Garnaut Climate Change Review

Impacts of climate change on Australia's World Heritage properties and their values

Prepared by
Lance Heath, ANU Institute for Environment, The Australian National University

June 2008

Contents

1 Executive summary

Australia is one of the oldest continents on earth, and it is unique in terms of its cultural, geographical and biological diversity. There are currently 17 sites in Australia recognised by United Nations Educational, Scientific and Cultural Organization (UNESCO) as possessing characteristics *considered to be of outstanding value to humanity*. Because of their universal significance, these 17 sites are listed as World Heritage sites. However, Australia's World Heritage properties, and their unique values, are under threat from global climate change.

The latest United Nations Intergovernmental Panel on Climate Change (IPCC) report states that 'global warming is unequivocal' and is due largely to an increase in greenhouse gases, such as carbon dioxide (CO_2), caused by burning fossil fuels. Australia's average surface temperature has increased by about 0.7º C since 1900 (IPCC, 2007). Global mean sea level rose at a rate of around 3 mm yr^{-1} (Bindoff et al., 2007) between 1993 and 2003. Thermal expansion of the oceans and widespread melting of land ice will result in further global sea level rise.

Reduced rainfall, higher sea and land-surface temperatures, more severe storm events, ocean acidification and rising sea levels are expected to impact significantly on Australia's unique world heritage values, particularly the natural values listed under UNESCO's criterion (x)—i.e. those sites that 'Contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation'.

Continued global warming is likely to result in substantial reductions in the area of highland rainforests, declines in the abundances of native fauna and flora, continued coral bleaching, and glacial retreat. Changes in the abundance and distribution of many species, including the extinction of indigenous plants and animals with limited dispersal capabilities and/or narrow climatic tolerance ranges, are also expected. These impacts are likely to occur because the rate of climate change is highly likely to occur faster than the rates of evolutionary adaptation of many plant and animal species. Extreme weather events are likely to result in irreversible damage (e.g. erosion) to geological, geomorphologic and physiogeographic heritage, whose values are expressed in UNESCO's criterion (viii)-i.e.: 'Outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features.' Furthermore, the integrity of unique cultural values including Aboriginal middens, sea-cave deposits, rock art and cave art sites, is highly dependent on the protection of their underlying landforms from climate change impacts. Cultural values, such as built heritage, are also likely to be affected by climate change but to a lesser extent, at least in the short term.

Because Australia's World Heritage sites are isolated from each other and have very different geographical characteristics, the severity of climate change threats is likely to vary across the World Heritage estate. Future work must focus on the development of mitigation and adaptation strategies that will ameliorate the effects of climate change, and on the need to identify the extent of vulnerabilities for risk-preparedness planning. Furthermore, because Australia's World Heritage sites do not share common management structures or systems, it is essential that efforts are undertaken to improve communication and networking across all World Heritage properties. The vulnerability of archaeological and other cultural heritage sites, as well as the social, legal and economic costs to the community from lost heritage, requires further identification and assessment.

2 Introduction

Seventeen regions or sites within Australia are recognised by United Nations Educational, Scientific and Cultural Organization (UNESCO) as having exceptional characteristics which are unique in the world. Because of their universal significance, these 17 jurisdictions are listed as World Heritage sites. In 2005 UNESCO's World Heritage Committee formally recognised that climate change is already affecting the natural and cultural values of many World Heritage sites and is likely to affect many more in the years ahead (UNESCO, 2006). The United Nations Intergovernmental Panel on Climate Change (IPCC) concluded that climate change is expected to cause significant loss of biodiversity in many ecologically rich sites, including Australia's Great Barrier Reef, Queensland's Wet Tropics, Kakadu National Park and Australia's sub-Antarctic islands, which are all World Heritage-listed properties.

The responsiveness and inherent (autonomous) adaptive capacity of these World Heritage sites to abrupt changes in climate resulting from anthropogenic effects is uncertain. There is also uncertainty as to the capacity of property managers and management systems to facilitate the adaptation of World Heritage properties and specific values in the face of both abrupt and gradual climate change.

This paper provides a brief synopsis of the impacts of potential climate change on Australia's World Heritage properties and the vulnerability and adaptive capacity of their natural and cultural values most likely to be affected significantly by the direct and indirect effects climate change. Recommendations for future research and actions are also outlined.

3 What is a World Heritage property?

In 1972 UNESCO adopted a convention dealing with the 'Protection of the World's Cultural and Natural Heritage'. This convention is UNESCO's mandate to 'encourage the identification, protection and preservation of cultural and natural heritage around the world considered to be of outstanding value to humanity'. In order to qualify for World Heritage status, heritage sites listed for nomination must have values that are 'outstanding as well as universal'. Australia currently has 17 UNESCO World Heritage properties with unique cultural and natural heritage values, covering regions of extreme climate variability. These range from the wet tropics of North Queensland and the savanna country of the 'top end', to the sub-Antarctic conditions of Heard and McDonald Islands. The locations of Australia's World Heritage properties and examples of their unique values are shown in Figure 1 and Table 1 respectively.

Properties nominated for World Heritage status have their values assessed according to UNESCO's natural and cultural criteria, which are explained in the *Operational Guidelines for the Implementation of the World Heritage Convention*.[1] UNESCO's natural criteria, for example, specify: 'Outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals', and, 'Outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features'. Similarly, UNESCO's cultural criteria include 'Outstanding examples of traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment', as well as unique cultural values associated with our built heritage (e.g. the Royal Exhibition Building and the Sydney Opera House). A summary of UNESCO's criteria is shown in Table 2. Table 3 lists Australia's World Heritage properties against their respective criteria/criterion.

[1] http://whc.unesco.org/archive/opguide05-en.pdf

4 Important aspects of climate change for World Heritage properties

Climate change scenario modelling indicates that there is a likelihood of more extreme weather events (e.g. heavy rainfall and hail, flash flooding, strong winds, and temperature extremes) and an increase in more severe cyclones. Extreme weather events are likely to affect most of Australia's World Heritage values, both cultural and natural. Extreme weather events may result in irreversible changes to geological and geomorphologic values. Unique cultural values, such as Aboriginal middens, sea-cave deposits, rock art and cave art sites, that are highly dependent on the integrity of their underlying landforms (i.e. geological and geomorphologic values), are also likely to be affected.

Higher sea and land temperatures, ocean acidification, and prolonged drought pose a significant threat to the natural values inherent in marine and terrestrial biodiversity across Australia's World Heritage estate. Changes in the abundance and distribution of many species, including the extinction of indigenous plants and animals with limited dispersal capabilities and/or narrow climatic tolerance ranges, are expected.

The effects of climate change cannot be considered in isolation. They must be viewed in the context of other current threats to Australia's World Heritage natural and cultural values. Climate change is likely to exacerbate the current problems caused by human-induced changes to the landscape such as deforestation, fire[2], urban expansion, water extraction, and tourism, as well as non-anthropogenic factors such as the spread of exotic pests and diseases. Management strategies should be aimed at strengthening the resilience of natural and cultural values to climate change through the management of these common environmental stress factors.

