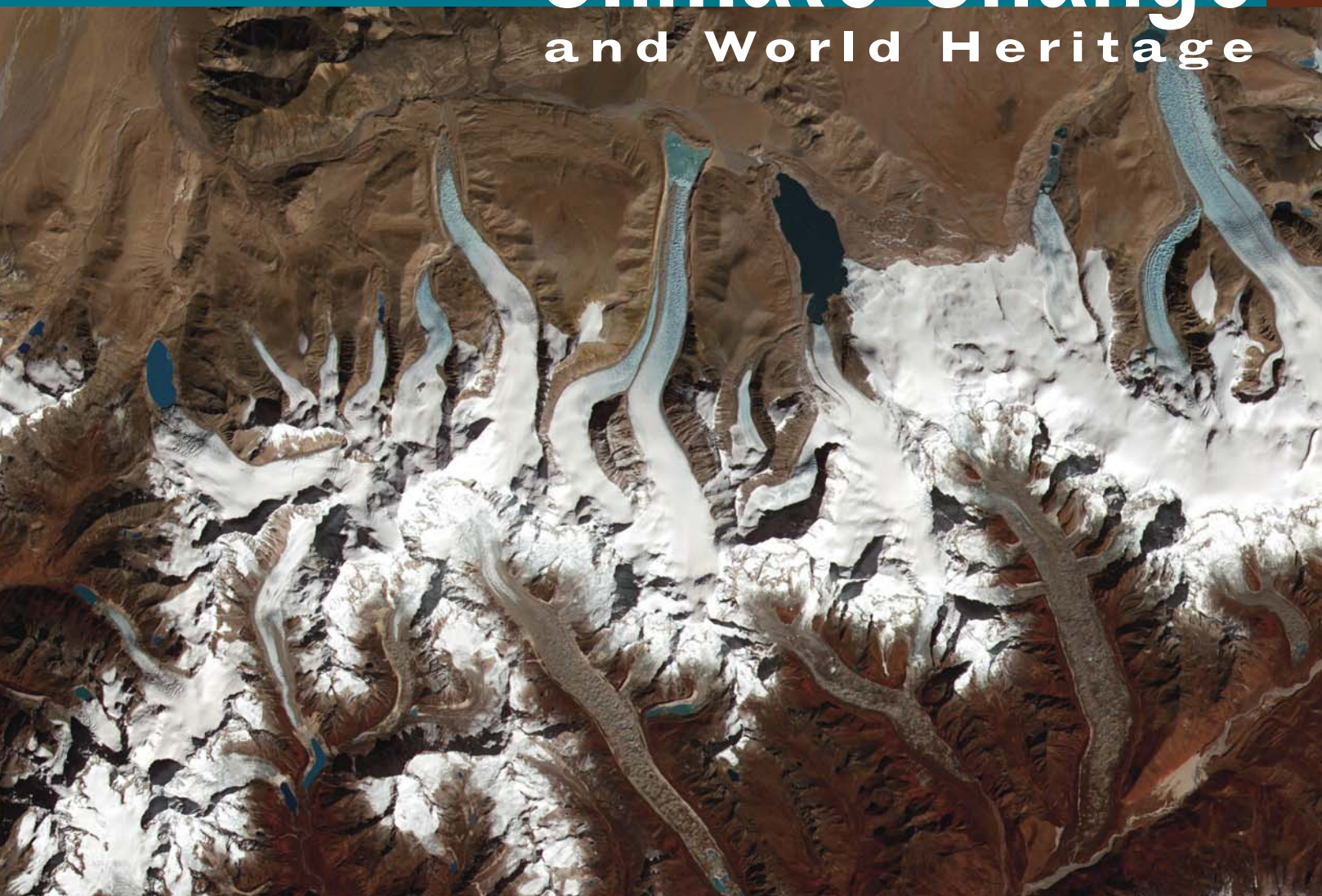


Case Studies on **Climate Change** and World Heritage



United Nations
Educational, Scientific and
Cultural Organization



World Heritage Convention

Cover Photo:

Himalayan glaciers in the Bhutan-Himalaya range are retreating and leaving glacial lakes in their stead. Satellite image from the Earth Imaging Instrument ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer).

