve leading to changes in the ecosystem with consequent impacts on marine life throughout the food chain.

The biodiversity of calcareous shell species including echinoderms and molluscs may reduce as increasing acidity threatens the integrity of the calcium carbonate shelled organisms.

Increasing surface ocean temperatures and rising acidity will increase the frequency and impact of coral bleaching. In extreme circumstances frequent occurrence of coral bleaching will lead to the permanent breakdown of symbiotic relationships within coral communities and the loss of coral habitat. This loss may have an effect on habitat dependant species such as the clownfish (*Amphiprion latezonatus*)

Changes to sea levels and storm intensity

Changing sea levels will increase ocean stratification and potentially limit the availability of nutrients. This will impact directly on phytoplankton numbers with consequent impacts on the entire food chain.

By 2070 increased storm intensity can be expected at more southerly locations in NSW. By 2070 the threat of tropical cyclones on the Solitary Islands is plausible. The impacts of such storms on the reserve are likely to arise as a consequence of impacts on land and the release of pollutants and nutrients into coastal waters of the marine environment. This can lead to the smothering of benthic communities and the development of algal blooms within the Reserve.

Loss of biodiversity and increased rates of extinction

Climate change may have negative affects on marine mammals such as the hump back whale. Humpback whales utilising Australian waters currently have tropical calving grounds along the mid and northern parts of the east and west coasts of Australia, and feeding grounds in the Southern Ocean. Any negative impacts on the calving grounds will have an impact on migration routes and potentially to the tourism industry around whale watching along the NSW coastline.

Grey nurse sharks have not recovered since their legal protection in 1984.

There are concerns that this population has fallen to such critically low numbers that individual animals are now failing to find mates and successfully reproduce. In these circumstances climate change impacts on ecosystem integrity, food supplies and or habitat could have substantial negative affects on grey nurse populations.

The potential loss of coral due to persistent bleaching may have dramatic impacts on biodiversity within the reserve and may lead to a transition to alternative ecological communities.

Increased competition, disease and pest outbreaks

Some temperate fish species are likely to shift to deeper water where temperatures are cooler, again resulting in competition for both habitat and food sources.

As a consequence of warming ocean temperatures invasive species are likely to enter the reserve from warmer waters to the north. Invasive species will compete for limiting resources within the reserve increasing the potential for loss of biodiversity and species extinction.

24.11 Principal management implications

Managing to increase resilience

- By 2070, climate change is likely to have significant impacts on the physical habitat in the Park and on the distribution, abundance and composition of marine species within it. Climate change is therefore likely to significantly reduce the ability to protect and conserve physical habitat in its natural condition, and to conserve populations of all native species. Management focus should be upon the elimination or mitigation of non climate related stresses including commercial fishing impacts and marine pollution impacts;
- Habitat loss, coral bleaching and coral death may also reduce visitor satisfaction and reduce recreational fishing opportunities through reduced ecosystem function and fish diversity;
- By 2070, climate change may have significant impacts on the values of the Park. Existing management strategies and recovery plans may no longer be appropriate under these changed climatic conditions. In particular, research and monitoring activities to support informed management decisions may require regular review;

- Actions to limit non climate stresses may need to be reviewed regularly, such as exclusion zones for all fishing activities and limitations on dive operations and recreational boating; and
- Ongoing monitoring of grey nurse populations provides a good indicator of ecosystem function and health. Review of efforts and resources allocated to the protection of habitat critical for the survival of Grey Nurse Sharks and to assess the recovery of the species is an important implication for Park management.
- Capacity to monitor and enforce marine activities and fishing will require regular review, particularly as circumstances change which affect the livelihood of fishing communities. Illegal fishing activities are expected to rise and this will exert pressure on existing resources to enforce the law and protect the natural assets of the Reserve.

Increasing decision-making capacity by improving understanding

- The combined impacts of ocean warming, ocean acidification, strengthening of the EAC and increase in incident solar radiation are likely to contribute to changes in abundance and distribution of primary productivity, fish and invertebrates in the Reserve. Efforts to maintain the current biodiversity and abundance within the reserve will therefore be impeded. The identification of impacts at the earliest opportunity via appropriately structured monitoring and research programs will facilitate timely management response to building the resilience of the reserves ecosystems;
- Many species (currently not identified) may undergo range shifts as a consequence of climate change. The Reserve may well prove to be either a stepping stone to new latitudes or a suitable alternative habitat. Significant efforts will be required to monitor these changes in species ranges in consultation with other relevant marine parks such as the Great Barrier Reef, Lord Howe and the Elizabeth and Middleton Marine Parks. Coordinated action plans will assist to ensure consistency of management approaches to invasive species;
- Knowledge relating to the recruitment and reproduction of temperate coral species is generally limited. Similarly for marine invertebrates, very little is known about the biology of smaller-sized taxa or those species that inhabit the deeper water;
- Invasive species, as a result of climate change, may dominate the Reserve. The identification of particular invasive species is currently unknown. Monitoring of invasive species and environmental conditions, in consultation with the neighbouring areas including the state reserve, will assist in gathering knowledge and therefore in the identification of potential manage strategies;
- The integrity of habitat within the Reserve depends on the status of existing water currents, ocean surface water temperatures and ocean acidity. Further study of these relationships to the Park biodiversity values is necessary to understand the complex interactions that exist and to identify biological indicators of change; and

- The effects of fishing and management effectiveness are largely unknown. Further information through monitoring both recreational and commercial fish catches, will assist in climate change risk assessments for vulnerable species.

More frequent monitoring of coral condition and indicators of potential coral bleaching may be required to facilitate on-going informed decision making.

Maintaining infrastructure and protocols to ensure visitor safety

- Based on projected changes in the physical characteristics of the Reserve there may be additional or heightened risks associated with current activities and operations taking place. Regular risk assessments will assist Reserve managers to take the latest information on projected climate change impacts into consideration and actual findings from field survey work; and
- Changing climatic conditions and natural environment will require regular review of communication protocols for workers, researchers, divers and tourists within the Reserve.

25 Tasmanian Seamounts Marine Reserve

25.1 Current Management Arrangements

The Tasmanian Seamounts Marine Reserve (the Reserve) was proclaimed on 19 May 1999 for the primary purposes of protecting the unique and vulnerable benthic communities of the seamounts.

In 2002 the first management plan was prepared for reserve (Environment Australia 2002). The plan is due to be updated and re-issued in 2009. The current management goals and activities focus on the benthic environments of the Reserve rather than the entire Tasmanian seamounts ecosystem which is poorly understood.

The Highly Protected Zone is managed primarily for scientific research and environmental monitoring. The primary objective is the full protection of the benthic biodiversity. The Managed Resource Zone is managed to ensure the long term protection and maintenance of natural processes in the region while providing access, under permit or a declaration, to commercial pelagic fishing. There are currently no determinations in place relating to the Reserve waters above 500 metres below the surface.

In 2007, it is anticipated that 13 new reserves will be declared in the south-east region. At this time, the Reserve will be revoked and this area will become part of the new Huon Commonwealth Marine Reserve (pers comm. H.Sullivan).

25.2 Bioregional Context

The Tasmanian seamounts are located 170 km south of Hobart in Australia's Exclusive Economic Zone. The Reserve covers an area of 38,900 ha within the Provincial Bioregion #10 (Tasmanian Province) according to the Benthic marine Bioregionalisation of Australia's Exclusive Economic Zone (Heap *et al*. 2005).

There are thought to be over 100 seamounts, which are coned-shaped remnants of extinct volcanoes in close proximity to each other. Approximately 25 of the seamounts are included in the Reserve, as a representative sample. The field of seamounts is a distinctive geological feature not known elsewhere in Australia.

The seamounts rise sharply from the ocean floor at depths of 1000-2000 metres beneath the sea surface and peak at depths of 660-1940 metres. The habitats of the seamounts, their values, and their relationship with the surrounding waters and seabed are not well understood.

25.3 Climate and Oceanography

There are three main water masses over the continental slope in the region of the seamounts (Figure 25-1). The upper water column to a depth of about 500 metres is dominated by Mode Water, formed by winter cooling. Mode Water sets the physical limit to the depth of water directly influenced by the atmosphere in this region.

Between depths of approximately 500 and 1500 metres, lies a separate water mass known as Antarctic Intermediate Water. This water mass flows in a northerly direction and covers much of the world's oceans at this intermediate depth. There appears to be little mixing of this water mass with shallower or deeper waters.

Below 1500 metres lies a water mass known as North Atlantic Deep Water, which has its origins in the far North Atlantic (Environment Australia, 2002). The physics and biology of oceanic systems are generally closely linked, such that the biogeography and depth zonation of marine communities are consistent with the salient features of physical circulation and water mass structure (Environment Australia 2002). Biological communities around the seamounts appear to be closely associated with those in the same water mass as opposed to the water column directly above (Environment Australia 2002).

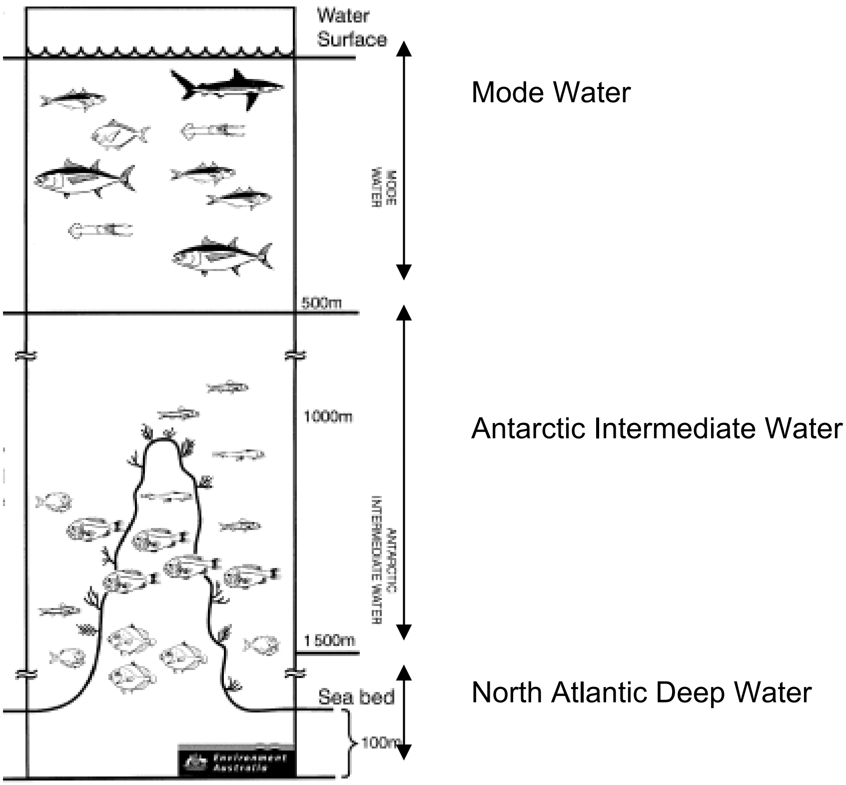

Figure 25-1: Cross section of water column and sea-bed showing different water masses

(Source: Environment Australia 2002)

The richness of the benthic ecosystems is partly due to the influence the seamounts have on the movement of ocean currents. The normally slow deepwater currents increase in speed as they move around the peaks of the seamounts, providing plankton and other organic organisms for corals and other suspension feeders to feed on.

25.4 Natural Values

The natural values of the Reserve include:

- Unique geological formation of seamounts;
- Distinctive benthic (seabed) community; principally hard corals and urchin-dominated communities;
- High species richness;
- High level of endemism in fish and invertebrate populations;
- Species of scientific value. The hard corals are known to provide key habitat for a number of unknown species which are yet to be taxonomically classified; and
- Nutrient rich waters acting as fish spawning and nursery areas.

25.5 Economic Values

- Nutrient rich waters acting as fish spawning and nursery areas; and
- Commercial species found in the area include two tuna fisheries, orange roughy (*Hoplostethus atlanticus*) and black and smooth oreos (*Pseudocyttus maculatus* and *Allocyttus niger*).

25.6 Existing Pressures on Values

Potential risks to natural values of the Reserve may occur as a result of natural pressures and human activities.

Potential natural pressures include:

- Changes in ocean currents leading to changes in water temperature and species composition;
- Increasing competition for resources;
- Rise in surface ocean water temperatures, and;
- Increasing ocean stratification and declines in ocean productivity.

Potential human-induced pressures include:

- Commercial fisheries are the primary human pressure on the Reserve;
- Pollution from commercial and recreational boats or petroleum/mineral exploration;
- Damage to benthic communities from research activities (e.g. sled and grab samples), pollution from research boats (including litter, accidental spills etc).

25.7 Management Responses

In order to achieve the aims of the Reserve, management is currently implementing strategies focused on the following key areas:

- Protecting the unique and vulnerable benthic communities of the seamounts Reserve from adverse human impacts;
- Protecting the conservation values of the Reserve from human induced damage;
- Increasing knowledge of the natural environments, for scientific purposes and management improvement of the seamounts within the Reserve;
- Developing an education and communication system that generates support for the Reserve;
- Managing the Reserve as part of the National Representative System for Marine Protected Areas; and
- Using the Reserve as a research site to increase knowledge of seamount ecosystems generally and the endemic species of the southern Tasmanian seamounts.