[2] Fire has always been a natural and cultural phenomenon in the Australian landscape. Current research and modelling suggests that wildfires are likely to become more intense and more frequent as a result of climate change. Increased fuel loads in association with reduced rainfall, higher temperatures and reduced humidity are likely to lead to an increase in the number of extreme fire danger days. Extreme wildfires are likely to threaten at least half of Australia's World Heritage properties, affecting both cultural and natural World Heritage values.

5 Adaptive capacity

The IPCC defines vulnerability as 'the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change' (IPCC, 2001). It is a function of exposure, sensitivity and adaptive capacity. In the global context, climate change adaptation research is a relatively new and evolving field. As yet, little is known or understood about the adaptive capacity and sensitivity of many of Australia's World Heritage values to the impacts of climate change, particularly with respect to some cultural values. However, based on our current level of knowledge and understanding of climate change impacts, it is possible to classify the adaptive capacity of Australia's World Heritage values (using UNESCO's criteria as a proxy) into three broad categories[3]: low, moderate and high. This categorisation is based on a comparative analysis over all world Heritage values. These are summarised in Table 1.

[3] This comparative assessment is based on our current knowledge of climate change impacts on World Heritage values. It should also be noted that the amount of time and research devoted to the effects of climate change on World Heritage values is disproportionate between the natural and cultural values. A broad scale state-of- the art vulnerability assessment is required across all properties and values.

6 Potential impacts of climate change on Australia's World Heritage properties and their values

Australia's World Heritage properties and their World Heritage values are diverse and will not be equally affected by climate change. Some properties, such as the Great Barrier Reef and the Wet Tropics of Queensland, are highly sensitive, whereas others, such as Naracoorte (Australian fossil mammal sites), are likely to be less susceptible to abrupt climate change.

The following points identify some of the direct (e.g. higher temperatures, elevated CO_2) and indirect impacts (e.g. fire, pests, diseases) of climate change on Australia's World Heritage properties and their values.

7 Potential impacts of climate change on natural World Heritage values of ecological and biological significance

About 70% of Australia's World Heritage properties contain values representing 'significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and/or contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation'.

These World Heritage properties include: Kakadu National Park, Wet Tropics of Queensland, Gondwana Rainforests of Australia, Fraser Island, Lord Howe Island, Greater Blue Mountains Area, Shark Bay, Uluru-Kata Tjuta National Park, Australian Fossil Mammal Sites, Heard Island and McDonald Islands, Tasmanian Wilderness and the Great Barrier Reef.

Higher temperatures, elevated CO_2 concentrations, ocean acidification, and prolonged drought are likely to have major impacts on these natural World Heritage values. The indirect effects of climate change (e.g. fire, alien invasions), are also likely to have significant impacts on these values.

7.1 Temperature

A 1˚C rise in temperature, expected to occur by about 2050, could result in a 50% decrease in the area of highland rainforests in the Wet Topics of Queensland world heritage property (Hilbert et al., 2001; Rainforest CRC, 2003). These forests could completely vanish with only a 2º C temperature rise resulting in the loss of the core habitats of many endemic vertebrate species. At least 10 endemic bird species in this World Heritage area are highly dependent on cool habitats for their survival, and are restricted to higher elevations where cooler conditions prevail. A 3.5˚ C increase in temperature combined with variable rainfall would result in the total loss of the core habitats of about 30 endemic vertebrates (Williams et al., 2003).

A rise in temperature could also have a direct impact on reptiles and amphibians, whose sex is determined by nest temperature (Webb et al., 1986). A sustained rise in atmospheric temperature could have a direct bearing on incubation temperature and hence reproduction and sex determination of reptiles, including marine turtles (Hays et al., 2003).

Global warming is probably affecting the distribution and abundance of plant and animal life on Australia's sub-Antarctic world Heritage Islands. There is a strong correlation between an increase in temperature and glacial retreat on these sub-Antarctic islands (Commonwealth of Australia, 2005). This has resulted in the exposure of large areas of bare ground previously covered by ice, and this has allowed fauna and flora to colonise newly-exposed areas, thus changing their distribution and abundance (Scott and Bergstrom, 2006). Global warming is likely to further impact on species distribution and abundance, as well as competition between species, in a way that is difficult to predict.

7.2 Carbon dioxide

An increase in atmospheric CO_2 concentration is also likely to impact on plant species through a process known as the 'CO_2 fertilisation effect', whereby plant growth is accelerated under high concentrations of CO_2. This is likely to lead to a change in the competitive balance between plant species. However, water and nutrient availability may limit the growth benefits of increased CO_2 levels. An increase in CO_2 concentration is also likely to affect the chemical composition, and hence nutritional value, of foliage (Curtis and Wang, 1998), which in turn is likely to affect leaf-eating marsupials (Kanowski, 2001).

7.3 Rainfall

Changes in rainfall and a potential increase in the basal altitude of mountain cloud-banks are likely to have a significant impact on Australia's natural World Heritage values. Most of Australia's World

Heritage properties have experienced a decline in rainfall over the last 35 years. CSIRO's climate change modelling indicates that mean annual rainfall will continue to fall in many regions across Australia (CSIRO, 2006). Even if annual rainfall remains unchanged, evaporation is likely to be higher, resulting in drier conditions.

A potential rise in the average basal altitude of the mountain cloud-bank due to global warming (Pounds et al., 1999; Still et al., 1999) is of concern for a range of World Heritage values across a number of properties, in particular in the Wet Tropics of Queensland and Lord Howe Island. The cloud-bank (also known as the orographic cloud layer[4]) shrouds the summits of the mountains of these World Heritage properties. It provides an essential source of water for many high altitude plants and animals, by a process known as 'cloud stripping' by high-altitude 'cloud-forests'. Although little is known about the hydrology of cloud stripping, the amount of water derived from this process is significant at high altitudes (McJannet et al., 2007). It is fairly certain that a lift in the basal altitude of the cloud bank would affect many plant and animal species (Williams et al., 2003) such as microhylid frogs[5] that rely on consistent moisture from the cloud mist for their long term survival. There is strong evidence to suggest that the disappearance of about 20 frog species in the highland forests of Monteverde, in Costa Rica, was related to changes in the extent of mountain mist following an increase in temperature (Pounds et al., 1999; Pounds et al., 2006).

7.4 Tropical cyclones and extreme weather events

There has been an increase in the destructiveness of cyclones since the 1970s, which correlates with the observed rise in sea surface temperature (Emanuel, 2005). Tropical cyclones are not uncommon in Kakadu National Park, the Great Barrier Reef, and the Wet Tropics of Queensland. Climate change scenario modelling indicates that cyclones are expected to be less common, but more intense with greater wind-speeds (CSIRO, 2006), which may inflict greater physical damage to vegetation including the up-rooting of trees. High-intensity cyclones may inflict greater damage on certain vegetation types. Eucalyptus trees taller than 9 m are particularly prone to wind damage (Williams and Douglas, 1995). The uprooting of trees can also lead to increased erosion during periods of intense rainfall.