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<http://visibleearth.nasa.gov/>

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and World Heritage



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Foreword

The international scientific community now widely agrees that climate change will constitute one of the major challenges of the twenty-first century. In recent years, it has become increasingly evident that its adverse consequences will be felt worldwide and that the hardest hit will be the disadvantaged and poorest people of the planet, precisely those who are least prepared to cope with the devastating effects of climate change.

*The scope of the impending global threats warrants action on the part of UNESCO in its capacity as the specialized UN agency for education, science, culture and communication. Indeed, through more than thirty programmes devoted to sustainable development, climate science, adaptation, monitoring and mitigation, UNESCO coordinates a wide range of initiatives related to world climate change, including projects on coral bleaching, ocean acidification, the hydrological cycle, mountainous biosphere reserves, drylands and desertification, to mention but a few. True to its mission to serve as a laboratory of ideas and clearinghouse for the dissemination and exchange of information and knowledge, UNESCO has organized international forums and produced reports and books on the subject, including the 2005 publication entitled *Climate Change*, aimed at a non-specialized public.*

The potential impact of climate change on the world's cultural and natural heritage is also a subject of growing concern. In 1972, UNESCO Member States adopted the Convention concerning the Protection of the World Cultural and Natural Heritage in order to create an appropriate framework for the preservation of our shared heritage for the benefit of current and future generations. At that time, the international community was not fully aware of the hidden threat of climate change to World Heritage properties. However, over the last two decades, leading experts have begun warning us that our planet's fragile ecological balance could be dramatically and irremediably disrupted as a consequence of certain unchecked human activities. The adoption of the UNESCO Convention for the Safeguarding of the Intangible Cultural Heritage in 2003 reflected not only the growing awareness of the interdependence between the world's tangible and intangible heritage and the overall importance of safeguarding cultural diversity, but also the need to adopt an integrated approach to issues of environmental preservation and sustainable development.

UNESCO's World Heritage Centre, guided by the World Heritage Committee and in cooperation with various partners and its principal Advisory Bodies (the International Council on Monuments and Sites, ICOMOS, the International Union for the Conservation of Nature, IUCN, and the International Centre for the Study of the Preservation and Restoration of Cultural Property, ICCROM), has launched several noteworthy initiatives, which resulted in the development of an overall strategy on managing heritage in the face of climate change. Furthermore, a general policy document on the impacts of climate change on World Heritage Properties was adopted by the General Assembly of States Parties at its 16th session (UNESCO, 2007).

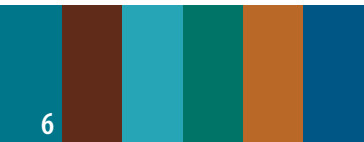
The present publication, which highlights several case studies illustrating the impact of climate change on World Heritage, marks another positive step in UNESCO's efforts in this area. Given the high-profile nature of World Heritage sites, this global network, now comprising 878 natural and cultural properties, is ideally suited to building public and political support through improved information dissemination and effective communication on the subject.

UNESCO is committed to working closely with all relevant actors, including civil society and the scientific community, to address the multiple challenges posed by climate change to the world's irreplaceable and fragile cultural and natural heritage. I am confident that this publication will contribute to raising international awareness and to promoting suitable responses on the part of decision makers around the planet.



Koïchiro Matsuura

Director-General of UNESCO



Preface

The World Heritage Committee at its 29th session in 2005 recognized that the impacts of climate change are affecting many World Heritage properties and are likely to affect many more, both natural and cultural, in the years ahead.

The outstanding and fragile character of World Heritage sites justifies the need for tailored management strategies protecting these very precious sites. The Convention concerning the Protection of the World Cultural and Natural Heritage, adopted by UNESCO in 1972, seeks to protect World Heritage sites against all kinds of threats, but the twenty-first century has seen the emergence of 'new' kinds of threats in climate change. For those sites which are affected by climate change, management strategies will have to account for these additional sources of stress in the future.