25.8 Climate Change Scenarios

The high range climate change scenarios most relevant to the area of the Reserve are shown in Table 25-1. CSIRO have also projected change to the physical and chemical characteristics of Australia's marine realm by 2070 as shown on Table 25-2.

Table 25-1: Climate change scenarios for Tasmanian region (Source: CSIRO 2006 & pers comm. P Whetton, 2006)

Climate change factor	Current (1975-2004)	2030 Scenarios	2070 Scenarios
Annual average potential solar radiation	N/A	+ 0.6% (±1.9%)	+1.9% (±5.7%)
CO_2 concentration	353ppm	+165ppm	+365ppm

Table 25-2: Projected changes in Australia's marine realm by 2070 (Source: Hobday *et al*, 2006a).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Warm by 1-2°C
Temperature at 500m depth	Warming of 0.5-1°C
Incident solar radiation	Increase between 2 and 7 units Wm^{-2}
Mixed layer depth	Greater stratification and shallowing of mixed layer by about 1m
Surface winds	Increase of 0-1ms^{-1} surface winds
Surface currents	Decline in strength of surface currents of between 0-1.2ms^{-1}

pH	Decline in pH by 0.2 units

A summary of the potential impacts of climate change on the values identified for the Reserve are described below. Implications of climate change on management of the Reserve are also discussed.

25.9 Summary of Potential Climate Change Impacts

The values of the Reserve are exposed to a number of challenges associated with climate change. The Reserve is likely to be most vulnerable to increases in atmospheric CO_2 concentrations (and associated changes in the aragonite saturation horizon), increases in temperature of the sea surface and water at depth, southward flow of the East Australian Current and greater stratification and shallowing of the mixed layer. The values of the marine ecosystem are intrinsically linked and therefore impacts on one value can have flow on effects to another. A summary of the key climate change impacts are described below:

Increased atmospheric CO_2 concentrations

Increases in atmospheric CO_2 levels will make the ocean more acidic. Increasing acidity adversely affects many organisms that use calcium carbonate for their skeletons and shells, including corals, molluscs and some phytoplankton species.

Aragonite is the form of calcium carbonate deposited by corals. The aragonite saturation horizon represents the limit between the upper saturated and the deeper under saturated waters; above the horizon calcium carbonate can form but below it dissolves (Hobday *et al*. 2006a). As atmospheric CO_2 levels increase, the depth of the aragonite saturation horizon will decrease with projections that the entire Southern Ocean could become under saturated by 2100 (Hobday *et al*. 2006a).

Saturation also decreases with depth and this coupled with decreases in the depth of the aragonite saturation horizon mean that by 2070, Tasmanian Seamount habitats will become increasingly inhospitable for cold water corals below a few hundred meters. Cold water corals represent essential fish habitat, providing shelter, feeding grounds, spawning grounds, nursery areas and other uses. The corals on the deeper seamounts within the Reserve and diverse communities they support could therefore disappear.

Sea surface temperature and water at depth

The southeast region is predicted to experience the largest increase in sea surface temperature due to likely strengthening effect of a poleward shift in zonal winds on the warm East Australia Current (discussed later in this chapter).

The large changes in the sea-surface temperatures are likely to have a strong effect on the ranges of many fish species and assemblages in this region which will be seen through a tendency for shifts in species distributions poleward and towards newly appropriate thermo-habitats and shifted food resources (Hobday *et al*. 2006a).

More specifically, increasing sea surface temperature may result in a shift in phytoplankton community composition towards warm-water species, reductions in the abundance of the existing phytoplankton flora and changes in the timing of phytoplankton. Phytoplankton are the primary source of organic material and energy in oceanic food webs. As such they directly support coral (which may be dependant on surface productivity filtering down) and zooplankton, including the larvae of many marine benthic invertebrates and fish and indirectly they support pelagic fish species such as pilchard, jack mackerel, and tuna (which often feed on zooplankton).

Changes to phytoplankton in the region of the Reserve are therefore likely to have significant consequences for the diverse benthic communities of the Reserve and commercially valuable species that it supports. Studies has projected that the expected increases in Australian ocean temperatures would cause a 35% overall economic decline of Australian fisheries by 2070, and that temperate Australian fisheries will be more vulnerable than tropical ones with Tasmanian fisheries projected to show 64% declines by 2070 (Hobday *et al*. 2006a).

Southward flow of EAC

The East Australian Current (EAC) originates in the Coral Sea and flows southwards before separating from the continental margin to flow northeast and eastwards into the Tasman Sea. Eddies spawned by the EAC continue southwards into the Tasman Sea bringing episodic incursion of warm water to temperate eastern Australia and Tasmanian waters (Hobday *et al*. 2006a).

Monitoring of ocean warming off Maria Island in Tasmania since the 1970's, reveals a warming trend three times greater than the global warming rate. This warming is mainly driven by Antarctic ozone depletion, which has caused changed circulation patterns in the stratosphere, which is in turn causing the strengthening of the circumpolar westerlies and weakening of the mid-latitude westerly winds. These wind changes are causing a strengthening of the East Australian current, which is shifting more warm water south, thus causing a warming of the Tasman Sea (Cai and Cowan 2007).

Additional impacts of the southward flow of the EAC may include an alteration to the timing of migration events of pelagic species and an increase in the suitable habitat for species such as yellowfin (*Thunnus albacares*) and bigeye tuna (*T. obesus*). As two of the main commercial target species in the region, an increase in abundance of these species in may also signify an increase in the interest of commercial fishing operations (Hobday *et al.* 2006b).

Greater stratification and shallowing of the mixed layer

Warming will not only affect surface waters, but will also penetrate deep into the ocean, warming waters down to 500m and beyond. The depth of the mixed surface layer affects sea surface temperature, the supply of light and nutrients to phytoplankton, and phytoplankton sinking losses. Mixing depth therefore strongly affects phytoplankton production and abundance in surface waters and deeper. A shallowing of the mixed layer may therefore affect phytoplankton production and community structure in the entire water column.

Changes of this nature are likely to have major consequences for bottom-dwelling fish and invertebrate communities (Hobday *et al*. 2006a). This will have significant implications for the benthic ecosystem of the Tasmanian Seamounts Marine Reserve; potentially causing the extinction of species that may or may not yet be known to science.

Some pelagic species are constrained by physiology to remain in the warmer mixed layer (e.g. skipjack tuna); however, the anticipated changes according the CSIRO Mk3.5 model are minor in the regions around Australia, and impacts on open ocean pelagic fishes and sharks may not be detectable, or significant (Hobday *et al*. 2006a).

Given the projected warming of the Tasman Sea waters and deep waters further south, the Reserve and its surrounds may be particularly sensitive to climate change. The poleward proximity of southern Australia and other restrictions to southern migration of species (including the aragonite saturation horizon and lack of available habitat) mean that projected climate changes will likely have profound impacts of the values of the Tasmanian Seamounts Marine Reserve. Disappearance of cold water corals, as the foundation species, may result in the disappearance of the entire ecosystem which they support.

The cold water coral and seamount communities of the Reserve are areas of high endemism and speciation and are thought to contain a high proportion of species unknown to science. The resulting loss of species to the local and Australian marine biodiversity will be significant if the seamount habitats are adversely impacted by climate change.

25.10 Principal Management Implications

Managing to increase resilience

- Impacts of over fishing, by catch problems and destructive fishing in areas adjacent to the Reserve will have an increasingly significant impact on the resilience of benthic and demersal fish populations within the reserve. Current adaptive management practices to maintain ecosystem resilience by reducing fishing impacts will be appropriate and require regular review to measure effectiveness of the controls;
- Climate change is likely to place additional pressure on seamount habitat and species within the Reserve; namely through increasing

- It is unclear if and how climate change will impact indirectly on the ability to implement an effective compliance and enforcement system that supports the protection of the Reserve. Current compliance and enforcement systems that support the protection of the Reserve may no longer be appropriate.
- Capacity to monitor and enforce marine activities and fishing will require regular review, particularly as circumstances change which affect the livelihood of fishing communities. Illegal fishing activities are expected to rise and this will exert pressure on existing resources to enforce the law and protect the natural assets of the Reserve.

Increasing decision-making capacity by improving understanding

- Understanding of the impacts and implications of climate change is evolving rapidly and as a consequence adaptive management strategies will require regular review and updating (annually or every two years). This may mean that on-line management plans are more appropriate than hard copy publications;
- The species and habitats within the Reserve that are vulnerable are likely to change as a consequence of climate change. As such more frequent review of monitoring and research activities will help to ensure that budgets and resources are prioritised appropriately to build resilience in vulnerable ecological communities;
- The habitats of the seamounts, their values, and their relationship with the surrounding waters and seabed are not well understood. The potential impacts of climate change make increasing knowledge of ecosystem for scientific purposes and management improvement an immediate priority. By 2070, the potential loss of species diversity in particular, may impede the gathering of knowledge;
- As climate change will impact on a range of conservation and business interests in the region, greater collaboration is likely to be required to manage and conserve the biological assets. This may mean that broader education and communication methods and systems are required to identify common interests and goals;
- The vulnerability and current gaps in knowledge about the ecosystem of the Reserve heightens the importance of monitoring change. This may become an increasing priority requiring greater resources and funding, particularly in relation to monitoring hard corals to learn about recovery rates, dynamics and effects of climate change;

- Ongoing support to electronic tagging of indicator species such as tuna, in order to develop habitat preference models and determine relationship between tuna and the physical or biological resources of the seamounts will be increasingly relevant and appropriate;
- Ongoing scientific research will identify species most at risk from climate change, including endemic species. The potential contribution to conservation played by ex-situ conservation in facilities such as aquaria and biospheres may have increasing relevance;
- With the changes in ocean conditions arising from climate change the significance of movement of pelagic species between Reserves and proposed MPAs is likely to be increasingly important and will necessitate increasing collaboration between protected area managers;
- The statement in the management plan that "further research to increase knowledge and better understand seamount ecosystems is needed" is increasingly relevant; and
- Climate change considerations and projections could add significance to the mid term Performance Assessment carried out during the life of the management plan.

Maintaining infrastructure and protocols to ensure visitor safety

- The Reserve will potentially be exposed to more severe weather events including intense storm activity that could compromise safety and communications. As a consequence of rapid change in climate, safety protocols and procedures will need to be reviewed regularly to ensure that they are appropriate and the risks have been fully considered.

26 Conclusions

26.1 Potential Impacts of Climate Change on Protected Areas

Warming of the climate system globally is now considered unequivocal, with observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC 2007a). This report has identified a broad range of climate change impacts for key values associated with twenty-two Commonwealth protected areas. Impacts identified have covered the following areas:

- Biodiversity, including consideration of species, habitat and ecosystems particularly vulnerable to climate change;
- Cultural heritage;
- Management, infrastructure and visitation; and
- Socio–economic values.

The potential impacts have been documented on a reserve specific basis. CSIRO climate change projections for 2030 and 2070 have been adopted for this assessment with an emphasis on managing for worst case scenarios (i.e. high range scenarios).

Both the impacts of climate change and the biological responses are complex and highly variable. Climate change poses a range of threats to protected areas, with virtually all the sites reviewed in this report having some value considered to be at risk from climate change.

Some natural environmental systems will become increasingly vulnerable to climate change impacts in the next decade (coral reefs), whilst other ecosystems will demonstrate a higher level of adaptability and resilience such as terrestrial plant communities. Climate change will have profound effects on biodiversity and on the structure and function of many Australian ecosystems. Climate change will affect species directly, by affecting their physiology and timing of life cycles, and indirectly, by affecting their interactions with other species. Together, these changes will alter species distributions and lead to changes in the structure and composition of communities. Impacts on dominant producer groups will be particularly significant, for example, impacts on phytoplankton and zooplankton which will have cascading effects throughout marine food webs (Hobday *et al*. 2006a).

The ability of species to track changing environments will depend on the rate of climatic change, the migratory potential of the species, changes in local disturbance regimes, and physical obstacles in the path of migrating individuals or ecosystems. There will be inevitable loss of species some currently unknown to science. The most vulnerable species will be those with long generation times, low mobility, highly specific host relationships, small or isolated ranges, and/or low genetic variation, an example of which is corals.

The vulnerability of natural systems will have broad implications for protected area management and may relate to socio-economic impacts (due to reduced visitor numbers / higher management costs) and the reduced integrity of supporting infrastructure (due to the removal of natural barriers of protection). This loss of income and or increase in park management costs will have adverse flow on effects to protected area income and Australia's macro economy, and may deplete the present value and income generated by tourism.

Climate change may also exacerbate pressures on the cultural values of protected areas. Direct impacts on physical cultural assets will arise through storm damage, an increase in intensity of rainfall and inundation as a consequence of sea level rise. Indirect impacts will arise through the erosion of traditional practises as a consequence of increased intensity of fire and or the loss of species used in traditional medicines or food sources.

26.2 Gaps in Knowledge

Climatic Modelling

Until recently, climate change was seen as a medium to long-term threat that paled in significance next to issues such as water quality and over-exploitation of resources (Wilkinson and Buddermeier 1994; Jackson *et al*. 2001). This perspective has changed in the past 5 years, with climate change impacts now being seen as equal to or surpassing threats to natural ecosystems from other causes. This change in perspective has come about for two reasons: firstly, the accumulation of incontrovertible evidence of severe impacts that have already begun to occur; and secondly, the increasing sophistication and reliability of models and projections of how conditions are likely to change. The acceptance of the reality of climate change as a major stress presents some significant issues with respect to the management of natural ecosystems, both present and future. Despite this progress there are significant gaps in understanding of climatic systems, particularly in terms of regional and remote area climatic impacts. As such fifteen of the twenty two protected areas included within the scope of the study fall outside the boundaries of available CSIRO scenario modelling which is limited to the Australian mainland.