7.5 Increased sea surface temperatures, changes in ocean circulation and ocean acidification

The impacts of rising sea surface temperatures and ocean acidification will most likely have catastrophic consequences for marine organisms, such as coral and the species dependent on these keystone species, as well as for calcifying organisms such as plankton, sea urchins and coral reef systems (Feely et al., 2004). Acidification of the oceans occurs as dissolved CO_2 reacts with water to produce carbonic acid, which in turn increases acidity. The resulting acidification could prevent calcifying organisms, such as corals, shellfish and some species of phytoplankton, from producing calcium carbonate and thus prevent shell formation. The coral communities around Lord Howe Island, which are the world's southern-most true coral reefs, and the Greet Barrier Reef, are likely to be affected by ocean acidification. There are no experimental studies examining the sensitivity of cold-water coral reef systems, such as those at Lord Howe Island, to CO_2-induced ocean acidification. However, it is expected that the acidification will affect the recruitment of cold corals more than their warm-water counterparts because the carbonate saturation state is generally lower at higher (southern) latitudes than at lower latitudes (The Royal Society, 2005).

The decline in sea bird populations on the Great Barrier Reef and of elephant seals on Macquarie Island, is probably related to a change in food supply associated with changes in the marine environment at large (McMahon et al., 2005; Smithers et al, 2003). Changes in fish stocks in the Pacific Ocean are associated with stronger, and more frequent, El Niño-Southern Oscillation (ENSO) cycle activity (Bunce et al., 2002). A change in the abundance or availability of food due to shifts between the Antarctic Circumpolar Wave (ACW) and the El Niño-Southern Oscillation (ENSO) could

[4] Mountain clouds produced by orographic lifting of moist air to saturation (Source: Lead glossary: http://frozone.itsc.uah.edu:8080/LEAD_Glossary/o.jsp).
[5] Microhylid frogs lay their eggs on the forest litter and therefore require a constant source of moisture from the cloud stripping process to prevent desiccation of eggs and larvae.

be one explanation for the decline in elephant seal numbers (McMahon et al., 2005). These climatic systems influence the extent of sea-ice retreat (Kwok and Comiso, 2002) and the recruitment of krill, which is a source of food for many marine predators (Loeb et al., 1997). However, the connection between global warming and changes in the earth's climatic systems, such ENSO and ACW, is still poorly understood. It is unclear how the frequency and intensity of El Niño events will respond to global warming (IPCC, 2007).

7.6 Chemical and physical changes to the coastal zone and its values

Kakadu National Park, Tasmanian Wilderness, Shark Bay, Fraser Island, Lord Howe Island, Macquarie Island, Heard and McDonald Islands, Great Barrier Reef and Wet Tropics of Queensland are likely to be affected to varying degrees by sea level rise. Rising sea levels and large storm surges pose significant threats to the integrity of the world heritage values of these sites. Changes in salinity and physical changes to the coastal zone of some properties may have significant implications for terrestrial and marine habitats.

Kakadu and Shark Bay will face a more immediate threat from further sea level rise causing an increase in flooding of low lying areas. The coastal plains of Kakadu are about 0.2 to 1.2 metres above the high tide water mark (Eliot et al., 1999). Large buffalo numbers during the mid-1980s accelerated the erosion of levee banks, leading to considerable alluvium displacement and a subsequent increase in salinity (Cobb et al., 2000). The sea level around Kakadu will probably rise by at least 8 cm, and possibly up to 30 cm, by 2030 (Eliot et al., 1999). A rise in sea level of this magnitude is likely to lead to a further expansion of tidal river systems, posing a significant threat to freshwater wetland systems, and resulting in a decline in saltwater sensitive plant species such as *Melaleuca*. It is believed that sea-level rise resulting from global warming has already led to changes in Kakadu's terrestrial ecosystem. For example, over the last 40 years there has been an expansion in the distribution of mangrove communities along tidal rivers (Lucas et al., 2002).

7.7 Indirect impacts—fire

More extreme and more frequent wildfires are likely to have a major impact on the fire-sensitive rainforest and alpine forest communities and the organisms that they support. The rainforests of the Great Blue Mountain World Heritage Area (WHA) provide a microclimate for primitive plant species with Gondwanian affinities, such as the Wollemi Pine (*Wollemia nobili*). This species, originally thought to be extinct, is found in only one specific location in this WHA. Although the effect of fire on the Wollemi Pine remains largely unknown, catastrophic fire events could threaten remaining stands (NSW Department of Environment and Conservation, 2006).

More intense and more frequent fires may also affect fire-sensitive plant species in the Tasmanian Wilderness WHA, including Huon pine, Pencil pine, myrtle-beech, deciduous beech, and King Billy pine (Parks and Wildlife Service, 2004). An increase in the extent and severity of peat fires in World Heritage sites such as Fraser Island and the Tasmanian Wilderness WHA is also of major concern. Extensive peat fires can often burn for weeks.

7.8 Excessive human visitation, exotic pests and diseases

The extent to which excessive human visitation, and the introduction of exotic pests and diseases will exacerbate climate change effects, is unknown. The threat of changes in disease dynamics brought about by climate change is a major concern, because pest and diseases are by nature opportunistic. Climate change might modify the incidence and geographic range of some vector-borne diseases (McMichael et al., 2006). Also, the response of alien plant and animal species to climate change remains largely unknown. However, it is likely that climate change will favour their existence and domination. The spread of alien species, such as the Cane Toad into the wetland systems of Kakadu, is of major concern to park managers. Alien expansion has been reported in other World Heritage sites. Heard Island's only recorded alien plant species, *Poa annua,* showed dramatic expansion between 1987 and 2000, which is attributed to an increase in seal disturbance and climatic change factors (Scott and Kirkpatrick, 2005).

The impacts of excessive human visitation to Australia's World Heritage sites are also likely to exacerbate the effects of climate change. For example, groundwater extraction on Fraser Island WHA has been described as 'potentially high risk' by the Fraser Island World Heritage Area Scientific Advisory Committee (The State of Queensland EPA, 2004) and has emerged as an important factor that may affect the integrity of World Heritage values such as mires or patterned fens[6] that derive their water and nutrient supply from the watertable.

[6] The location of mires at sub-tropical latitudes is rare as they are normally found in cold climates where lower temperatures and slower decomposition rates favour peat formation. Mires which derive their water and nutrient supply from the watertable (as opposed to bogs, which derive their water and nutrients from rainfall), are referred to as fens.

8 Potential impacts of climate change on natural World Heritage values representing significant geomorphic or physiographic features of the landscape

About 90% of Australia's World Heritage properties contain values of 'superlative natural phenomena or areas of exceptional natural beauty as well as outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features.' These World Heritage properties include: Kakadu National Park, Wet Tropics of Queensland, Gondwana Rainforests of Australia, Fraser Island, Lord Howe Island, Shark Bay, Uluru-Kata Tjuta National Park, Macquarie Island, Purnululu National Park, Willandra Lakes Region, Tasmanian Wilderness, Australian Fossil Mammal Sites, Heard Island and McDonald Island and the Great Barrier Reef.