The year 2006 marked the beginning of a new chapter in the involvement of the World Heritage Centre in climate change issues. As decided by the World Heritage Committee, a meeting of experts was held at UNESCO Headquarters in March 2006 to review the nature and scale of the risks suffered by World Heritage properties arising specifically from climate change. This meeting brought together nearly 50 climate change and World Heritage specialists, including representatives from the Intergovernmental Panel on Climate Change (IPCC), the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Environment Programme (UNEP), the Ramsar Convention on Wetlands, the World Resources Institute (WRI), and the Advisory Bodies to the World Heritage Convention: the International Union for the Conservation of Nature (IUCN), the International Council on Monuments and Sites (ICOMOS), and the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM); as well as several academics, scientists and non-governmental organizations.

Following the meeting of experts, a report on 'Predicting and Managing the Effects of Climate Change on World Heritage' and a 'Strategy to Assist States Parties to Implement Appropriate Management Responses' was presented to the World Heritage Committee at its 30th session in Vilnius, Lithuania, in July 2006.

The iconic character of World Heritage sites is an important asset for raising public concern and enthusiasm and, therefore, building up support to take preventive and precautionary measures for adapting to climate change. As the conservation of World Heritage sites is regularly monitored and assessed, any adverse impact is systematically reported to the World Heritage Committee which recommends appropriate corrective action. World Heritage sites are, thus, crucial places for gathering and disseminating information regarding the impacts of climate change on our cultural and natural heritage. I hope that this compilation of case studies will be an important contribution to this effort.



Francesco Bandarin

Director of the UNESCO World Heritage Centre

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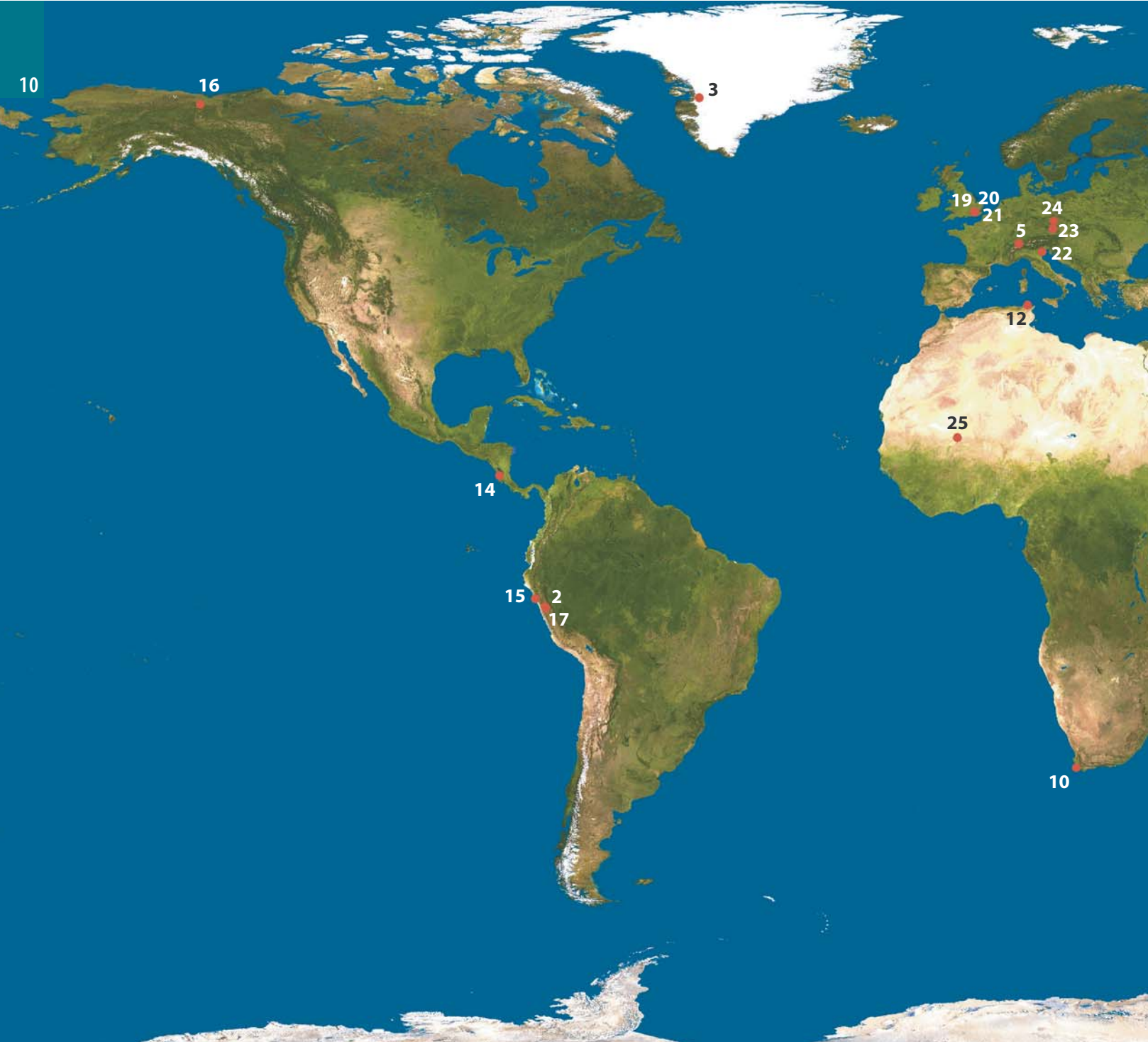