Scientific Monitoring and Research

Monitoring and understanding biotic response to climate change is a complex undertaking requiring a considerable investment in time and resources to understand the ecosystem dynamics and further understand how a particular ecosystem responds under climate induced stress. Whilst there are on-going scientific research projects studying various aspects of the Australian Government's protected areas there is a lack of ecosystem specific research related to the impacts of climate change.

26.3 Implications for Protected Area Managers

This report has identified a broad range of potential implications for park management relating to:

- Increased expenditure through increased maintenance and infrastructure requirements;
- Changes to management strategies and activities and risk assessments including, but not limited to, recovery plans, fire control, erosion control, water supply and pest control; and associated changes to management effort and resources;
- Increased use of chemicals in invasive pest control with associated cost and environmental implications;
- Increased monitoring and research effort to understand ecosystem dynamics and the response to changing climate through a focus on indicator species;
- Loss of revenue due to an increase in the frequency of park closures for visitor safety reasons;
- Changes in visitor recreational requirements and comfort;
- Focus on minimising ecosystem stress to build resilience to direct climate change stresses;
- Consideration of ex situ conservation for species unable to migrate;
- Increased collaboration at all levels to share information and strategies to manage the impacts of climate change, including consideration of bioregional collaboration;
- Changes to water quality and to circulation patterns affecting species populations, breeding success and food availability;
- Economic losses through declines in fish populations in response to changes to food availability;
- Increased competition, disease and pest outbreaks resulting in a species shift with Parks with the loss of some species and introduction of new species;
- Increased air and surface water temperatures resulting in the creation of new ice-free areas which can result in the loss of cultural heritage and also favour the establishment of new species; and,
- Changes to breeding and migration patterns of migratory birds and marine species.

26.3.1 Managing for uncertainty

Despite a growing body of scientific knowledge, there remains uncertainty around climate change projections and about the rate and magnitude of species and ecosystem response. It is with this background that protected area managers will be required to manage in an increasingly uncertain environment.

However, despite the uncertainties, there is a range of actions that may help reduce the impact of climate change and the vulnerability of values to identified impacts. These actions include knowledge improvement, monitoring of values and increasing resilience of values to potential change by managing external stresses.

Managing Threats

The impacts of climate change are complex and cumulative and will require broad scale responses to manage the impeding threats. For example, drier ground conditions and prolonged drought will increase the cumulative impact of other climate induced effects for example, erosion and sedimentation, pest and invasive species, dust storms, impact of lightening strikes and fire, water catchment function and stress related impacts on vegetative communities and the species that inhabit them. Managing such interconnected threats will require an increasingly comprehensive understanding of ecosystem function and response.

Knowledge Management

Direct action is required to adapt to climate change impacts and threats, but is constrained in most cases by a lack of reliable information and understanding of both impacts and effects on ecosystem dynamics. Critical knowledge gaps need to be addressed and programs identified to inform management decisions. Gathering better knowledge about these aspects will require significant additional investment in monitoring and research efforts. It is vital that as information is gathered on the impacts of climate change and appropriate management responses that it is entered into a centralised database to facilitate knowledge sharing and cross fertilization of ideas between scientists, park managers and regulators (CRES 2006).

Whilst knowledge bases are being constructed and populated actions can be implemented to build the resilience of existing protected areas to the impacts of climate change. Fundamentally this requires planning at a national level to achieve CAR objectives under the worst case climate change projections. At a park level this has many implications for park managers ranging from changes to zoning arrangements, to limiting access or restricting certain activities within the park boundaries, to redesign of infrastructure (drainage, roads, visitor centres etc.) to changes in management regimes for pest control or fire management.

Whilst the above efforts will improve our knowledge and encourage co-operation between researchers, scientists and park managers, this may not be sufficient for the conservation of many species. Of particular concern here is the impact of climate change on coral reef systems.

Increasing Resilience

The challenge of building resilience to the long term impacts on protected areas from human encroachment, fragmentation, pollution and invasive species is further complicated by climate change. Protected area managers will need to consider future climate change scenarios and the resulting configurations of habitat, communities and ecosystem. This will require a flexible approach to management that considers the conservation and protection of habitat and species, migration pathways, and climatic refugia in order to provide adequate representation.

A key focus of building ecosystem resilience is to manage as far as possible existing non-climate related stresses. These are many and varied and include activities such as limiting human disturbance, controlling weeds and feral animals extending no go areas for commercial fishing, mitigating pollution, limiting water abstraction etc.

To be effective management approaches will need to be both flexible and responsive. Approaches to protected area management will require regular review and updating to respond to changing environmental circumstances or new ecological monitoring data. Active intervention will be a feature of on-going protected area management and will be necessary to maintain resilience and adaptive capacity. In this way the genetic diversity and species biodiversity can potentially be managed and conserved, therefore preserving protected area values for future generations to enjoy. Where direct intervention and mitigation is not feasible, options such as ex-situ conservation may need to be considered.

26.3.2 Managing existing values versus managing for changed values

There is now clear evidence that the relatively modest climatic changes over the past century have already had significant impacts on the distribution, abundance, life cycles and physiology of a wide range of species globally. Further climate changes are likely to increase the pressure on the existing values and may give rise to new values for protected areas.

A key aspect of this adjustment will be understanding and managing community expectations. Considerable investment in public perception about an area may be required if its values are likely to change; or conversely, social opinion about losing a particular value may be the driver for investment in that value. Decision makings will need to objectively assess such decisions as they may need to occur at the expense of other management decisions.

Ex situ conservation

Botanic gardens have played a significant role in the preservation of species and genetic material over time. With climate change impacting upon the environment it is anticipated that botanic gardens including living collections and herbariums will have an increasingly important role to play.

In terms of timescale it is important to start this process now so that we build sufficient capacity to cope with an increasing future demand for ex situ preservation and conservation of species. In current thinking this applies predominantly to terrestrial flora, however, there is no reason why we should not be planning significant oceanariums to replicate this effort for the marine environment. As can be concluded from this report the threats to the coral reef environments are potentially more significant and threatening over a shorter time horizon.

The authors are unaware of any national response plan to climate change prepared on behalf of the botanic gardens. In the first instance this would require a change in the definition and role of botanic gardens to include the preservation and conservation of species and genetic material from the threat posed by climate change.

A national response plan would assess current and predicted risks to flora with the aim of establishing suitably located botanic garden facilities to preserve representative samples of native flora, both in living collections and in preserved forms. It is anticipated that such a program would require significant capital investment for the expansion of existing facilities, the acquisition of new sites and for the staffing and running of an expanded network of facilities.

The same ex situ conservation principles apply to the marine environment and this report has recommended a role for aquariums and oceanariums in species conservation as a direct consequence of climate change. As with the botanic gardens this would require a national response plan to determine the appropriate course of action. A specific remit to provide for the conservation of species threatened by climate change is anticipated and in particular, an emphasis on coral reef ecosystems.

Appendix A

References

References

Executive Summary

http://www.greenhouse.gov.au/impacts/index.html

CSIRO (2006) Climate Change Impacts & Risk Management – A Guide for Business and Government. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

IPCC (2007a) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC (2007b) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change Summary for Policymakers. IPCC Secretariat, Switzerland

Nicholls, N. and D. Collins, 2006: Observed change in Australia over the past century. *Energ. Environ.*, **17**, 1-12.

Hoegh-Guldberg, O. (1999). Coral bleaching, Climate Change and the Future of the World's Coral Reefs. Marine and Freshwater Research Mar. Freshwater Res. 50: 839-866.

Pittock, N. (2003) Climate Change: An Australian guide to the science and potential impacts.

Preston, B.L. and Jones, R.N.: (2006) *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions.* A consultancy report for the Australian Business Roundtable on Climate Change.

Cai, W., G. Shi, T. Cowan, D. Bi and J. Ribbe, 2005: The response of the Southern annular mode, the East Australian current, and the southern mid-latitude ocean circulation to global warming. *Geophys. Res. Lett.*, **32**, L23706.

Director of National Parks, 2006. Annual Report 2005-06

Hughes L. (2000) Biological consequences of global warming: is the signal already apparent? *Trends Ecol. Evol.* **15**, 56-61.

Parmesan C. P. & Yohe G. (2003) A globally coherent fingerprint of climate change across natural systems. *Nature* **421**, 37-42.

Root T. L, Price J. T., Hall K. R., Schneider S. H., Rosenzweig C. & Pounds J. A. (2003) Fingerprints of global warming on wild animals and plants. *Nature* **421**, 57-60.

Root TL, MacMynowski DP, Mastrandrea MD, *et al*. (2005) Human-modified temperatures induce species changes: Joint attribution. *Proceedings Of The National Academy Of Sciences Of The United States Of America* 102 (21): 7465-7469

Chapter 1 - Introduction

Great Barrier Reef Marine Parks Authority 2007, Great Barrier Reef Marine Parks Authority, Townsville Viewed 31st August 2007 <http://www.gbrmpa.gov.au>

AGO 2007, Department of the Environment and Water Resources, Canberra. Viewed 31st August 2007 <http://www.greenhouse.gov.au/impacts/index.html>

Pittock, B. 2003, Climate Change: *An Australian guide to the science and potential impacts.* Australian Greenhouse Office, Canberra

Chapter 2 – Protected Area Management

ANZECC 1999, *Strategic Plan of Action for the National Representative System of Marine Protected Areas: A Guide for Action by Australian Governments*. ANZECC Task Force on Marine Protected Areas

DEW 2001 *Australian National Botanic Gardens Management Plan 2002 – 2008* Department of the Environment and Water Resources, Canberra

CHABG 2006, Council of Heads of Australian Botanic Gardens, Canberra. Viewed 31st August 2007, < http://www.chabg.gov.au /chabg/abg/index.html>

DEW, 2007a, Department of the Environment and Water Resources, Canberra. Viewed 31st August 2007 <http://www.deh.gov.au/parks/nrs/ibra/index.html>

Director of National Parks, 2006. Annual Report 2005-2006.

DEW, 2007b, Department of the Environment and Water Resources, Canberra. Viewed 31st August 2007 <http://www.environment. gov.au/coasts/mbp/imcra/nmb.html>

Pandolfi J.M, Bradbury R.H, Sala E, Hughes T.P, Bjorndal K.A, Cooke R.G, McArdle D, McClenachan L, Newman M.J.H, Paredes G, Warner R.R, Jackson J.B.C. 2003, Global trajectories of the long-term decline of coral reef ecosystems. *Science* 301:955-958

Thackway, R. & Cresswell, I.D. (eds) 1995, *An Interim Biogeographic Regionalisation for Australia: A Framework for Establishing the National System of Reserves, Version 4.0,* Australian Nature Conservation Agency, Canberra

Chapter 3 – Global and Australian Climate Trends

Abbs, D.J., 2004: A high-resolution modelling study of the effect of climate change on the intensity of extreme rainfall events. *Staying Afloat: Floodplain Management Authorities of NSW 44th Annual Conference*, BoM, 2003 *The Greenhouse Effect and Climate Change,* Australian

Bureau of Meterology, Melbourne. Veiwed 31st August 2007 <http://www.bom.gov.au/info/GreenhouseEffectAndClimateChange.pdf>

Alexander, L., P. Hope, D. Collins, B. Trewin, A. Lynch and N. Nicholls, 2007: Trends in Australia's climate means and extremes: a global context. *Aust. Meteorol. Mag.*, in press.

BoM 2007, *Annual Australian Climate Statement 2006* issued 3rd January 2007

Burke, E.J., S.J. Brown and N. Christidis, 2006: Modelling the recent evolution of global drought and projections for the 21st century with the Hadley Centre climate model. *J. Hydrometeorol.*, **7**, 1113-1125.

Cai, W., G. Shi, T. Cowan, D. Bi and J. Ribbe, 2005: The response of the Southern annular mode, the East Australian current, and the southern mid-latitude ocean circulation to global warming. *Geophys. Res. Lett.*, **32**, L23706.

Cary, G.J., 2002: Importance of a changing climate for fire regimes in Australia. *Flammable Australia: Fire Regimes and Biodiversity of a Continent*, R.A. Bradstock, J.E. Williams and A.M. Gill, Eds., Cambridge University Press, Melbourne, 26-49.

Church, J., J. Hunter, K. McInnes and N.J. White, 2004: Sea-level rise and the frequency of extreme event around the Australian coastline. *Coast to Coast '04: Australia's National Coastal Conference*, Hobart, Tasmania. Viewed 14th July 2007 <http://www.cmar.csiro.au/cgibin /abstract_srch.pl?_abstract_available_795>

CSIRO 2001 *Climate change projections for Australia*. Summary document CSIRO, Canberra.

CSIRO 2006: *Climate change scenarios for initial assessment of risk in accordance with risk management guidance,* Australian Greenhouse Office, Department of the Environment and Heritage Canberra

Gallant, A., K. Hennessy, and J. Risbey, 2006: A re-examination of trends in rainfall indices for six Australian regions. Australian Meteorological Magazine.