The geological and geomorphologic values of World Heritage sites are particularly vulnerable to extreme weather events, such as more intense cyclones, rising sea levels, and the effects of fire.

8.1 Extreme weather events

Extreme weather events are likely to result in irreversible changes to geological and geomorphologic values. After all, many modern landforms are the result of climatic forces that have taken place over millions of years. Purnululu and Willandra Lakes were nominated for world heritage status because of their distinctive landforms, which are largely due to the effects of climatic changes. However, the extent to which human-induced climate change will significantly affect these unique landform values, such as the banded[7] sandstone beehive structures found in Purnululu WHA, is difficult to predict.

The threat of increased erosion triggered by severe storm events is of major concern in regions which are already vulnerable due to the impacts of over-grazing and fire. For example, erosion is a major concern to the geo-conservation values of the north-eastern portion of the Tasmanian Wilderness WHA, particularly on the Central Plateau, where alpine sheet erosion has been described as the 'worst alpine erosion in Australia' (Parks and Wildlife Service, 2004).

8.2 Rising sea levels

Rising sea levels and large storm surge events pose a significant threat to the integrity of the coastline of Australia's World Heritage properties. These threats are likely to result in physical changes (beach erosion, rockfalls, and slumping) to the coastal zone (Sharples, 2006). For example, beaches will either disappear or shift landwards in response to a further rise in sea level. Over the last couple of years managers of the Tasmanian Wilderness WHA have noticed a substantial increase in the extent of beach erosion, with many beaches exhibiting faster rates of beach loss than occurred during the last century. On Lord Howe Island a rise in sea level and/or changes in wave characteristics may alter the rate at which the coastal cliffs crumble, as well as the nature of the rocky shore platforms (Dickson and Woodroffe, 2002).

8.3 Indirect impacts—fire

Changed fire regimes could also have devastating impacts on geomorphic or physiographic features. Sandstone outcrops and rocky cliff faces are more likely to become weak and brittle from extreme heat generated by intense fire storms, thus predisposing these natural features of the landscape to fire-induced rock weathering, such as spalling (flaking) (Shakesby and Doerr, 2006). Rock measurements conducted in the Greater Blue Mountains WHA show that wildfires can increase the rate of rock weathering and dislodgement (Adamson et al., 1983). Heat from fire can lead to the deterioration of karst environments by stimulating erosion and changes to chemical and hydrological processes.

[7] The sandstone towers are marked by horizontal bands of single-celled photosynthetic microorganisms called cyanobacteria.

9 Potential impacts of climate change on cultural World Heritage values relating to traditional human settlement, living traditions and beliefs as well as exceptional testimony to a civilisation which has disappeared

The Tasmanian Wilderness and Willandra Lakes WHAs exhibit values that 'bear a unique or at least exceptional testimony to a civilisation which has disappeared. Uluru-Kata Tjuta National Park has 'outstanding examples of a traditional human settlement, land-use, which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change'. Kakadu National Park, Tasmanian Wilderness and Uluru-Kata Tjuta National Park also have World Heritage values 'directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance'.

9.1 Physical changes to the coastal zone

As well as exhibiting intrinsic geomorphic values, the coastal regions of Kakadu and Tasmanian Wilderness WHA's contain significant Aboriginal cultural values. These unique values include middens and sea-cave deposits. Their integrity is dependent on the maintenance and protection of their underlying landforms from climate change impacts, such as erosion, sea level rise, wildfires and storm surges. Clearly, these non-renewable cultural features will require significant attention to their management.

9.2 Rainfall and extreme weather events

Climate change scenario modelling indicates an increase in extreme weather events and flash flooding in Australia's World Heritage sites containing unique cultural values. Although erosion is a natural process, accelerated wind, stream and sheet erosion can be detrimental to cultural heritage including archaeological sites such as the Pleistocene and Holocene burial sites in Willandra Lakes Region WHA. An increase in severe storms, flash flooding and cyclones could also affect access to sacred sites.

9.3 Indirect impacts—fire

An increase in the frequency of extreme fire danger days is likely to result from global warming. Dry-season wildfires create large quantities of smoke, dust and black ash which contaminate the atmosphere and result in the formation of highly acidic rain during tropical storms (Watchman, 1991). Proper fire control strategies can help to reduce the destructive force of wildfires. Fire control programs in Kakadu involve traditional owners at all stages including planning, execution and monitoring, and programs now are very much influenced by indigenous burning practices, giving effect to a World Heritage value i.e.—'the ongoing, active management of the landscapes by Aboriginal people through the use of fire.' While on-going monitoring in the park has shown that past fire management practices have not been optimal for the environment, the application of traditional burning practices and knowledge has contributed significantly to improved fire management practices.

10 Potential impacts of climate change on cultural World Heritage values that represent a unique artistic achievement, and a masterpiece of the creative genius, interchange of human values and developments in architecture or technology, monumental arts, town-planning or landscape design

There are three world heritage sites that have unique world heritage values representing 'an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design' (e.g. The Royal Exhibition Building and Carlton Gardens in Melbourne) and 'unique artistic achievement and a masterpiece of the creative genius', (e.g. The Sydney Opera House and Aboriginal rock art in Kakadu National Park). CSIRO's climate change scenarios (CSIRO, 2006) for Sydney and Melbourne indicate a 0.5º to 1.1º C increase in temperature by 2030. They also suggest there is the likelihood of extreme weather events and prolonged drought with a tendency for more extreme storm events and flash flooding in Kakadu National Park. Tropical cyclones are likely to become more intense with an expected 5–10% increase in wind speeds (CSIRO, 2006).

Higher temperatures and changes in humidity, as well as extreme weather events such as higher wind speeds, severe rain, lightning and hail, can have a direct impact on the fabric of buildings. Changes in rainfall (prolonged drought or excessive rainfall) can also affect building fabric and soil chemistry (UNESCO, 2006). Soils containing a high clay content may exhibit serious cracking during prolonged droughts. In addition, timber buildings may become more vulnerable to fungal and insect attacks. Newer buildings made from concrete, steel and tiles (e.g. the Sydney Opera House) are likely to be more resilient to these climatic factors than older buildings constructed from brick, timber, steel and slate (e.g. The Royal Exhibition Building). The potential impact of climate change on the Sydney Opera House and the Royal Exhibition Building is likely to be of lesser significance, than for the other World Heritage properties discussed in this paper. The most discernible effect of climate change on the Sydney Opera house is likely to be due to a rise in sea level.

The Aboriginal rock art sites[8] in Kakadu 'represent a unique artistic achievement'. Water is the primary agent of rock art deterioration (Pearson, 1978). Rainwater flowing over rock surfaces, as well as flooding, can result in damage to painted surfaces (Gillespie, 1983). Wildfires can also lead to the deterioration of rock art, particularly where thick vegetation is growing in close proximity to rock art sites (Lambert, 1989). An increase in extreme weather events, as well as an increase in the frequency and intensity of wildfires brought about by climate change, could pose an on-going threat to these unique cultural values.