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Location of World Heritage sites presented



as case studies

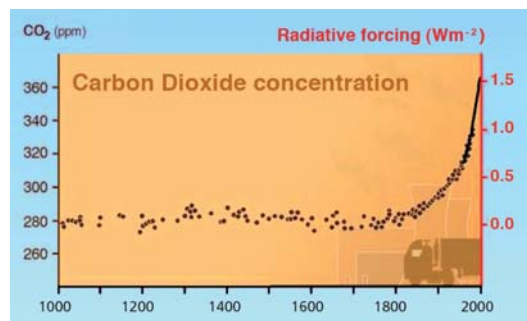


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Introduction

The climate of our planet is changing. The climate has always been variable, but today there is a growing concern over climate change issues, perhaps because the magnitude of the change seems to be unprecedented but, more importantly, because there is strong evidence to suggest that humanity might be directly responsible for climate change.

Any change in climate would lead to destabilization of environmental and social conditions all around the globe. These disturbances could jeopardize the conservation of natural ecosystems and sustainability of socioeconomic systems. Consequently, climate change will also adversely affect, and indeed is already affecting, the conservation of World Heritage properties, both natural and cultural. Heritage is an irreplaceable source of life and inspiration, it is humankind's legacy from the past, with which we live in the present and pass on to future generations.



Records of past changes in atmospheric composition over the last millennium demonstrate the rapid rise in greenhouse gases that is attributable, primarily, to industrial growth since 1750.

Early sporadic data taken from air trapped in ice (symbols) matches up with continuous atmospheric observations from recent decades (solid line). The estimated positive radiative forcing from these gases is indicated on the right-hand scale. (IPCC, 2001).

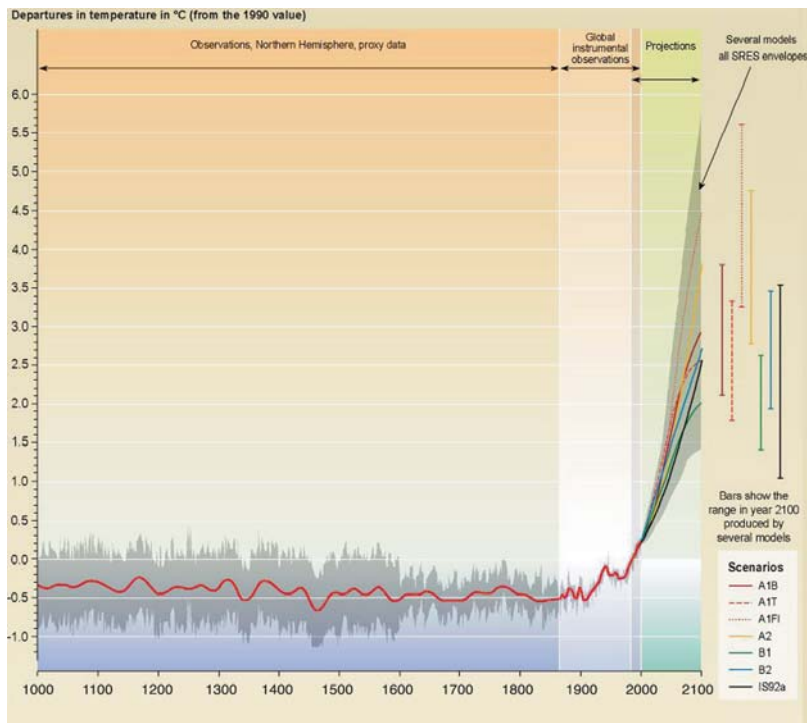
Our planet is kept warm due to the so-called greenhouse effect. This effect consists of trapping the energy – radiated by the earth into the atmosphere – instead of allowing it to escape into outer space. The greenhouse gases involved in this regulatory mechanism are usually found in the atmosphere at very low concentrations.