Hennessy, K., C. Lucas, N. Nicholls, J. Bathols, R. Suppiah and J. Ricketts, 2006: *Climate Change Impacts on Fire-Weather in South-East Australia.*. CSIRO Atmospheric Research and Australian Government Bureau of Meteorology <http://www. Greenhouse.gov.au/impacts/publications/pubs/bushfire-report.pdf>

Hennessy, K., McInnes, K., Abbs, D., Jones, R., Bathols, J., Suppiah, R., Ricketts, J., Rafter, T., Collins D. and Jones, D. 2004. *Climate Change in New South Wales, Part 2: Projected changes in climate extremes.* CSIRO Atmospheric Research and the National Climate Centre of the Australian Government Bureau of Meteorology

Hennessy K, Page C, McInnes K, Walsh K, Pittock B, Bathols J and Suppiah R, 2004. Climate change in the Northern Territory. CSIRO Climate Impact Group, CSIRO Atmospheric Research.

Hennessy, K.J., 2004: Climate change and Australian storms. *Proceedings of the International Conference on Storms*, Brisbane, Hennessy, K.J., P.H. Whetton, J. Bathols, M. Hutchinson and J. Sharples, 2003: *The Impact of Climate Change on Snow Conditions in Australia* CSIRO Atmospheric Research. <http://www.cmar.csiro.au/e-print/open/hennessy_2003a.pdf.>

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Australian Greenhouse Office, Canberra, Australia.

Hoegh-Guldberg, O. 1999. Coral bleaching, Climate Change and the Future of the World's Coral Reefs. *Marine and Freshwater Research Mar. Freshwater Res*. 50: 839-866.

Hughes, L., 2003: Climate change and Australia: trends, projections and impacts. *Austral Ecol.*, 28, 423-443.

IPCC *2007a Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment*. Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC 2007b. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change Summary for Policymakers.* IPCC Secretariat, Switzerland

Kuleshov, Y.A., 2003: *Tropical Cyclone Climatology for the Southern Hemisphere. Part 1. Spatial and Temporal Profiles of Tropical Cyclones in the Southern Hemisphere.* National Climate Centre, Australian Bureau of Meteorology, 1-22

Leslie, L.M. and D.J. Karoly, 2007: Variability of tropical cyclones over the southwest Pacific Ocean using a high-resolution climate model. *Continuum Mechanics and Thermodynamics*, 19(3-4). 133-175

Lioubimtseva E, 2004. Climate change in arid environments: revisiting the past to understand the future. *Progress in Physical Geography* 28(4) 502–530

Lough, J.M., 2000. 1997-98: Unprecedented thermal stress to coral reefs? *Geophys. Res. Lett.*, 27, 3901-3904.

Mpelasoka, F., K.J. Hennessy, R. Jones and J. Bathols, 2007: Comparison of suitable drought indices for climate change impacts assessment over Australia towards resource management. *Int. J. Climatol.,* accepted 2007.

Nicholls, N. and D. Collins, 2006: Observed change in Australia over the past century. *Energ. Environ.*, 17, 1-12.

Nicholls, N., 2004: The changing nature of Australian droughts. *Climatic Change*, 63, 323-336.

Nicholls, N., 2005: Climate variability, climate change and the Australian snow season. *Aust. Meteorol. Mag.*, 54, 177-185.

Pittock, B. 2003 Climate Change: *An Australian guide to the science and potential impacts.* Australian Greenhouse Office, Canberra

Pittock, A.B., K. Walsh, and K. McInnes, 1996: Tropical cyclones and coastal inundation under enhanced greenhouse conditions. *Water, Air and Soil Pollution,* 92, 159-169.

Preston, B.L. and Jones, R.N.: 2006, *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions.* Consultancy report for the Australian Business Roundtable on Climate Change.

Smith, I.N., 2004b: Trends in Australian rainfall: are they unusual? *Aust. Meteorol. Mag.*, 53, 163-173.

Tapper, N., 2000: Atmospheric issues for fire management in Eastern Indonesia and northern Australia. *Proceedings of an International Workshop: Fire and Sustainable Agricultural and Forestry Development in Eastern Indonesia and Northern Australia*, J. Russell-Smith, G. Hill, S. Djoeroemana and B. Myers, Eds., Northern Territory University, Darwin, 20-21 <http://www.arts.monash.edu.au/ges/who/pdf/Atmospheric %20Issues%20for%20Fire%20Management.pdf.

United Nations, 1992. *United Nations Framework Convention on Climate Change* Viewed 31st August 2007 <http://unfccc.int/resource/docs/ convkp/conveng.pdf>

Walsh K, Pittock AB, 1998. Potential changes in tropical storms, hurricanes, and extreme rainfall events as a result of climate change. *Climatic Change* 39 (2-3): 199-213

Walsh KJE, Ryan BF. 2000, Tropical cyclone intensity increase near Australia as a result of climate change *Journal of Climate* 13 (16): 3029-3036

Walsh, K., K. Hennessy, R. Jones, K.L. McInnes, C.M. Page, A.B. Pittock, R. Suppiah and P. Whetton, 2001: *Climate Change in Queensland Under Enhanced Greenhouse Conditions: Third Annual Report, 1999-2000.* CSIRO Consultancy Report for the Queensland Government, Aspendale. <http://www.cmar.csiro.au/e-print/open/walsh_2001a.pdf>

Walsh, K.J.E., K.C. Nguyen and J.L. McGregor, 2004: Finer-resolution regional climate model simulations of the impact of climate change on tropical cyclones near Australia. *Clim. Dynam.*, 22, 47-56.

Williams, A.A., D.J. Karoly and N. Tapper, 2001: The sensitivity of Australian fire danger to climate change. *Climatic Change*, 49, 171-191.

World Meteorological Organisation 2006 WMO statement on the status of the global climate in 2006, issued on 14 December 2006.

Chapter 4 – Climate Change Impacts on the Values of Protected Areas

Augee M & Fox M 2000 Biology *of Australia and New Zealand.* Pearson Education Australia, Sydney.

Australian Bureau of Meterology, 2007 < http://www.bom.gov.au/ lam/climate/levelthree/ausclim/ausclim.htm>, Australian Bureau of Meterology, Melbourne. Veiwed 31st August 2007

Baker R. H. A., Sansford C. E., Jarvis C. H., Cannon R. J. C., MacLeod A. & Walters K. F. A. 2000 The role of climatic mapping in predicting the potential geographical distribution on non-indigenous pests under current and future climates. *Agric. Ecosyst. Environ*. 8, 57-71.

Bayliss B, Brennan K., Eliot I., Finlayson, Hall R., House T., Pidgeon B., Walden D. and Waterman P. 1997 Vulnerability assessment of predicted climate change and sea level rise in the Alligator Rivers Region, Northern Territory Australia. *Supervising Science*.

Beaumont, L.J., I.A.W. McAllan and L. Hughes, 2006: A matter of timing: changes in the first date of arrival and last date of departure of Australian migratory birds. *Global Change Biol*., 12, 1339-1354.

Bowman, D.M.J.S., A. Walsh and D.J. Milne, 2001: Forest expansion and grassland contraction within a Eucalytpus savanna matrix between 1941 and 1994 at Litchfield National Park in the Australian monsoon tropics. *Global Ecol Biogeogr Lett*, 10, 535-538.

Brereton R., Bennett S. & Mansergh I. 1995 Enhanced greenhouse climate change and its potential effect on selected fauna of south-eastern Australia: a trend analysis. *Biol. Conserv.* 72, 339-54.

Bull C. M. & Burzacott D. 2001 Temporal and spatial dynamics of a parapatric boundary between two Australian reptile ticks. *Molec. Ecol.* 10, 639-48.

Burgman M.A and Lindenmayer D.B 1998 *Conservation biology for the Australian environment*. Surrey Beattie, Chipping Norton.

Busby J. R. 1991 BIOCLIM - a bioclimatic analysis and prediction system. *Plant Prot. Quart*. 6, 8-9.

Cai. W 2006, ‘Antarctic Ozone Depletion causes an intensification of the Southern Ocean super gyre circulation’, *Geophysical Research Letters*, Vol 33, Aspenvale

Cai, W., and T. Cowan 2007, Trends in Southern Hemisphere circulation in IPCC AR4 models over 1950–99: Ozone depletion versus greenhouse forcing, *J. Climate*, 20, 681-693.

Chambers, L.E., 2005: Migration dates at Eyre Bird Observatory: links with climate change? *Climate Res.*, 29, 157-165.

Chambers, L.E., L. Hughes and M.A. Weston, 2005: Climate change and its impact on Australia’s avifauna. *Emu*, 105, 1-20.

Chapman A. D & Milne D. J. 1998 *The Impact of Global Warming on the Distribution of Selected Australian Plant and Animal Species in Relation to Soils and Vegetation.* ERIN Unit, Environment Australia, Canberra.

Coles, S.L., Jokiel, P.L. 1978, Synergistic effects of temperature, salinity and light on the hermatypic coral Montipora verrucosa. *Marine Biology*. 49:187-195.

CSIRO 2002 Marine Research, *The Indonesian Flow Through,* CSIRO Canberra <http://www.cmar.csiro.au/e-print/open/CMReport_240.pdf>

Dexter E. M., Chapman A. D. & Busby J. R. 1995 *The Impact of Global Warming on the Distribution of Threatened Vertebrates* (ANZECC 1991). ERIN, ANCA, Canberra.

Done, T. J. 1999. Coral community adaptability to environmental change at the scales of regions, reefs, and reef zones. *American Zoologist* 39:66-79.

Done, T. J., Whetton, P., Jones, R., Berkelmans, R., Lough, J., Skirving, W., Wooldridge, S. 2003, *Global Climate Change and Coral Bleaching on the Great Barrier Reef, Final report to the State of Queensland Greenhouse Taskforce*, Department of Natural Resources and Mining. Townsville.

Dunlop N. 2001 Sea-change and fisheries: a bird's-eye view. *West. Fisheries Mag*. Spring, 11-4.

Edgar, G.J., Samson, C.R. & Barrett, N.S. 2005. Species extinction in the marine environment: Tasmania as a regional example of overlooked losses in biodiversity. *Conservation Biology* 19, 1294-1300.

Edgar, G.J., Moverley, J., Barrett, N.S., Peters, D. & Reed, C. 1997. The conservation-related benefits of a systematic marine biological sampling programme: the Tasmanian reef bioregionalisation as a case study. *Biological Conservation* 79, 227-240.

Edyvane, K.S. 2003. Conservation, monitoring and recovery of threatened giant kelp *(Macrocystis pyrifera) beds in Tasmania*. Final Report for Environment Australia. Department of Primary Industries, Water and Environment, Hobart, Tasmania.

Farquhar G. D. 1997 Carbon dioxide and vegetation. *Science* 278, 1411.

GCRMN 2000 *Global Coral Reef Monitoring Network: Status of coral reefs of the world in 2000.* Ed. C.R. Wilkinson, Australian Institute of Marine Science, Townsville, Queensland, Australia

GCRMN 2004 *Global Coral Reef Monitoring Network: Status of coral reefs of the world in 2004.* Ed. C.R. Wilkinson, Australian Institute of Marine Science, Townsville, Queensland, Australia

Gleason, D. F., Wellington, G. M. 1993, Ultraviolet radiation and coral bleaching. *Nature* 365, 836–8.

Glynn, P. W., DCroz, L. 1990, Experimental evidence for high temperature stress as the cause of El Niño coincident coral mortality. *Coral Reefs* 8: 181-91.

Green K. & Pickering C. M. 2002 A potential scenario for mammal and bird diversity in the Snowy Mountains of Australia in relation to climate change. In: *Mountain Biodiversity: a Global Assessment.* (eds Ch. Korner & E. M. Spehn). pp. 241-249. Parthenon Publishing, London.

Guinotte J.M, Orr, J, Cairns, S, Freiwald A, Morgan L & George R, 2006, Will human induced changes in seawater chemistry alter the distribution of deep sea scleractinian corals? *Front Ecol Environ* 4(3): 141-146

Hilbert, D.H., B. Ostendorf and M.S. Hopkins, 2001: Sensitivity of tropical forests to climate change in the humid tropics of North Queensland. *Austral Ecol.*, 26, 590-603.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006b. *Impacts of climate change on Australian marine life: Part B. Technical Report September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006c. *Impacts of climate change on Australian marine life: Part C Literature Review September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Hoegh-Guldberg O 2005 Low coral cover in a high-CO_2 world. *Journal Of Geophysical Research-Oceans 110* (C9):

Hoegh-Guldberg, O., 1999: Climate change, coral bleaching and the future of the world's coral reefs. *Mar. Freshwater Res.*, 50, 839-866.

Hoegh-Guldberg, O. & Fine, M. 2004. Cold weather causes coral bleaching. *Coral Reefs*, 23(3), 44.

Hoegh-Guldberg, O. & Smith, G.J. 1989. The effect of sudden changes in temperature, irradiance and salinity on the population density and export of zooxanthellae from the reef corals *Stylophora pistillata* Esper (1797) and *Seriatopora hystrix* Dana (1846). *Journal of Experimental Marine Biology and Ecology* 129, 279-303.