10.1 Flow-on effects for industry and society

Apart from the physical threats of climate change, there will inevitably be considerable social and economic costs, with many communities either forced to adapt to change or to migrate elsewhere (UNESCO, 2006).

The tourism industry is likely to be hit hardest by climate change. During 2003/04, tourism accounted for around 11.7% of the total jobs in the Northern Territory, 5.6% in Queensland, 6.7% in Tasmania (STCRC, 2007) and 55% on Lord Howe Island (TTF Australia, 2007). Clearly, those industries relying on World Heritage sites as their main source of tourist revenue are likely to be most affected by climate change. Put simply, if the Great Barrier Reef was to vanish, there would be no *unique universal attraction* and therefore tourist operators providing trips to the reef would lose business. There would also be flow-on effects to other industries providing services in accommodation, food, fuel transport, sport fishing and recreation (TTF Australia, 2007).

Furthermore, the marketing of Australia as an attractive and exciting international destination relies on the promotion of the Australia's natural values as a key tourism experience (TTF Australia, 2007). The

[8] They represent one of the greatest concentrations of rock art in the world.

World Heritage sites provide a significant component of this experience. Approximately $23 billion was spent by tourists during 2006 on nature-based adventures (TTF Australia, 2007) in places such as Kakadu, Shark Bay, Great Barrier Reef, Tasmanian Wilderness, and Fraser Island World Heritage sites. The Tourism and Transport Forum of Australia, considers measures to 'preserve Australia's ecological diversity to be a top priority for the Action Plan on Climate Change' (TTF Australia, 2007). A Tourism Action Plan will be available in 2008 from the Department of Resources Energy and Tourism.

10.2 Adaptation to impacts

The natural values listed in UNESCO's criteria ix and x (i.e. 'Outstanding examples of on-going biological and ecological processes in evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals.' And those values that 'Contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation') have a low level of adaptive capacity to climate change. Because climate change is likely to occur faster than the natural rate and frequency of species evolution, many of the natural values such as our plants and animals would be unable evolve fast enough to cope with the effects of climate change.

Likewise, the cultural values representing 'outstanding example(s) of a traditional human settlement, or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change' are also likely to be affected by climate change. Hence human intervention is crucial in ensuring that sustainable adaptive responses are developed and incorporated in management strategies. They therefore require, as a matter of priority, the application of appropriate adaptive management strategies to strengthen their resilience.

The built heritage is likely to be more resilient than the natural heritage to the impacts of climate change. However, it is important to recognise that our knowledge of climate change impacts on our built heritage is limited or, in some cases, non-existent. Clearly, there is a need for regular monitoring and reporting of climate change impacts across all properties and values. UNESCO has recommended the use of state-of-the-art vulnerability assessments that could be adopted for all World Heritage sites (UNESCO, 2006).

Several actions are required in the short term to improve the adaptive capacity of our World Heritage values to climate change, and these are outlined below.

11 Recommendations for future research and action

There are three actions that need to be taken to ensure that that the world's unique heritage sites are protected from the effects of climate change. These are described in detail in a paper[9] prepared for UNESCO's Special Expert Meeting of the World Heritage Convention on the Impacts of Climate Change on World Heritage.

- **Mitigation: '**monitoring, reporting and mitigation[10] of climate change effects through environmentally sound choices and decisions at a range of levels: individual, community, institutional and corporate'.
- **Adaptation: '**to the reality of climate change through global and regional strategies and local management plans'.
- **Creating and sharing knowledge:** 'including best practices, research, communication, public and political support, education and training, capacity building, networking, etc'.

The summary below outlines the key findings and recommendations based on a study commissioned by the Commonwealth Department of Climate Change on the impacts of climate change on Australia's World Heritage properties and their values[11]. The recommendations derived from this study reflect the actions and recommendations described in UNESCO's report 'Predicting and Managing the Effects of Climate Change on World Heritage' (UNESCO, 2006).

11.1 Mitigate or lose

Mitigation involves the intervention by humans to reduce atmospheric greenhouse gas concentrations through the creation of carbon sinks (e.g. forest plantations) and by reducing emissions through the use of sustainable technologies and renewable energy sources.

11.2 Adaptation strategies and management plans

UNESCO's panel of experts recommends that appropriate adaptation measures need to be defined in the context of climate change and the sharing of knowledge among stakeholders should be enhanced.

Key recommendations

- Implementation of more comprehensive vulnerability assessments for each World Heritage property, as recommended by UNESCO (see appendix for more detail).
- Reduction of non-climatic stress factors, such as the spread of alien species, to increase the resilience of Australia's World Heritage values (particularly the natural values listed under criterion x) to climate change impacts. This will require the removal or eradication of introduced pest species and the constant review of human access to World Heritage sites.
- Development of ex situ conservation measures and techniques, such as living collections and seed banks, for species at greatest risk from the effects of climate change. An example is those species restricted to the cloud forests of Lord Howe Island (See Auld and Hutton, 2004) and the Wet Tropics of Queensland.

[9] Background paper: The Impacts of Climate Change on World Heritage Properties. http://whc.unesco.org/uploads/activities/documents/activity-393-1.doc

[10] The IPCC defines mitigation as "an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases".

[11] Implications of climate change for Australia's World Heritage properties: a preliminary assessment. The Fenner School of Environment and Society, The Australian National University. Draft Paper, April 2007.

- Creation of buffer zones around heritage properties and, where necessary, the reclamation of suitable land for refugia. There is also a need to improve connectivity between reserves to allow species to move freely between habitats.

11.3 Creating and sharing knowledge

Information on potential climate change impacts is steadily growing and this growth will continue. However, there is no universal mechanism allowing policy makers and land managers to coherently assemble and assimilate the vast amount of scientific literature and data to assist with the development of best management practices for the protection of Australia's World Heritage properties. Knowledge sharing, cross-fertilisation of ideas and networking across jurisdictions is vital for the development of efficient and effective climate change response strategies for Australia's World Heritage properties. It is essential that managers of World Heritage properties develop an appropriate knowledge management system for reporting and monitoring climate change effects on World Heritage values, and that this information be shared amongst stakeholders and managers alike.

Key recommendations

- More research[12] is required on the impacts of climate change on World Heritage values. Enhancement of the collection of baseline data (ecological, species-based, genetic, ecosystem/landscape-scale) and the monitoring of parameters critical for adaptive management is required. There is a need to clearly identify and assess those values that are likely to be more susceptible to the impacts of climate change and to further our understanding of the adaptive capacity and resilience of species, communities and ecosystems.