Carbon dioxide (CO₂) molecules are never found at concentrations higher than a few hundred parts per million (ppm) of air parcels. Nevertheless they play a critical role in the climatic equilibrium of the planet. Prior to the Industrial Revolution, CO₂ concentration was 280 ± 10 ppm for several thousand years. But the present atmospheric CO₂ concentration is above 360 ppm and such a level has never been reached over the past 420,000 years.^{1,2}

Changing CO₂ concentrations in the atmosphere will undoubtedly have an impact on the climate system, but the processes involved are multiple, complex, and feedback on one another. Extensive research is being carried out worldwide to understand better our impact

1. *Climate Change, 2001, The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK, 881 pp. http://www.grida.no/climate/ipcc_tar/. [Hereafter referred to as IPCC 2001, WG1]. Section 3.

2. This estimate has recently been updated by IPCC (Summary for Policy Makers of The Fourth Assessment Report of Working Group 1, 2007, available at <http://www.ipcc.ch/SPM2feb07.pdf>). Atmospheric carbon dioxide concentration reached 379 ppm in 2005, exceeding by far the natural range over the last 650,000 years (180 to 300 ppm).



Variations of the Earth's surface temperature: years 1000 to 2100.

Over the period 1000 to 1860, observations are shown of variations in average surface temperature of the Northern Hemisphere constructed from proxy data (tree rings, corals, ice cores, and historical records). The line shows the 50-year running average and the grey region the 95% confidence limit in the annual data. From the years 1860 to 2000, observations are shown of variations of global and annual averaged surface temperature from the instrumental record. The line shows the decadal average.

Over the period 2000 to 2100, projections are shown for different emission scenarios [referred to as the Special Report on Emission Scenarios (SRES)] * estimated by a model with average climate sensitivity. The grey region 'several models/all SRES envelope' shows the range of results from the full range of scenarios and models. (IPCC, 2001).

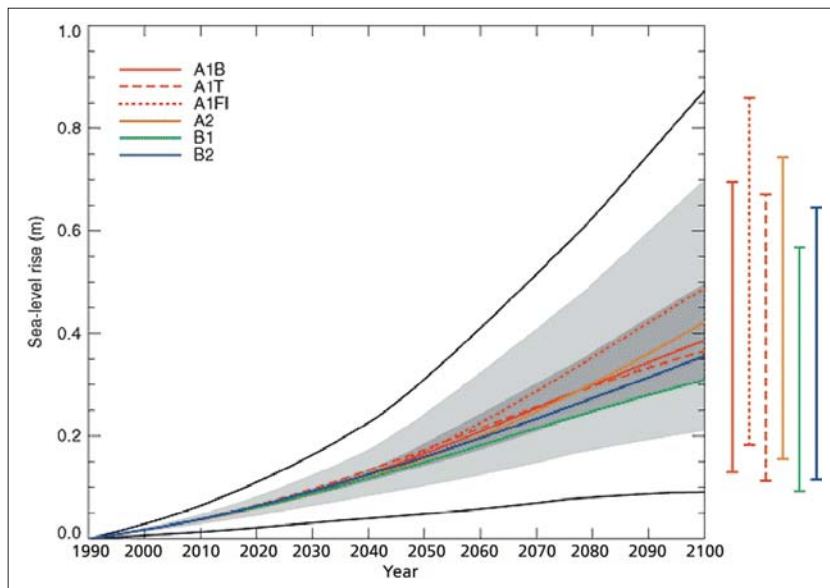
* N. Nakicenovic et al., 2000, IPCC Special Report on Emissions Scenarios, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 599 pp.

on the changing climate of planet Earth. The Intergovernmental Panel on Climate Change (IPCC) was established under the auspices of the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess, compile and synthesize scientific, technical and socio-economic information relevant to our comprehension of climate change, its potential impacts, and outline options for adaptation and mitigation. The periodic Assessment Reports of the IPCC constitute the best synthesis of the state of our knowledge of climate change.