Howden S. M., McKeon G. M. & Reyenga P. J. 1999b *Global Change Impacts on Rangelands.* Working Paper Series 99/09 Australian Greenhouse Office.CSIRO Wildlife and Ecology, Canberra. <www.dwe.csiro.au/research/futures/publications/WkgDocs99.htm>

BoM 2007, Bureau of Meteorology, Melbourne, viewed 23rd July 2007, <http://www.bom.gov.au/lam/climate/levelthree/ausclim/ausclim.htm>

University of Berkley (2007) University of Berkley, California Viewed 13th July 2007 <http://www.ucmp.berkeley.edu/help/timeform.html>

Hughes L. 2000 Biological consequences of global warming: is the signal already apparent? *Trends Ecol. Evol.* 15, 56-61.

Hughes, L., 2003: Climate change and Australia: trends, projections and impacts. *Austral Ecol.*, 28, 423-443.

Hughes L. & Westoby M. 1994 Climate change and conservation policies in Australia: coping with change that is far away and not yet certain. *Pacific Cons. Biol.* 1, 308-18.

Isdale, P. 1984. Fluorescent bands in massive corals reflect centuries of coastal rainfall. *Nature* 3 (10): 578-579.

Jokiel, P. L., Coles, S. L. 1990, Response of Hawaiian and other Indo–Pacific reef corals to elevated temperatures. *Coral Reefs* 8, 155–161

Jones R.J, Hoegh-Guldberg O 1999 Effects of cyanide on coral photosynthesis: implications for identifying the cause of coral bleaching and for assessing the environmental effects of cyanide fishing. *Marine Ecology Progress Series* 177:83-91

Jones, R.J. 1997, Changes in zooxanthellar densities and chlorophyll concentrations in corals during and after a bleaching event. *Marine Ecology Progress Series* 158, 51-9

Kerswell, A.P. & Jones, R.J. 2003. Effects of hypo-osmosis on the coral *Stylophora pistillata*: nature and cause of 'low-salinity bleaching'. *Marine Ecology Progress Series* 253,145-154.

Kingsford, R 2000 Ecological impacts of dam, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology*, 25, 109-127.

Kriticos, D.J., R.W. Sutherst, J.R. Brown, S.W. Adkins and G.F. Maywald, 2003a: Climate change and biotic invasions: a case history of a tropical woody vine. *Biol. Invasions*, 5, 147-165.

Kriticos, D.J., R.W. Sutherst, J.R. Brown, S.W. Adkins and G.F. Maywald, 2003b: Climate change and the potential distribution of an invasive alien plant: *Acacia nilotica* spp. *indica* in Australia. *J. Appl. Ecol.*, 40, 111-124.

Kushmaro, A., Loya, Y., Fine, M., Rosenberg, M. 1996, Bacterial infection and coral bleaching. *Nature* 380:396.

Langdon, C., 2002: Review of experimental evidence for effects of CO_2 on calcification of reef builders. *Proceedings of the 9th International Coral Reef Symposium*, Ministry of Environment, Indonesian Institute of Science, International Society for Reef Studies, Bali 23–27 October, 1091-1098.

Langdon, C., T. Takahashi, F. Marubini, M. Atkinson, C. Sweeney, H. Aceves, H. Barnett, D. Chipman and J. Goddard 2000. Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef. *Global Biogeochemical Cycles* 14: 639-654.

Lesser, M. P., Stochaj, W. R., Tapley, D. W., Shick, J. M. 1990, 'Bleaching in coral reef anthozoans: effects of irradiance, ultraviolet radiation, and temperature on the activities of protective enzymes against active oxygen.' *Coral Reefs* 8: 225-232

Lough, J.M., 2000: 1997-98: Unprecedented thermal stress to coral reefs? *Geophys. Res. Lett.*, 27, 3901-3904.

Moore, J.L., S.M. Howden, G.M. McKeon, J.O. Carter and J.C. Scanlan, 2001: The dynamics of grazed woodlands in southwest Queensland, Australia and their effect on greenhouse gas emissions. *Environ. Int.*, 27, 147-153.

Mulrennan M. E. & Woodroffe C. D. 1998 Saltwater intrusions into the coastal plains of the Lower Mary River, Northern Territory, Australia. *J. Environ. Manage.* 54, 169-88.

National Parks and Wildlife Service 2004 Department of Environment and Climate Change, NSW. Viewed 31st August 2007 <http://www.national parks.nsw.gov.au/npws.nsf/content/bioregions_nswoutline_landform>

Pittock, B. A. 1999. Coral Reefs and Environmental Change: Adaption to what? *American Zoology* 39: 10-29.

Porter, J. W. and Meier, O. W. 1992. The effect of Hurricane Andrew on coral reefs. *Am. Zoo*l. 32, 625

Pouliquen-Young O. & Newman P. 2000 *The Implications of Climate Change for Land-Based Nature Conservation Strategies. Final Report 96/1306.* Australian Greenhouse Office, Environment Australia, Canberra, and Institute for Sustainability and Technology Policy, Murdoch University, Perth.

Power, S., F. Tseitkin, S. Torok, B. Lavery, R. Dahni and B. McAvaney, 1998: Australian temperature, Australian rainfall and the Southern Oscillation, 1910-1992: coherent variability and recent changes. *Aust. Meteorol. Mag.*, 47, 85-101.

Pryor L. D. & Johnson L. A. S. 1981 *Eucalyptus*, the universal Australian. *Ecological Biogeography of Australia.* (ed A. Keast) pp. 501-36.

Puotinen, M.L., 2006: Modelling the risk of cyclone wave damage to coral reefs using GIS: a case study of the Great Barrier Reef, 1969-2003. *Int. J. Geogr. Inf. Sci.*, 21, 97-120.

Raven, J., K. Caldeira, H. Elderfield, O. Hoegh-Guldberg, P. Liss, U. Riebesell, J. Shepherd, C. Turley and A. Watson, 2005: *Ocean acidification due to increasing carbon dioxide.* The Royal Society, London,. <http://www.royalsoc.ac.uk/displaypagedoc. asp?id=13539>

Root T. L, Price J. T., Hall K. R., Schneider S. H., Rosenzweig C. & Pounds J. A. 2003. Fingerprints of global warming on wild animals and plants. *Nature* 421, 57-60.

Root T.L, MacMynowski D.P, Mastrandrea M.D, *et al*. 2005 Human-modified temperatures induce species changes: Joint attribution. *Proceedings Of The National Academy Of Sciences Of The United States Of America* 102 (21): 7465-7469

Saintilan N. & Williams R. J. 1999 Mangrove transgression into saltmarsh environments. *Global Ecol. Biogeog. Letts* 8, 117-24.

Saxby T, Dennison WC, Hoegh-Guldberg O 2003 Photosynthetic responses of the coral Montipora digitata cold temperature stress. *Marine Ecology Progress Series* 248: 85-97

Shoo, L. P., S. E. Williams, and J.-M. Hero, 2005: Climate warming and the rainforest birds of the Australian Wet Tropics: using abundance data as a sensitive predictor of change in total population size. *Biological Conservation*, 125**,** 335-343.

Sutherst R. W., Maywald G. F., Stevens P. M. & Yonow T. 1998 *CLIMEX for Windows Version 1.1 User's Guide.* CRC for Tropical Pest Management, Brisbane.

Tidemann C. R. 1999 Biology and management of the grey-headed flying fox, *Pteropus poliocephalus. Acta Chiropterol.* 1, 151-64.

University of Queensland 2006, *Larrys cool change good for reef*, 22nd March 2006, Viewed 3rd September 2007 < http://www.physorg.com/news12037.html>

University of California 2007, Museum of Paleontology at Berkley, Viewed 3rd September 2007 <http://www.ucmp.berkeley.edu/help/timeform.html>

Wearne, L.J. and J.W. Morgan, 2001: Recent forest encroachment into sub-alpine grasslands near Mount Hotham, Victoria, Australia. *Arct. Antarct. Alp. Res.*, 33, 369-377.

Williams, S.E., E.E. Bolitho and S. Fox, 2003: Climate change in Australian tropical forests: an impending environmental catastrophe. *P. Roy. Soc. Lond. B Biol. Sci.*, 270, 1887-1892.

Woodroffe C. D. & Mulrennan M. E. 1993 *Geomorphology of the Lower Mary River Plains, Northern Territory.* Australian National University and the Conservation Commission of the Northern Territory, Darwin.

Yonge, C. M., Nichols, A. G. 1931 'Studies on the physiology of corals: V. The effect of starvation in light and in darkness on the relationship between corals and zooxanthellae.' *Scientific Report of the Great Barrier Reef Expedition* 1:177-211.

Zann L.P 1995 *State of the Marine Environment Report for Australia: The Marine Environment*, Commonwealth of Australia, Department of the Environment and Water Resources, Canberra. Viewed 3rd September 2007 < http://www.environment.gov.au/coasts/publications/ somer/annex1/land-sea.html#HDR7>

Chapter 6 – Booderee National Park

Commonwealth of Australia 2002. *Booderee National Park Management Plan*, Booderee National Park Board of Management, Director of National Parks,

CSIRO 2006, Climate Change Impacts & Risk Management – A Guide for Business and Government Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Department of Environment and Conservation 2006. *NSW Threat Abatement Plan –Invasion of native plant communities by Chrysanthemoides monilifera (bitou bush and boneseed)*.Department of Environment and Conservation (NSW), Hurstville. <http://www. nationalparks.nsw.gov.au/pdfs/bitou_tap_text.pdf>

Department of Environment and Heritage, 2005b *Australia's biogeographical regions,* Department of Environment and Heritage, Canberra <http://www.deh.gov.au/parks/nrs/ibra/index.html>

Director of National Parks, 2006. Annual Report 2005-06

Hennessy, K., McInnes, K., Abbs, D., Jones, R., Bathols, J., Suppiah, R., Ricketts, J., Rafter, T., Collins D. and Jones, D. 2004. *Climate Change in New South Wales, Part 2: Projected changes in climate extremes.* Climate Impact Group of CSIRO Atmospheric Research and the National Climate Centre of the Australian Government Bureau of Meteorology

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

DEW 2006 Department of the Environment and Water Resources Viewed 12th July 2005 <http://www.environment.gov.au/parks/booderee/statemap.html>

Pittock, B. 2003 *Climate Change: An Australian guide to the science and potential impacts.* Australian Greenhouse Office, Canberra

Short, F.T., Neckles H.A., 1999. The effects of global climate change on Seagrasses. *Aquatic Botany*, 63(3), pp. 169-196

Chapter 7 – Christmas Island National Park

Abbott K.L, 2006. Spatial dynamics of supercolonies of the invasive yellow crazy ant, *Anoplolepis gracilipes*, on Christmas Island, Indian Ocean. *Diversity and Distributions* 12, 101-110

DEH 2002 *Christmas Island National Park Management Plan 2002* Department of Environment and Heritage Canberra

CSIRO 2006. *Climate Change Impacts & Risk Management – A Guide for Business and Government*. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Fritts T.H 1993. The common wolf snake, *Lycodon aulicus capucinus*, a recent colonist of Christmas Island in the Indian Ocean. *Wildlife Research* 20, 261-266

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

DEW 2007, Department of the Environment and Water Resources, Canberra, viewed August 20th 2007 <http://www.environment.gov.au/parks/christmas/parkhistory.html>

Poloczanska, E.S. & Milton, D. 2006 Impacts of climate change on marine turtles. Paper contributed to CSIRO Study on "Impacts of climate change on Marine Life" (Hobday *et al*, 2006c). CSIRO Marine and Atmospheric Research

Shuraleff II, G. 2000. *Manta birostris,* Animal Diversity Web <http://animaldiversity.ummz.umich.edu/site/accounts/information/Manta_birostris.html>

Chapter 8 – Kakadu National Park

Andersen A.N, Cook G.D, Corbett L.K, Douglas M.M, Eager RW, Russell-Smith J, Setterfield SA, Williams RJ, Woinarski JCZ 2005. Fire frequency and biodiversity conservation in Australian tropical savannas: implications from the Kapalga fire experiment. *Austral Ecology* 30, 155-167

Araujo, M. B., Thuiller, W., Pearson, R. G. 2006: Climate warming and the decline of amphibians and reptiles in Europe. *Journal of Biogeography* 33 (10): 1712-1728 October 2006

Australian Greenhouse Office 2004. *Climate change in the Cairns and Great Barrier Reef Region: Scope and focus for an integrated assessment.* Australian Greenhouse Office, Canberra

Bardsley, I. N. 1985 The effects of cyclone Kathy on Mangrove vegetation: In Coastal and Tidal wetlands of the Australian monsoon region in Darwin. In: Bardsley, K.N. Davie, J.D.S. and Woodroffe, C.D [Eds] Mangrove Monograph No1 pp 167-185, Australian National University, North Australian Research Unit, Darwin.

Bayliss, B.L. K.G. Brennan, I. Eliot, C.M. FInalyson, R.N. Hall, T. House, R.W.J. Pidgeon, D. Waldmen, and P. Waterman, 1997: Vulnerability Assessment of Predicted Climate Change and Sea Level Rise in the Alligator Riveres Region, Northern Territory, Australia. Supervising Scientist Report 123, *Supervising Scientist*, Canberra, Australia,

Bayliss, B.L., Brennan, K.G., Eliot, I., Finlayson, C.M., Hall, R.N.,House, T., Pidgeon, R.W.J., Walden, D. and Waterman, P. 1998. Vulnerability assessment of predicted climate change and sea level rise in the Alligator Rivers Region, Northern Territory, Australia, *Supervising Scientist Report 123,* Jabiru, Australia.