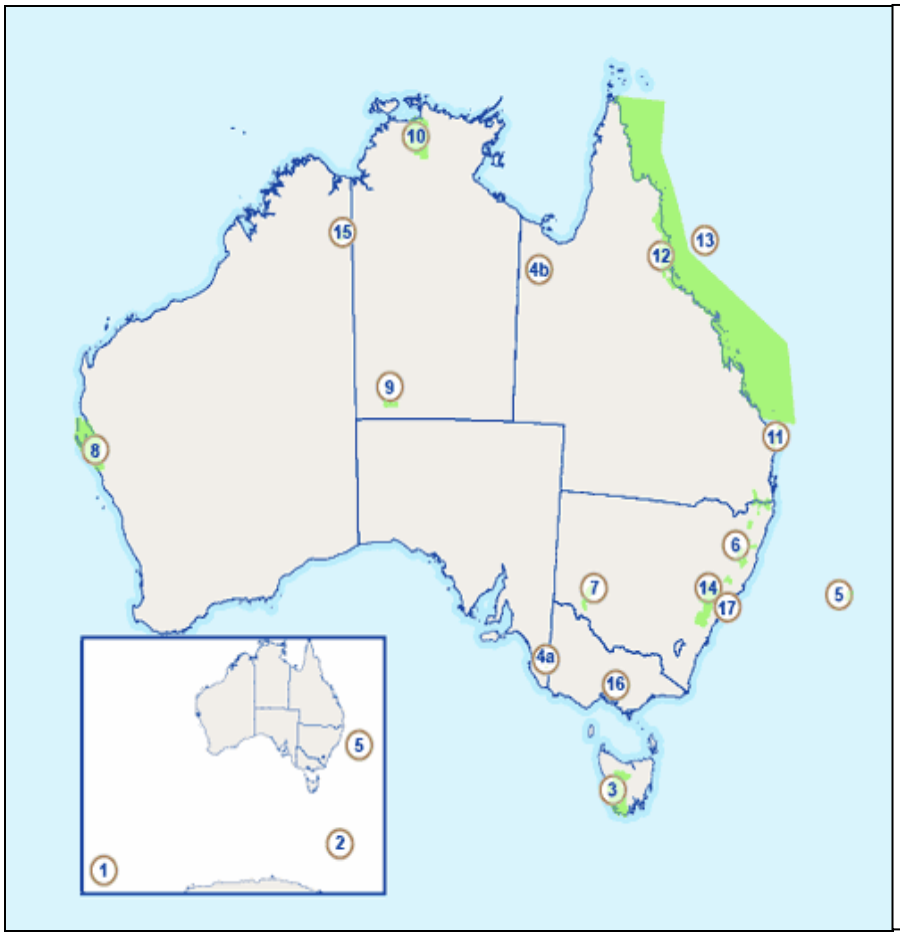
- Development of a coherent climate change management plan for Australia's World Heritage sites, coordinated by a steering committee consisting of land managers, landowners, state and federal government representatives, and researchers.

- Creation and support of networks to encourage 'cross-fertilisation' of knowledge and experience amongst researchers and between researchers and managers.

- Capacity building, both human and institutional, in climate change science, policy and management through development of multidisciplinary training programs to improve understanding of climate variability and climate change.

[12] Where do the critical thresholds lie in terms of both rate and magnitude of climate change for the majority of Australia's World Heritage values?

Figure 1 Location of Australia's World Heritage properties. Courtesy of Department of the Environment, Water, Heritage and the Arts



1. Heard and McDonald Islands
2. Macquarie Island
3. Tasmanian Wilderness
4 Australian Fossil Mammal Sites
   4a Naracoorte
   4b Riversleigh
5. Lord Howe Island
6. Gondwana Rainforests of Australia
7. Willandra
8. Shark Bay
9. Uluru Kata Tjuta National Park
10. Kakadu National Park
11. Fraser Island
12. Wet Tropics of Queensland
13. Great Barrier Reef
14. Greater Blue Mountains Area
15. Purnululu National Park
16. Royal Exhibition Building and Carlton Gardens
17 Sydney Opera House

Table 1 Summary of likely climate change threats and assessment of the adaptive capacity of Australia's World Heritage properties

World Heritage properties	Examples of property features reflecting World Heritage values	Major threats from climate change	Adaptive capacity
Kakadu National Park Wet Tropics of Queensland Gondwana Rainforests of Australia Fraser Island Greater Blue Mountains Area Shark Bay Macquarie Island Heard Island and McDonald Islands Tasmanian Wilderness Lord Howe Uluru-Kata Tjuta National Park Australian Fossil Mammal Sites Great Barrier Reef	• Open forest and woodlands. • Rainforest communities. • Invertebrates. • Diverse plant and animal species. • Relict species with Gondwanan affinities. • Examples of Stromatolites/ • Microbial mats.	• Changes in annual and seasonal rainfall. • More intense storms and cyclones. • Increase in temperature. • Changed fire regimes (more frequent and intense). • More frequent severe droughts, affecting conditions on land. • Reduced run-off into streams and creeks. • Elevated CO_2.	• Low
Shark Bay Great Barrier Reef Lord Howe Island Fraser Island Macquarie Island Tasmanian Wilderness	• Coral Reefs. • Diverse marine benthic algae. • Diverse marine fish species.	• Sea level rise. • Ocean acidification. • Storm surges. • Increase in sea surface temperatures.	
Kakadu National Park Wet Tropics of Queensland Great Barrier Reef Gondwana Rainforests of Australia Fraser Island Willandra Lakes Region Australian Fossil Mammal Sites Heard Island and McDonald Islands Tasmanian Wilderness Macquarie Island Lord Howe Shark Bay Uluru-Kata Tjuta National Park Purnululu National Park	• Coastal dunes. • Plateau tops, ridges, exposed rocks, cliffs, rocky slopes. • Archaeological sites. • Freshwater dune lakes. • Subtropical patterned fens. • Cone karst formations. • Fossil sites.	• Changed fire regimes. • Acidic rainfall. • More intense storms and cyclones. • Increased erosion. • Increase in temperature. • Sea level rise.	• Moderate
Kakadu National Park Uluru-Kata Tjuta National Park Tasmanian Wilderness Willandra Lakes Region	• Human settlement and land-use. • Aboriginal sacred sites.	• Changed fire regimes. • More intense storms and cyclones. • Increased erosion. • Increase in temperature and changes in humidity. • Sea level rise.	• Moderate
Royal Exhibition Building and Carlton Gardens	• Built environment.	• Increase in temperature. • Drought. • Acid rain. • Increase in storm frequency. • Increase in pest and biological infestations.	• High
Kakadu National Park Sydney Opera House	• Built environment. • Aboriginal rock art.	• Acid rain. • Fire. • Increase in storm intensity and flash flooding. • Increase in pest and biological infestations. • Sea level rise.	• Moderate for rock art • High for Sydney Opera House

Table 2 Summary of World Heritage criteria used to justify World Heritage status

Criterion number	Cultural criteria
(i)	Represent a unique artistic achievement and a masterpiece of the creative genius.
(ii)	To exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design.
(iii)	Bear a unique or at least exceptional testimony to a civilisation which has disappeared.
(iv)	An outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history.
(v)	Outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change.
(vi)	Directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance. (The Committee considers that this criterion should preferably be used in conjunction with other criteria).
	Natural criteria
(vii)	Contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance.
(viii)	Outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features.
(ix)	Outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals.
(x)	Contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