According to the IPCC, global average temperature increase has reached 0.6 ± 0.2 °C over the twentieth century.³ There has been a widespread retreat of mountain glaciers in non-Polar Regions. Northern Hemisphere spring and summer sea-ice extent has decreased by about 10% to 15% since the 1950s. The global ocean heat content has increased since the late 1950s and the global average sea level rose by at least 0.1 m during the twentieth century.

The IPCC also develops possible scenarios for anthropogenic emissions in order to project future climate trends. Depending on these scenarios, climate models project that by 2100 atmospheric CO₂ concentrations will reach 540 to 970 ppm. The global average surface temperature is projected to increase by 1.4 °C to 5.8 °C over the period 1990 to 2100.⁴ Global mean sea level is projected to rise by 0.09 m to 0.88 m between 1990 and 2100.⁵ Global average water vapour concentration and precipitation are projected to increase during the twenty-first century, and larger year-to-year variations in precipitation are very likely over most areas where an increase in mean precipitation is projected. Changes in extreme and/or severe weather events such as heat waves, droughts, extreme precipitations, severe tropical cyclones, can also be expected.

3. In 2007, WG1 of IPCC provided an updated 100-year linear temperature trend (1906–2005) of 0.74 ± 0.18 °C which is larger than the previous estimate for 1901–2000. The linear warming trend over the last 50 years (0.13 ± 0.03 °C per decade) is nearly twice that for the last 100 years.
 4. The 2007 update of the span of projected temperature change is [1.8 – 4 °C] which is broadly consistent, although not directly comparable (because numerical climate models improved significantly), with the projections provided in 2001.



Projected global average sea-level rise between 1990 and 2100 for the six SRES emission scenarios of future emissions. (IPCC, 2001).

Such changes will have possible adverse impact on the conservation of properties inscribed on the World Heritage List. These properties are protected under the *Convention concerning the Protection of the World Cultural and Natural Heritage*⁶ which was adopted by UNESCO in 1972 in order to encourage the identification, protection and preservation of cultural and natural heritage considered to be of outstanding value to humanity. What makes the concept of World Heritage exceptional is its universal application. While fully respecting the national sovereignty, and without prejudice to property rights provided by national legislation, World Heritage sites belong to all the peoples of the world, irrespective of the territory on which these sites are located.

The *World Heritage Convention* has so far been ratified by 183 States Parties, and 878 sites are inscribed on the World Heritage List in 138 countries. For inscription of any site on the List it must meet one or more of the ten criteria contained in the *Operational Guidelines for the Implementation of the World Heritage Convention*⁷ and their related conditions of integrity. Among the sites inscribed on the World Heritage List, 679 are related to outstanding cultural values, 174 sites have remarkable natural values, and 25 present a mixture of both cultural and natural values.

These World Heritage properties, either natural or cultural, could be exposed to the unfavourable effects of changing climatic conditions e.g. in the following manner:

- Glaciers are melting worldwide and the appearance of some mountainous sites, inscribed because of their exceptional aesthetic beauty, could change dramatically.
- Sea-temperature changes, and increased level of carbon dioxide dissolved in the ocean make the conditions for conservation of coral reefs more difficult, with more frequent occurrences of bleaching, potentially leading to widespread death of corals.
- Climate change will force some plant and animal species to migrate as they are unable to adapt to their changing environments, which poses a problem for the conservation of biodiversity hotspots listed as natural World Heritage sites.