Bell D., Menges C., Ahmad W., Van Zyl J.J. 2001. The application of dielectric retrieval algorithms for mapping soil salinity in a tropical coastal environment using airborne polarimetric SAR. *Remote Sensing*. 75:375–384

Braithwaite R.W and Muller W.J 1997 ‘Rainfall, groundwater and refuges: predicting extinctions of Australian tropical mammal species’. *Australian Journal of Ecology* 22, 57-67

Brooks, M.L. D’Antonio, C.M. *et al,* 2004. 'Effects of invasive alien plants on fire regimes.' *Bioscience* 54(7): 677-88.

Bureau of Meteorology 2007 Defoliation – Junction Bay, Commonwealth of Australia, Canberra Viewed 3rd September 2007 <http://www.bom .gov.au/announcements/sevwx/nt/defoliation_junction_bay.shtml>

Cook G.D, Setterfield S.A, Maddison J.P 1996. Shrub invasion of a tropical wetland: implications for weed management. *Ecological Applications* 6, 531-537

Cowie ID, Werner PA 1993 Alien plant-species invasive in Kakadu National park, tropical northern Australia. *Biological Conservation* 63, 127-135

CRES 2006 *The Vulnerability of the World Heritage Values of Australia’s World Heritage Properties to Climate Change Impacts.* Report to: The Australian Greenhouse Office Department of Environment and Heritage (Centre for Resource and Environmental Studies The Australian National University) (Draft) Department of Environment and Heritage, Canberra

CSIRO 2002 *Climate change and Australia’s coastal communities* CSIRO, Canberra

D'Antonio, C.M. and Vitousek, P.M. 1992. 'Biological invasions by exotic grasses, the grass/fire cycle, and global change.' *Annual Review of Ecology and Systematics*, 23: 63-87.

Department of Natural Resources, Environment and the Arts 2005. Northern Territory Bioregions - assessment of key biodiversity values and threats - A resource document to accompany the Northern Territory Parks and Conservation Masterplan. Document produced by Bryan Baker, Owen Price, John Woinarski, Stuart Gold, Greg Connors, Alaric Fisher and Craig Hempel, July 2005, Darwin, Northern Territory

Department of the Environment and Heritage 2004: Saltwater intrustion – a natural process in *Supervising Scientist*, October 2004

Doody J.S, Green B, Sims R, Ehind D, West P, Steer D 2006. 'Indirect impacts of invasive cane toads (Bufo marinus) on nest predation in pig-nosed turtles (Carettochelys insculpta)'. *Wildlife Research* 33, 349-354

Dukes, J.S., 2002. Comparison of the effect of elevated CO sub(2) on an invasive species (*Centaurea solstitialis*) in monoculture and community settings. *Plant Ecology* 160, (2) 225-234.

Dunlop EA, Wilson JC, Mackey AP 2006, 'The potential geographic distribution of the invasive weed *Senna obtusifolia* in Australia'. *Weed Research* 46, 404-413

Edwards A, Kennett R, Price O, Russell-Smith J, Spiers G, Woinarski J 2003. Monitoring the impacts of fire regimes on vegetation in northern Australia: an example from Kakadu National Park. *International Journal of Wildland Fire* 12, 427-440

Eliot, I., Waterman, P. and Finlayson, C.M. 1999. 'Monitoring and assessment of coastal change in Australia's wet-dry tropics,' *Wetlands Ecology and Management* 7, 63-81.

Ficke, A, A, Myrick, C, A and Hansen L.J.. 2007. The potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries* <http://www.springerlink.com/content/50576k6256336271 /fulltext.pdf>

Finlayson, C.M., Eliot. I., & Waterman, P.: Climate change and sea level rise in the Alligator Rivers Region, Northern Australia in Rovis-Hermann J, Evans KG, Webb AL & Pidgeon RWJ (eds) 2002. Environmental Research Institute of the Supervising research summary 1995.2000. *Supervising Scientist Report 166, Supervising Scientist*, Dawin NT.

Franklin, D.C., Whitehead, P.J., Pardon, G., Mathews, J., McMahon, P and McIntyre, D. 2005. Geographic patterns and correlates of the decline of granivorous birds in North Australia. *Wildlife Research,* 32(5) 399-408

Gill A.M, Ryan P.G, Moore P.H.R, Gibson M 2000. 'Fire regimes of World heritage Kakadu National Park, Australia'. *Austral Ecology* 25, 616-625

Greenlees MJ, Brown GP, Webb JK, Phillips BL, Shine R 2006. 'Effects of an invasive anuran (the cane toad *Bufo marinus*) on the invertebrate fauna of a tropical Australian floodplain.' *Animal Conservation* 9, 431-438

Hare, W. 2003 Assessment of Knowledge on Impacts of Climate Change – Contribution to the Specification of Art. 2 of the UNFCCC, WGBU, Berlin

Hennessy K, Page C, McInnes K, Walsh K, Pittock B, Bathols J and Suppiah R 2004. *Climate change in the Northern Territory. Report to the Northern Territor*y Government Dept of Infrastructure, Planning and Environment. CSIRO Climate Impact Group, CSIRO Atmospheric Research.

Hennessy, K., Lucas, C.Nicholls, N., Bathols, J. and Suppiah, R. 2005. *Climate change impacts on fire-weather in south-east Australia. CSIRO Marine and Atmospheric Research,* Bushfire CRC and Australian Bureau of Meteorology

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Finlayson C.M, Davidson N.C and Stevenson N.J. 1999. Department of the Environment and Heritage <http://www.environment.gov.au/ssd/ publications/ssr/pubs/ssr166-ecology-inventory.pdf >

Tropical Savannas CRC, 2006 *Storms give insight into savanna patterns* Tropical Savannas CRC, Charles Darwin University, Darwin Viewed, 3rd September 2007 <http://savanna.ntu.edu.au/publications/savanna _links_issue33.html?tid=257670>

DEH 2004 *Saltwater Intrusion – A Natural Process*, Department of the Environment and Heritage – Supervising Scientist, Darwin < http://www .environment.gov.au/ssd/publications/ssnotes/pubs/ssnote-saltwater-intrusion.pdf>

IUCN 2002 *World Heritage Nomination – IUCN Summary 147 (BIS): Kakadu National Park (Australia*), World Conservation Monitoring Centre/IUCN

Director of National Parks 2007, *Kakadu National Park Management Plan 2007 – 2014,* Director of National Parks ,Darwin.

Kiesecker J.M. Blaustein A.R. and Belden L.K. 2001 Complex causes of amphibian populations declines. *Nature,* 410, 681-684

Lucas, R.M.; Milne, A.K.; Mitchell, A.; Donnelly, B.; Ellison, J. 2002. Use of stereo aerial photography for assessing changes in the extent and height of mangrove canopies in tropical Australia. Geoscience and Remote Sensing Symposium, 2000. Proceedings. IGARSS 2000. IEEE 2000 International Volume 5, Issue, 2000 Page(s):1880 - 1882 vol.5

Mims, F.M. Holben, B.N. Eck T.F. Montgomery B.C. & Grant W.B. 1997 Smoky Skies, mosquitoes and disease, *Science,* 15, 1774-1775

Pittock *et al* 2006, Asia Pacific Partnership on clean development and climate: Implications for Australia's future (in progress)

Prior L.D, Brook B.W, Williams R.J, Werner P.A, Bradshaw C.J.A, Bowman D.M.J.S. 2006. Environmental and allometric drivers of tree growth rates in a north Australian savannah. *Forest Ecology and Management* 234, 164-180

Reading, C. J. 2007. Linking global warming to amphibian declines through its effects on female body condition and survivorship. *Oecologia* 151 (1): 125-131 February 2007

Rossiter N.A, Setterfield S.A, Douglass M.M, Hutley L.B 2003. Testing the grass-fire cycle: alien grass invasion in the tropical savannas of northern Australia. *Diversity and Distributions* 9, 169-176

Russell-Smith J, Ryan PG, Klessa D, Waight G, Harwood R 1998 Fire regimes fire-sensitive vegetation and fire management of the sandstone Arnhem Plateau monsoonal Northern Australia. *Journal of Applied Ecology* 35, 829-46.

Russell-Smith J, Setterfield SA 2006. Monsoon rain forest seedling dynamics, northern Australia: contrasts with regeneration in eucalypt-dominated savannas. *Journal of Biogeography* 33, 1597-1614.

Russell-Smith, J. 1991. Classification, species richness, and environmental relations of monsoon rain forest in northern Australia. *Journal of vegetation science*. Vol. 2, no. 2, pp. 259-278, Apr 1991

Russell-Smith, J. 1995, Fire management, in *Kakadu: Natural and Cultural Heritage and Management,* A. J. Press, D. A. M. Lea, A. Webb and A Graham (eds), Australian Nature Conservancy Agency and North Australia Research Unit, Darwin.

Russell-Smith, J. Edwards, A.C. and Cook G.D. 2003. Reliability of biomass burning estimates from savanna fires: Biomass burning in Northern Australia during the 1999 Biomass Burning and Lightning Experiment B field campaign, *J. Geophys. Res. 108*(D3), 8405, doi:10.1029/2001JD000787.

Russell-Smith, J. Lucas, D.E. 1994. Regeneration of monsoon rain forest in northern Australia: the dormant seed bank. *Journal of vegetation science: official organ of the International Association for Vegetation Science*., vol. 5, no. 2, pp. 161-168, Apr 1994

Smith, S.D., Huxman, T.E. Zitzer, S.F., Charlet, T.N. Housman, D.C., Coleman, J.S., Fenstermakerk, L.K, Seemann, J.R., Nowak, R.S 2000. Elevated CO2 increases productivity and invasive species success in an arid ecosystem *NATURE*, 408 (2)

Vigilante T, Bowman DMJS 2004. Effects of individuals fire events on the flower production of fruit-bearing tree species, with reference to Aboriginal people's management and use, at Kalamburu, North Kimberley, Australia. *Australian Journal of Botany* 52, 405-415

Werner P.A 2005. Impact of feral water buffalo and fire on growth and survival of mature savannah trees: an experimental field study in Kakadu National Park, northern Australia. *Austral Ecology* 30, 625-647

Williams R.J, Douglas M 1995. Windthrow in a tropical savanna in Kakadu National Park, Northern Australia. *Journal of Tropical Ecology* 11: 547-558

Williams, R. J. Griffiths, A. D. and Allan, G. 2002. *Fire regimes and biodiversity in the wet-dry tropical savanna landscapes of Northern*

Australia. In: Flammable Australia: The Fire Regimes and Biodiversity of a Continent. Eds R.A. Bradstock, J.A. Williams and A.M. Gill. Cambridge University Press, Cambridge. Pp281-304.

Woinarski J.C.Z, Connors G, Oliver B 1996. The reservation status of plant species and vegetation types in the Northern Territory. *Australian Journal of Botany* 44, 673-689

Woinarski J.C.Z, Risler J, Kean L 2004. Response of vegetation and vertebrate fauna to 23 years of fire exclusion in a tropical *Eucalyptus* open forest, Northern Territory. *Austral Ecology* 29, 156-176

Woinarski, J. C. Z. Williams, R. J. Price, O. & Rankmore, B. 2005. Landscapes without boundaries: wildlife and their environments in Northern Australia. *Wildlife Research* 32: 377-388.

Woodroffe C. D. Chappell J. M. A. Thom B. G. & Wallensky E. 1986. *Geomorphological Dynamics and Evolution of the South Alligator Tidal River and Plains, Northern Territory.* North Australia Research Unit, Darwin.

Chapter 9 – Norfolk Island National Park

Braggins 1998. *Report on the Conservation Status of Norfolk Island Ferns,* School of Biological Sciences, University of Auckland, Auckland

CSIRO 2006. *Climate Change Impacts & Risk Management – A Guide for Business and Government.* Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Hennessy, K., Lucas, C.Nicholls, N., Bathols, J. and Suppiah, R. 2005. *Climate change impacts on fire-weather in south-east Australia. CSIRO Marine and Atmospheric Research,* Bushfire CRC and Australian Bureau of Meteorology

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Bureau of Meteorology 2007 Defoliation – Junction Bay, Commonwealth of Australia, Canberra Viewed 3rd September 2007 <http://www.bom .gov.au/weather/nsw/norfolk/climate.shtml>

Lawton, R.O., U.S. Nair, R.A. Pielke Sr. and R.M. Welch, 2001: Climatic impact of tropical lowland deforestation on nearby montane cloud forests. *Science*, 294, 584-587.

Environment Australia 2000, *Norfolk Island National Park and Norfolk Island Botanic Garden Plans of Management, 2000* Commonwealth of Australia

Pittock, B. 2003 *Climate Change: An Australian guide to the science and potential impacts.* Australian Greenhouse Office, Canberra

Sykes, W.R. & I.A.E. Atkinson, 1988, *Rare and Endangered Plants of Norfolk Island, Botany Division*, DSIR, New Zealand.

Chapter 10 – Pulu-Keeling and Cocos (Keeling) National Park

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government.* Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Hoegh-Guldberg, O. 2004. Coral reefs in a century of rapid environmental change. Symbiosis 37: 1–31.

Hoegh-Guldberg, O., 1999: Climate change, coral bleaching and the future of the world’s coral reefs. *Mar. Freshwater Res.*, 50, 839-866

Bureau of Meteorology 2007 Defoliation – Junction Bay, Commonwealth of Australia, Canberra Viewed 3rd September 2007 <http://www.bom.gov.au/weather/wa/cocos_island/climate.shtml>

Director of National Parks 2004. *Pulu Keeling National Park Management Plan, 2004,* Commonwealth of Australia, 2004.