Table 3 World Heritage properties listed against their respective criteria

	Criteria for World Heritage status	
World Heritage property	Natural criteria	Cultural criteria
Kakadu National Park	(vii)(ix)(x)	(i)(vi)
Wet Tropics of Queensland	(vii)(viii)(ix)(x)	
Gondwana Rainforests of Australia (CERRA)	(vii)(ix)(x)	
Fraser Island	(vii)(ix)	
Greater Blue Mountains Area	(ix)(x)	
Lord Howe Island	(vii)(x)	
Shark Bay	(vii)(viii)(ix)(x)	
Uluru-Kata Tjuta National Park	(vii)(ix)	(v)(vi)
Purnululu National Park	(vii)(viii)	
Australian Fossil Mammal Sites (Riversleigh/Naracoorte)	(viii)(ix)	
Willandra Lakes Region	(viii)	(iii)
Macquarie Island	(vii)(viii)	
Heard Island and McDonald Islands	(viii)(ix)	
Tasmanian Wilderness	(vii)(viii)(ix)(x)	(iii)(iv)(vi)
Great Barrier Reef	(vii)(viii)(ix)(x)	
Royal Exhibition Building and Carlton Gardens		(ii)
Sydney Opera House		(i)

Note: see table 2 for explanation of criteria.

12 References

Adamson, D., Selkirk, P.M. and Mitchell, P. (1983). The role of fire and Lyrebirds in the landscape of the Sydney Basin. In: Young, R.W and Nanson, G.L [Eds], Aspects of Australian Sandstone Landscapes. University of Wollongong, NSW., Australia. Aust & NZ Geomorph. Group, Spec. publication, No 1: 81–93.

Auld, T.D. and Hutton, I. (2004). Conservation issues for the vascular flora of Lord Howe Island. *Cunninghamia,* 8(4): 490–500.

Bindoff, N.L., Willebrand, J., Artale, V., Cazenave, A., Gregory, J., Gulev, S., Hanawa, K., LeQuere, C., Levitus, S., Nojiri, Y.,Shum, C.K., Talley, L.D. and Unnikrishnan, A.S. (2007). Observations: Oceanic Climate Change and Sea Level. In: 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.

Bunce A., Norman, F. I., Brother, N. and Gales, R. (2002). Long-term trends in the Australasian gannet (*Morus serrator*) population in Australia: the effect of climate change and commercial fisheries. *Marine Biology,* 141(2): 263–269.

Cobb, S.M., Saynor, M.J., Eliot, I. and Hall, R. (2000). Saltwater intrusion in the Alligator Rivers Region, northern Australia. In: Eliot, I., Saynor, M., Eliot, M. and Finlayson, C. M. [Eds] Assessment and Monitoring of Coastal Change in the Alligators Rivers Region, Northern Australia, pp. 118–131. Supervising Scientist Report, 157, Supervising Scientist, Environment Australia, Canberra, Australia.

CSIRO. (2006). Climate change scenarios for initial assessment of risk in accordance with risk management guidance. Report prepared for the Australian Greenhouse Office, Department of Environment and Heritage [Eds] Hennessay, K., Macadam, I and Whetton, P. CSIRO Marine and Atmospheric Research.

Curtis, P. S. and Wang, X. (1998). A meta-analysis of elevated CO_2 effects on woody plant mass, form, and physiology. *Oecologia,* 113(3): 299–313.

Commonwealth of Australia. (2005). Heard Island and McDonald Islands Marine Reserve Management Plan, Australian Antarctic Division ISBN 1876-934085

Commonwealth of Australia. (1983). The Rock Art Sites of Kakadu National Park. Some Preliminary Research Findings for their Conservation and Management. [Ed] Gillespie. D. National Parks and Wildlife Service. Special publication No 10.

Dickson, M. E. and Woodroffe, C. D. (2002). Rocky coastline around Lord Howe Island and potential changes in the dynamics of coastal erosion with global climate change. *Proceedings Coast to Coast 2002 Conference, Tweed Heads*, pp. 515–518.

Eliot, I, Finlayson, C. M. and Waterman, P. (1999). Predicted climate change, sea level rise and wetland management in the Australian wet-dry tropics. *Wetlands Ecology and Management,* 7(1–2): 63–81.

Emanuel, K. (2005). Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, 436: 686–688.

Feely, R. A., Sabine, C. L., Lee, K., Berelson, W., Kleypas, J., Fabry, V. J. and Millero, F. J. (2004). Impact of anthropogenic CO_2 on the $CaCO_3$ system in the ocean*. Science,* 305(5682): 362–366.

Gillespie, D. (1983). The Rock Art sites of Kakadu—Some Preliminary Research Findings for their Conservation and Management, Special Publication Number 10, Australian National Parks and Wildlife Service, Canberra.

Hays, G. C., Broderick, A.C., Glen, F. and Godley, B. J. (2003). Climate change and sea turtles: a 150-year reconstruction of incubation temperatures at a major marine turtle rookery, *Global Change Biology,* 9(4): 642–646

Hilbert, D., Ostendorf, B. and Hopkins, M. (2001). Sensitivity of tropical forests to climate change in the humid tropics of north Queensland. *Austral Ecology,* 26(6): 590–603.

IPCC. (2001). Intergovernmental Panel on Climate Change. *Climatic Changes 2001*. *The scientific basis*. Technical summary from Working Group I. IPCC, Geneva.

IPCC. (2007) 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.)]. Summary for Policymakers. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kanowski, J. (2001). Effects of elevated CO_2 on the foliar chemistry of seedlings of two rainforest trees from north-east Australia: Implications for folivorous marsupials. *Austral Ecology,* 26(2): 165–172.

Kwok, R. and Comiso, J. C. (2002). Spatial patterns of variability in Antarctic surface temperature: Connections to the Southern Hemisphere Annular Mode and the Southern Oscillation. *Geographical Research Letters,* 29(14):1029–1032.

Lambert, D. (1989). Conserving Australian Rock Art. A manual for site managers. [Ed] Ward, G. K. *The Institute Report Series*. Aboriginal Studies Press, Canberra.

Loeb, V., Siegel, V., Holm-Hansen, O., Hewitt, R., Fraser, W., Trivelpiece, W. and Trivelpiece, S. (1997). Effects of sea-ice extent and krill or salp dominance on the Antarctic food web. *Nature*, 387: 897–900.

Lucas, R. M., Ellison, J. C., Mitchell, A., Donnelly B., Finlayson, M. and Milne, A.K. (2002). 'Use of stereo aerial photography for quantifying changes in the extent and height of mangroves in tropical Australia'. *Wetlands Ecology and Management*, 10(2): 161–175.

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 hypothesis explaining the recent declines of the southern elephant seal *Mirounga leonina*. *Mammal Review*, 35(1): 82–100.

McMichael, A. J, Woodruff, R. and Hales, S. (2006). Climate change and human health: Present and future risks. *Lancet*; 367(9513): 859–869.

McJannet, D., Wallace, J., Fitch, P., Disher, M. and Reddell, P. (2007). Water balance of tropical rainforest canopies in north Queensland, Australia. *Hydrological Processes*, 21(25): 3473–3484.

NSW Department of Environment and Conservation (2006). *Wollemi Pine (Wollemia nobilis) Recovery Plan.* Hurstville, Sydney. ISBN 1 9020 887 636

Parks and Wildlife Service. (2004). *State of the Tasmanian Wilderness World Heritage Area—an evaluation of management effectiveness*, Report No. 1, Department of Tourism, Parks, Heritage and the Arts. Hobart, Tasmania.

Pearson, C. (1978) [Ed]. Conservation of Rock Art, *Proceedings of the International Workshop on the conservation of Rock Art.* Perth, September, 1977, The Institute for the Conservation of Cultural Material. (IACMM) Sydney 112pp.

Pounds, J. A., Bustamante, M. R., Coloma, L. A., Consuegra, J. A., Fogden, M. P. L., Foster Pru. N., La Marca, E., Masters, K. L., Merino-Viteri, A., Puschendorf, R., Ron, S. R., Sánchez-Azofeifa, G. A., Still, C.J. and Young, B. E. (2006). Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature,* 439: 161–167.

Pounds, J. A., Fogden, M. P. L. and Campbell, J. H. (1999). Biological response to climate change on a tropical mountain. *Nature,* 398: 611–615.

Rainforest CRC. (2003). Global Warming in the Wet Tropics. *Issues in Tropical Forest Landscapes. (2003)* Rainforest CRC, Issue 2, August 2003.

Scott, J. J. and Bergstrom, D. M. (2006). Vegetation of Heard Island and the McDonald Islands. Pp 69–90. In *Heard Island: Southern Ocean Sentinel.* [Eds] Green, K. and Woehler, E. Surry Beatty Publishers, Sydney. ISBN 0 949324 98 1.

Scott, J. J. and Kirkpatrick, J. B. (2005). Changes in subantarctic Heard Island vegetation at sites occupied by *Poa annua*, 1987–2000. *Arctic, Antarctic, and Alpine Research*, 37(3): 366–371.

Shakesby, R. A and Doerr, S. H. (2006). Wildfire as a hydrological and geomorphological agent. *Earth Science Reviews,* 74(3–4): 269–307

Sharples, C. (2006). Indicative Mapping of Tasmanian Coastal Vulnerability to Climate Change and Sea-Level Rise: *Explanatory Report.* Report to Department of Primary Industries, Water and Environment. 2nd edition.

Smithers, B. V., Peck, D. R., Krockenberger, A.K. and Congdon, B. C. (2003). Elevated sea-surface temperature, reduced provisioning and reproductive failure of wedge-tailed shearwaters (*Puffinus pacificus*) in the southern Great Barrier Reef, Australia. *Marine and Freshwater Research,* 54(8): 973–977.

Still, C. J, Foster, P. N. and Schneider, S. H. (1999). Simulating the effects of climate change on tropical montane cloud forests. *Nature,* 398: 608–610.

The Royal Society. (2005). Ocean acidification due to increasing atmospheric carbon dioxide*. The Royal Society.* The Clyvedon Press Ltd, Cardiff, UK. Pp 1–59. ISBN 0 85403 617 2.

The State of Queensland EPA. (2004). Environment Protection Agency. The State of Queensland. Fraser Island World Heritage Area*.* Review of Outstanding Universal Value. A report for Fraser Island World Heritage area Ministerial Council by the Fraser Island World Heritage Area Scientific Advisory Committee. [Eds] Ingram, G. J., Brown,T. J., Hergerl. E., Hockings, M., Lamb. D., Thompson, C. H. and Haig, J. pp1–91.

TTF Australia. (2007). Submission on the Tourism Action Plane on Climate Change. Tourism and Transport Forum Australia. [Ed] Dimech, M.

STCRC. (2007). Tourism Satellite Account: Northern Territory 2003–04: Tasmania 2003–04, Queensland 2003–04. [Eds] Spurr, R., Van Ho, T., Forsyth, P., Dwyer, L., Pambudi, D and Hoque. S. Sustainable Tourism Cooperative Research Centre, Griffith University Queensland, March 2007.

UNESCO. (2006). Predicting and Managing the Effects of Climate Change on World Heritage*.* A joint report from the World Heritage Centre, its Advisory Bodies, and a broad group of experts to the 30th session of the World Heritage Committee (Vilnius, 2006). Prepared by May Cassar (Centre for Sustainable Heritage, University College London), Christopher Young (English Heritage), Tony Weighell (Joint Nature Conservation Committee), David Sheppard (IUCN), Bastian Bomhard (IUCN), and Pedro Rosabal (IUCN), in collaboration with the World Heritage Centre and its Advisory Bodies.

Watchman, A. L. (1991). Age and Composition of Oxalate-rich Crusts in the Northern Territory, Australia. *Studies in Conservation,* 36(1): 24–32.

Webb, G. J. W., Choquenot, D. and Whitehead, P. J. (1986). Nests, eggs and embryonic development of *Carettochelys insculpta (*Chelonia: Carettochelidae) from northern Australia. *Journal of Zoology, London* 1B:521–550.

Williams, S., Bolitho, E. and Fox, S. (2003). Climate change in Australian tropical rainforests: An impending environmental catastrophe. *Proceedings of the Royal Society of London Series* B, 270: 1887–1893.

Williams, R. J. and Douglas, M. (1995). Windthrow in a tropical savanna in Kakadu National Park, northern Australia. *Journal of Tropical Ecology*, 11(4): 547–558.

Appendix An eight-step approach to guide vulnerability assessments

1. Define study area together with stakeholders and choose spatial and temporal scale.
2. Get to know place over time by reviewing literature, contacting and collaborating with researchers, spending time in the field with stakeholders and assessing nearby areas.
3. Hypothesise who is vulnerable to what: refine focus on stakeholder subgroups and identify driving stresses and interactions of stresses.
4. Develop a causal model of vulnerability:
   - Examine exposure, sensitivity and adaptive capacity.
   - Formalise into model(s).
5. Find indicators for the elements of vulnerability.
   - Exposure indicators.
   - Sensitivity indicators.
   - Adaptive capacity indicators.
6. Operationalise model(s) of present vulnerability.
   - Apply model(s) to weigh and combine indicators.
   - Apply model(s) to produce a measure of present vulnerability.
   - Validate results with stakeholders etc.
7. Project future vulnerability.
   - Choose scenarios with stakeholders.
   - Scenarios should demonstrate full range of likely trends.
   - Apply model(s) to produce a measure of future vulnerability.
8. Communicate vulnerability creatively.
   - Use multiple interactive media.
   - Be clear about uncertainty.
   - Trust stakeholders.

For a detailed discussion see Schröter *et al.* (2005). Assessing vulnerabilities to the effects of global change: an eight step approach. *Mitigation and Adaptation Strategies for Global Change 10, 573–596).* According to these authors, for vulnerability assessments the role of numerical modelling is the projection of future states of a system. Here, steps 1–3 take place prior to modelling, whereas steps 4–8 take place as part of the modelling and model refinement process. Source: UNESCO 2006.