Chapter 11 – Uluru-Kata Tjuta National Park

Allan G.E and Southgate R.I 2002, ‘Fire regimes in the spinifex landscapes of Australia’. pp 145-176 in *Flammable Australia’*: The fire regimes and biodiversity of a continent (RA Bradstock, JE Williams, MA Gill eds). Cambridge University Press, Cambridge

Brooks, M.L., D’Antonio C.M., Richardson D.M., Grace J.B., Keely J.E, DITomaso, J.M., Hobbs R.J, Pellant, M, and Pyke D. 2004 'Effects of invasive alien plants on fire regimes.' *Bioscience* 54(7): 677-88.

CRES 2006 *The Vulnerability of the World Heritage Values of Australia’s World Heritage Properties to Climate Change Impacts.* Report to: The Australian Greenhouse Office Department of Environment and Heritage (Centre for Resource and Environmental Studies The Australian National University) (Draft) Department of Environment and Heritage, Canberra

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government*. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

D'Antonio, C.M. and Vitousek, P.M. 1992 'Biological invasions by exotic grasses, the grass/fire cycle, and global change.' *Annual Review of Ecology and Systematics*, 23: 63-87.

Director of National Parks, 2006. Annual Report 2005-06

Dukes J.S 2002. Comparison of the effect of elevated CO_2 on an invasive species (*Centaurea solstitialis*) in monoculture and community settings. *Plant Ecology* 160: 225-234

Griffin G.F, Friedel M.H 1985 'Discontinuous change in central Australia: some implications of major ecological events for land management.' *Journal of Arid Environments* 9, 63-80

Griffin G.F, Price N.F, Portlock H.F 1983 'Wildfires in the central Australian rangelands 1970-1980'. *Journal of Environmental Management* 17, 311-323

Hodgkinson K.C, Griffin G.F 1982 '*Adaptation of shrub species to fires in the arid zone. In Evolution of the Flora and fauna of Arid Australia'* (WR Barker, P.J.M Greenslade eds). Pp 145-152. Peacock Publications, Frewville SA.

DEW 2007, <http://www.environment.gov.au/parks/uluru/natural/fire.html> Department of the Environment and Water Resources, Commonwealth of Australia, Canberra. Viewed 3rd September 2007.

Lioubimtseva E 2004, Climate change in arid environments: revisiting the past to understand the future. *Progress in Physical Geography* 28: 502-530

Morton, S.R., J. Short and R.D. Barker 1995. *Refugia for biological diversity in arid and semi-arid Australia*. Biodiverity Series, Paper 4. Department of Environment Sport and Territories, Canberra.

Reid J.R.W, Kerle J.A, Morton S.R (eds) 1993 *Uluru-Kata-Tjuta Fauna: The Distribution and abundance of vertebrate fauna of Uluru (Ayers Rock – Mt Olga)* National Park, N.T. (Australian National Parks and Wildlife Service)

Rossiter N.A, Setterfield S.A, Douglass M.M, Hutley LB 2003. Testing the grass-fire cycle: alien grass invasion in the tropical savannas of northern Australia. *Diversity and Distributions* 9, 169-176

Rudmann S.G, Milham P.J, Conroy J.P 2001. Influence of high CO_2 partial pressure on nitrogen use efficency of the C4 grasses *Panicum coloratum* and *Cenchrus ciliaris*. *Annals of Botany* 88: 571-577

Serventy D.L 1971. Biology of desert birds. In Farner DS and JR King (eds) *Avian Biology*, 287-339. Academic press, New York

Smith S.D, Huxman T.E, Zitzer S.F, Charlet T.N, Housman D.C, Coleman J.S, Fenstermaker L.K, Seemann J.R, Nowak R.S 2000. Elevated CO_2 increases productivity and invasive species success in an arid ecosystem. *Nature* 408: 79-82

Parks Australia 2000*. Uluru-Kata Tjuta National Park Plan of Management, 2000.* Uluru-Kata Tjuta Board of Management & Parks Australia, Commonwealth of Australia

Whitehead P.J, Bowman D.M.J.S, Tidemann S.C 1992. Biogeographic patterns, environmental correlates and conservation of avifauna in the Northern Territory, *Australia. Journal of Biogeography* 19, 151-161

Wolf B 2000. Global warming and avian occupancy of hot deserts; a physiological and behavioural perspective. *Revista Chilena de Historia Natural* 73, 395-400

Chapter 12 – Australian National Botanic Gardens

ANBG 2004 Department of the Environment and Water Resources, Viewed 23rd August 2007 <http://www.anbg.gov.au/anbg/introduction /captions/aerial-anbg.html>

APII 2007 Australia National Botanic Gardens, Viewed 23rd August 2007 <http://www.anbg.gov.au/anbg/photo-collection/photo.index.html>

ANBG 2007 National Botanic Gardens, Viewed 23rd August 2007 <http://www.anbg.gov.au/internal/visitor-stats.html>

BoM 2007a Bureau of Meteorology, Viewed 12th August 2007 <http://www.bom.gov.au/weather/nsw/canberra/climate.shtml.>

BoM 2007b Bureau of Meteorology, Viewed 12th August 2007 <http://www.bom.gov.au/climate/averages/tables/cw_070282.html>

DEW 2001 *Australian National Botanic Gardens Management Plan 2002 – 2008* Department of the Environment and Water Resources, Canberra

CSIRO 2006, *Climate Change Impacts & Risk Management – A Guide for Business and Government.* Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Hennessy, K., McInnes, K., Abbs, D., Jones, R., Bathols, J., Suppiah, R., Ricketts, J., Rafter, T., Collins D. and Jones, D. 2004. *Climate Change in New South Wales, Part 2: Projected changes in climate extremes.* Consultancy report for the New South Wales Greenhouse Office by the Climate Impact Group of CSIRO Atmospheric Research and the National Climate Centre of the Australian Government Bureau of Meteorology

DEW 2007 Department of the Environment and Water Resources. Viewed 11th August 2007 <http://www.environment.gov.au/heritage/ commonwealth/act.html#bot>

Chapter 13 – Booderee Botanic Gardens

Commonwealth of Australia, 2002. *Booderee National Park Management Plan,* Booderee National Park Board of Management, Director of National Parks

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government*. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Hennessy, K., Lucas, C.Nicholls, N., Bathols, J. and Suppiah, R. 2005 *Climate change impacts on fire-weather in south-east Australia. CSIRO Marine and Atmospheric Research,* Bushfire CRC and Australian Bureau of Meteorology

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life:*

Part A. Executive Summary September 2006. Report to the Australian Greenhouse Office, Canberra, Australia.

Howden Mark, Lesley Hughes, Michael Dunlop, Imogen Zethoven, David Hilbert and Chris Chilcott 2003: Climate Change Impacts On Biodiversity In Australia, Outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1–2 October 2002, Commonwealth of Australia, Canberra.

Hughes, L., 2003: Climate change and Australia: trends, projections and impacts. *Austral Ecol.*, 28, 423-443.

Pittock, B. 2003 *Climate Change: An Australian guide to the science and potential impacts.* Australian Greenhouse Office, Canberra

Chapter 14 – Norfolk Island Botanic Garden

Bisgrove, R. and Hadley, P. 2002 *Gardening in the Global Greenhouse: The Impacts of Climate Change on Gardens in the UK*. Technical Report. UKCIP, Oxford.

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government.* Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Hennessy, K., McInnes, K., Abbs, D., Jones, R., Bathols, J., Suppiah, R., Ricketts, J., Rafter, T., Collins D. and Jones, D. 2004. *Climate Change in New South Wales, Part 2: Projected changes in climate extremes.* Consultancy report for the New South Wales Greenhouse Office by the Climate Impact Group of CSIRO Atmospheric Research and the National Climate Centre of the Australian Government Bureau of Meteorology

Hennessy, K., Lucas, C.Nicholls, N., Bathols, J. and Suppiah, R. 2005. *Climate change impacts on fire-weather in south-east Australia. CSIRO Marine and Atmospheric Research,* Bushfire CRC and Australian Bureau of Meteorology

BoM 2007 Bureau of Meteorology. Viewed 12th August 2007 <http://www .bom.gov.au/weather/nsw/norfolk/climate.shtml>

Environment Australia 2000*, Norfolk Island National Park and Norfolk Island Botanic Garden Plans of Management, 2000* Commonwealth of Australia

Chapter 15 – Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve

Environment Australia 2002. *Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve (Commonwealth Waters) Management Plans*, Commonwealth of Australia, Canberra.

Brown, G.R. 1999 *A Preliminary Report on the Insects of Ashmore Reef Nature Reserve*. Report of the Northern Territory Museum, Darwin (Unpublished)

CSIRO 2002. Marine Research, *The Indonesian Flow Through,* Viewed 25th July 2007 <http://www.cmar.csiro.au/e-print/open/CMReport_240.pdf>

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government*. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Director of National Parks, 2006. Annual Report 2005-06

Graham N.A.J, Wilson S.K., Jennings S, Polunin N.V.C, Bijoux J.P, and Robinson J (2006) Dynamic fragility of oceanic coral reef ecosystems. *Proceedings of the National Academy of Sciences*, 103, 8425–8429.

Guinea, M.L. 1993 *Reptilia, aves and mammalia, in Marine Biological and Heritage Resources of Cartier and Hibernia Reefs, Timor Sea*, eds. B.C. Russell and J.R. Hanley. Northern Territory Museum of Arts and Sciences, Darwin.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Hoegh-Guldberg O 2005 Low coral cover in a high-CO_2 world. *Journal Of Geophysical Research-Oceans 110* (C9): Art. No. C09S06

Hutchins, J.B. 1988 *Survey of the Fishes of Ashmore Reef*. Report for Parks Australia North (unpublished) Western Australian Museum of Natural Science.

IUCN 1994 *Guidelines for protected area management categories. IUCN Commission on National Parks and Protected Areas with the assistance of the World Conservation Monitoring Centre*. IUCN, Gland.

Veron, J. E. N. 1993 *Hermatypic Corals of Ashmore Reef and Cartier Island, in Marine Faunal Surveys of Ashmore Reef and Cartier Island, North-western Australia,* ed. P.F. Berry.Western Australian Museum, Perth.

Whiting, S.D. 1999, Use of the remote Sahul Banks, Northwestern Australia, by dugongs, including breeding females. *Marine Mammal Science* Vol 15 No. 2, 609–615.

Wilson *et al*. 2006. 'Multiple disturbances and the global degradation of coral reefs: are reef fishes at risk or resilient?' *Marine Ecology Progress Series* (in press)

Chapter 16 – Coringa Herald National Nature Reserve & Lihou Reef National Nature Reserve

ANPWS 1989a Coringa-Herald National Nature Reserve Plan of Management. Australian National Parks and Wildlife Service, Canberra

ANPWS 1989b Lihou Reef National Nature Reserve Plan of Management. Australian National Parks and Wildlife Service, Canberra

DEH 2001, Coringa-Herald National Nature Reserve and Lihou Reef National Nature Reserve Management Plan, Commonwealth of Australia, 2001

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government.* Prepared for the Australian Greenhouse

Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

IUCN 1994 *Guidelines for protected area management categories. IUCN Commission on National Parks and Protected Areas with the assistance of the World Conservation Monitoring Centre*. IUCN, Gland.

Chapter 17 – Elizabeth and Middleton Reefs Marine National Nature Reserve

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government.* Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Director of National Parks, 2006. Annual Report 2005-06

Director of National Parks 2006 Elizabeth and Middleton Reefs Marine National Nature Reserve Management Plan 2006-2013., Director of National Parks Canberra

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Jaensch, R., Long, W. L., Kenkins, A. 2002 Infomraiton Sheet on Ramsar Wetlands – Elizabeth and Middleton Reefs Marine National Nature Reserve

Chapter 18 – Great Australian Bight Marine Park

CRES 2006 *The Vulnerability of the World Heritage Values of Australia's World Heritage Properties to Climate Change Impacts.* Report to: The Australian Greenhouse Office Department of Environment and Heritage (Centre for Resource and Environmental Studies The Australian National University) (Draft) Department of Environment and Heritage, Canberra

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government.* Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

DEH, 2005 Great Australian Bight Marine Park, Commonwealth Waters Management Plan, Commonwealth of Australia,

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

BoM 2007 Bureau of Meteorology Viewed 23rd August 2007 <http://www.bom.gov.au/lam/climate/levelthree/ausclim/ausclimsa.htm>

Chapter 19 – Heard Island and McDonald Island Marine Reserve

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government*. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

AAD (2005) Heard Island and McDonald Islands Marine Reserve Management Plan, Australian Antarctic Division, Commonwealth of Australia,

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Chapter 20 – Lord Howe Island Marine Park (Commonwealth Waters)

Allen, G.R., Hoese, D.F., Paxton, J.R., Randal;l, J.E., Russell, B.C., Starck, W.A. Talbot, F.H., and Whitley, G.P 1976 *Annotated checklist of fishes of Lord Howe Island*. Records of the Australian Museum, 30:365-454.

CRES 2006 *The Vulnerability of the World Heritage Values of Australia's World Heritage Properties to Climate Change Impacts.* Report to: The Australian Greenhouse Office Department of Environment and Heritage (Centre for Resource and Environmental Studies The Australian National University) (Draft) Department of Environment and Heritage, Canberra

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government*. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Hutton, I. 1986 *Discovering Australia's World Heritage: Lord Howe Island.* Conservation Press: Canberra.

Lord Howe Island Board 1985 *Lord Howe Island Regional Environmental Study volume 1*. Lord Howe Island Board: Sydney

DEH 2002 *Lord Howe Island Marine Park (Commonwealth Waters) Management Plan, 2002*, Environment Australia, Commonwealth of Australia 2002.

Chapter 21 – Macquarie Island Marine Park

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government*. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Cunningham, D.M and Morrs, P.J. 1994, The decline of Rockhopper Penguins *Eudyptes chrysocome* at Campbell Island, Southern Ocean and the influence of Rising Sea Temperatures*, EMU,* 94, 27-36

Director of National Parks, 2006. Annual Report 2005-06

Guinard, E., Weimerskirch, Hand Jouventin, P. 1998. Population changes and demography of the Northern Rockhopper Penguin on Amsterdam and Saint Paul Islands. *Colonial Waterbirds,* 21, 222-228

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Kwok R and Comiso J.C. 2002 Spatial patterns of variability in Antartic surface temperature: Connections to the Southern Hemisphere Annular Mode and the Southern Oscillation. *Geographical Research Letters.* 29(14) 51-54

Loeb V, Siegel, V., Holm-Hanoen, O., Hewitt, R., Fraser, W., Trivelpiece, W and Trivelpiece, S, 1997, Effects of sea-ice extent and krill or salp dominance on the Antartic food web. *Nature,* 387, 897-900

BoM 2007 Bureau of Meteorology, Viewed 23rd July 2007 <http://www.bom.gov.au/weather/tas/macquarie/climate.shtml>

Environment Australia 2001, *Macquarie Island Marine Park Management Plan, 2001*, Commonwealth of Australia

McMahon, C.R., Bester, M.N., Burton, H.R., Hindell, M.A and Bradshaw, C.J.A, 2005 Population status, trends and re-examination of the recent hypothesis explaining the recent declines of the southern elephant seal *Mirounga leonine Mammal Review* 35(1) 82-100

Murphy, E.J and Ried, K. 2001 Modelling Southern Ocean krill population dynamics: biological processes generating flucuations in the South Georgia ecosystem. *Marine Ecology Progress Series,* 217, 175-189.

Parks and Wildlife Service Tasmania 2006 *Macquarie Island world heritage area*< http://www.parks.tas.gov.au/macquarie/history.html>

Parks and Wildlife Service 2003, *Macquarie Island Nature Reserve and World Heritage Area. Management Plan.* Parks and Wildlife Service, Department of Tourism, Parks Heritage and the Arts, Hobart.

Vergani D.F., Stanganelli Z.B and Bilenca, D. 2004. Effects of El Nino and La Nina events on the sex ration of southern elephant seals at King George Island, *Marine Ecology Progress Series* 268, 293-300.

Weirmerskirch, H. 2004 Diseases threaten Southern Ocean albatrosses. *Polar Biology,* 27, 374-379

Chapter 22 – Mermaid Reef Marine National Nature Reserve

AIMS, 2007 Coral reef commuities at the Rowley Shoals, north-western Australia: state of knowledge and management implications (Draft).

CRES 2006 *The Vulnerability of the World Heritage Values of Australia's World Heritage Properties to Climate Change Impacts.* Report to: The Australian Greenhouse Office Department of Environment and Heritage

(Centre for Resource and Environmental Studies The Australian National University) (Draft) Department of Environment and Heritage, Canberra

CSIRO 2002 *Climate change and Australia's coastal communities* CSIRO Canberra

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government*. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Heap, D. A., Harris, P. T., Hinde, A. and Woods, M. 2005*. Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone.* Report to the National Oceans Office on the Development of a National Benthic Marine Bioregionalisation in support of Regional Marine Planning

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Hoegh-Guldberg, O. 2004. Coral reefs in a century of rapid environmental change. *Symbiosis* 37: 1–31.

Hoegh-Guldberg, O., 1999: Climate change, coral bleaching and the future of the world's coral reefs. *Mar. Freshwater Res.*, **50**, 839-866

Holloway, P. E. and Nye, H.C. 1985. Leeuwin Current and wind distributions on the southern part of the North West Shelf between January 1982 and July 1983. *Australian Journal of Marine and Freshater Resarch, 36: 123-137*

IPCC 2001 *Climate Change 2001: the Third Assessment Report, Working Group 2: Impacts, Adaptation, and Vulnerability, Chapter 5: Ecosystems and Their Goods and Services.*

Parmesan C. P. & Yohe G. 2003 A globally coherent fingerprint of climate change across natural systems. *Nature* 421, 37-42.

United Nations Environment Program / International Union for the Conservtion of Nature 1988. *Coral Reefs of the World. Volume 2: Red Sea, Indian Ocean and Gulf.* UNEP Regional Seas Directories and Bibliographies. IUCN, Gland and Cambridge & UK/UNEP, Nairobi, 1-389.

Chapter 23 – Ningaloo Marine Park (Commonwealth Waters)

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government*. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006c. *Impacts of climate change on Australian marine life: Part C. Literature Review.* Report to the Australian Greenhouse Office, Canberra, Australia. September 2006.

Howden Mark, Lesley Hughes, Michael Dunlop, Imogen Zethoven, David Hilbert and Chris Chilcott 2003: Climate Change Impacts on Biodiversity in Australia, Outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1–2 October 2002, Commonwealth of Australia, Canberra.

Environment Australia 2002 *Ningaloo Marine Park (Commonwealth Waters) Management Plan,* Environment Australia, Commonwealth of Australia

Shuraleff II, G. (2000). *Manta birostris,* Animal Diversity Web. University of Michigan <http://animaldiversity.ummz.umich.edu/site/accounts/information/Manta_birostris.html>

Chapter 24 – Solitary Islands Marine Reserve (Commonwealth Waters)

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government.* Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Director of National Parks, 2006. Annual Report 2005-06

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006b. *Impacts of climate change on Australian marine life: Part B. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Otway NM and Burke AL 2004, *Mark-recapture population estimate and movements of Grey Nurse Sharks,* NSW Fisheries

Environment Australia 2001 Solitary Islands Marine Reserve (Commonwealth Waters) Management Plan. Environment Australia, Commonwealth of Australia

Chapter 25 – Tasmanian Seamounts Marine Reserve

CSIRO 2006 *Climate Change Impacts & Risk Management – A Guide for Business and Government*. Prepared for the Australian Greenhouse Office, Department of Environment and Heritage by: Broadleaf Capital International Marsden Jacob Associates.

Heap, D. A., Harris, P. T., Hinde, A. and Woods, M. 2005. *Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone.* Report to the National Oceans Office on the Development of a National Benthic Marine Bioregionalisation in support of Regional Marine Planning

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006c. *Impacts of climate change on Australian marine life: Part C. Literature Review.* Report to the Australian Greenhouse Office, Canberra, Australia. September 2006.

Environment Australia 2002 *Tasmanian Seamounts Marine Reserve Management Plan*, Environment Australia, Commonwealth of Australia

Chapter 26 - Conclusions

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006a. *Impacts of climate change on Australian marine life: Part A. Executive Summary September 2006.* Report to the Australian Greenhouse Office, Canberra, Australia.

IPCC 2007a *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Jackson, RB, SR Carpenter, CN Dahm, DM McKnight, RJ Naiman, SL Postel, and SW Running. 2001. Water in a changing world. *Ecological Applications* 11:1027-1045.

Wilkinson, C. R. and Buddermeier, R. W. 1994. *Global Climate Change and Coral Reefs: Implications for People and Reefs.* Report of the UNEP-IOC-ASPEI-IUCN Global Task Team on Coral Reefs. IUCN, Gland, Switzerland, 124 pp.

Appendix B

Glossary of Terms

Glossary of Common Terms

Algal Blooms

A reproductive explosion of algae in a lake, river, or ocean.

Adaptive Capacity

The ability of a system to adjust to *climate change* (including *climate variability* and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Anthropogenic
Resulting from or produced by human beings.

Aquifer
A stratum of permeable rock that bears water. An unconfined aquifer is recharged directly by local rainfall, rivers, and lakes, and the rate of recharge will be influenced by the permeability of the overlying rocks and soils. A confined aquifer is characterized by an overlying bed that is impermeable and the local rainfall does not influence the aquifer.

Baseline/Reference
The baseline (or reference) is any datum against which change is measured. It might be a "current baseline," in which case it represents observable, present-day conditions. It might also be a "future baseline," which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.

Benthic Organisms
The *biota* living on, or very near, the bottom of the sea, river, or lake.

Biodiversity
The numbers and relative abundances of different genes (genetic diversity), species, and ecosystems (communities) in a particular area. See also *functional diversity*.

Biodiversity Hot Spots
Areas with high concentrations of *endemic* species facing extraordinary habitat destruction.

Biota
All living organisms of an area; the flora and fauna considered as a unit.

Carbon Dioxide (CO_2)

A naturally occurring gas, also a by-product of burning fossil fuels and *biomass*, as well as from land-use changes and other industrial processes. It is the principal *anthropogenic greenhouse* gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1.

Climate
Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands of

years. The classical period is 3 decades, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate Change
Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the *United Nations Framework Convention on Climate Change (UNFCCC)*, which defines "climate change" as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." See also *climate variability*.

Climate Projection
A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from *climate predictions* in order to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions, concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Climate Scenario
A plausible and often simplified representation of the future *climate*, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate. A "climate change scenario" is the difference between a climate scenario and the current climate.

Coral Bleaching
The paling in color of corals resulting from a loss of symbiotic algae. Bleaching occurs in response to physiological shock in response to abrupt changes in temperature, salinity, and turbidity.

Drought

The phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.

Ecosystem

A distinct system of interacting living organisms, together with their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth.

El Niño-Southern Oscillation (ENSO)

El Niño, in its original sense, is a warmwater current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. This oceanic event is associated with a fluctuation of the intertropical surface pressure pattern and circulation in the Indian and Pacific Oceans, called the *Southern Oscillation*. This coupled atmosphere-ocean phenomenon is collectively known as El Niño Southern Oscillation. During an El Niño event, the prevailing trade winds weaken and the equatorial countercurrent strengthens, causing warm surface waters in the Indonesian area to flow eastward to overlie the cold waters of the Peru current. This event has great impact on the wind, sea surface temperature, and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world. The opposite of an El Niño event is called La Niña.

Erosion
The process of removal and transport of soil and rock by weathering, mass wasting, and the action of streams, glaciers, waves, winds, and underground water.

Eutrophication
The process by which a body of water (often shallow) becomes (either naturally or by pollution) rich in dissolved nutrients with a seasonal deficiency in dissolved oxygen.

Extinction
The complete disappearance of an entire species.

Greenhouse Effect

Greenhouse gases effectively absorb infrared radiation emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus greenhouse gases trap heat within the surface-troposphere system. This is called the "natural greenhouse effect." Atmospheric radiation is strongly coupled to the temperature of the level at which it is emitted. In the troposphere, the temperature generally decreases with height. Effectively, infrared radiation emitted to space originates from an altitude with a temperature of on average -19°C, in balance with the net incoming solar radiation, whereas the Earth's surface is kept at a much higher temperature of on average 14°C. An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere, and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing, an imbalance that can only be compensated for by an increase of the temperature of the surface-troposphere system. This is called the "enhanced greenhouse effect."

Greenhouse Gases

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. This property causes the *greenhouse effect*. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances which are dealt with under the Montreal Protocol. Beside CO_2, N_2O, and CH_4, the *Kyoto Protocol* deals with the greenhouse gases sulfur hexaflouride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

Habitat

The particular environment or place where an organism or species tends to live; a more locally circumscribed portion of the total environment

Herbaceous

Flowering, non-woody plants.

Introduced Species

A species occurring in an area outside its historically known natural range as a result of accidental dispersal by humans (also referred to as "exotic species" or "alien species").

Invasive Species

An introduced species that invades natural habitats.

Oligotrophic

A body of water containing relatively little plant life and nutrients in its waters but rich in dissolved oxygen

Phenology

The study of natural phenomena that recur periodically (e.g., blooming, migrating) and their relation to climate and seasonal changes.

Photosynthesis

The process by which plants take carbon dioxide from the air (or bicarbonate in water) to build carbohydrates, releasing oxygen in the process. There are several pathways of photosynthesis with different responses to atmospheric CO_2 concentrations.

Phytoplankton

The plant forms of *plankton* (e.g., *diatoms*). Phytoplankton are the dominant plants in the sea, and are the basis of the entire marine food web. These single-celled organisms are the principal agents for photosynthetic carbon fixation in the ocean. See also *zooplankton*.

Resilience

Amount of change a system can undergo without changing state.

Respiration

The process whereby living organisms convert organic matter to carbon dioxide, releasing energy and consuming oxygen.

Riparian
Relating to or living or located on the bank of a natural watercourse (as a river) or sometimes of a lake or a tidewater.

Runoff

That part of precipitation that does not evaporate. In some countries, runoff implies *surface runoff* only.

Sensitivity

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related *stimuli*. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to *sea level rise*).

Transpiration

The emission of water vapor from the surfaces of leaves or other plant parts.

Vulnerability

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.