5. In 2007, it is estimated that, depending on the emission scenario, sea-level rise could reach [0.18 – 0.38] to [0.26 – 0.59] m in average for 2090-2099 compared to 1980-1999. Previous projections were made for 2100, and uncertainties were not treated in the same way but for each scenario, the midpoint of the updated range is within 10% of the model average for 2090-2099 established in 2001.

6. UNESCO, 1972, *Convention Concerning the Protection of the World Cultural and Natural Heritage*, <http://whc.unesco.org/archive/convention-en.pdf>

7. UNESCO, 2005, *The Operational Guidelines for the Implementation of the World Heritage Convention*, <http://whc.unesco.org/archive/opguide05-en.pdf>

- Archaeological evidences buried in the ground could be lost rapidly if the stratigraphic integrity of the soils were to change as a result of increased floods, changes in precipitation, or permafrost melting.
- Some properties listed as cultural heritage are built in coastal lowlands, and increased sea level and coastal erosion could threaten their conservation.

The UNESCO World Heritage Centre (WHC) initiated an assessment of the impacts of climate change on World Heritage in 2005, after the World Heritage Committee noted that 'the impacts of climate change are affecting many and are likely to affect many more World Heritage properties, both natural and cultural in the years to come'.⁸ A meeting of experts was convened in March 2006 bringing together over 50 representatives from the States Parties to the *World Heritage Convention*, various international organizations, non-governmental organizations, the Advisory Bodies to the World Heritage Committee, and academic and scientific experts, to discuss current and future impacts of climate change on World Heritage sites. The outcome of this initiative included a 'Report on Predicting and Managing the Effects of Climate Change on World Heritage', as well as a 'Strategy to Assist States Parties to Implement Appropriate Management Responses' which were endorsed by the World Heritage Committee at its 30th session in July 2006, Vilnius, Lithuania.⁹

The outcome of this work has shown that it is timely to develop and implement appropriate management responses to protect World Heritage in the face of climate change. The solutions to global warming are the subject of continuing debate. Some of these measures, beyond the scope of the *World Heritage Convention*, are discussed under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC). But although climate change is a global challenge, there are many adaptation and preventive measures that can be taken at the local scale, i.e. at the level of the World Heritage sites.

Studies are currently being conducted at several World Heritage sites to monitor climate change impacts and plan appropriate adaptation measures. But the World Heritage network is also a useful tool to share and promote lessons learnt and best practices, as well as to raise awareness regarding climate change impacts using their iconic value.

This publication presents several case studies of selected natural and cultural World Heritage sites in order to illustrate the impacts of climate change that have already been observed and those which can be anticipated in the future. For each of the featured sites, some adaptation measures are also reviewed. It is hoped that these examples would not only be of interest to World Heritage professionals and practitioners but also to the public at large.

8. Decision 29 COM 7B.a.Rev. Adopted at the 29th session of the World Heritage Committee held in Durban, South Africa, 2005, <http://whc.unesco.org/archive/2005/whc05-29com-22e.pdf>

9. Document WHC06-30COM7.1 and Decision 30COM7.1 Endorsed and Adopted at the 30th session of the World Heritage Committee, Vilnius, Lithuania, 2006, available at: <http://whc.unesco.org/archive/2006/whc06-30com-07.1e.pdf> and <http://whc.unesco.org/archive/2006/whc06-30com-19e.pdf>

Glaciers

Most mountain glaciers and small ice caps have been in general retreat since the end of the Little Ice Age, between 100 and 300 years ago.¹ But in the recent past, glaciers have begun melting at rates that cannot be explained by natural climate variability.² The global average temperature increase projected by the end of the century ranges from 1.4 °C to 5.8 °C.³ However, a 4 °C increase of atmospheric temperature would eliminate nearly all glaciers on earth.⁴

The melting of glaciers not only has obvious adverse consequences for the values of the sites on which they are located in the context of World Heritage, but it also impacts on surrounding ecosystems:

- Glacier melting leads to the formation of glacial lakes. The banks of such lakes are made of moraines (accumulated earth and stones deposited by the glacier) that may collapse when the lakes fill up – leading to sudden and violent

flooding in the downstream valleys. Any flood of this sort can have disastrous consequences for the population and biodiversity of the entire region downstream of the lakes.

- The annual melting of mountainous glaciers drives the hydrological cycles of the related watershed; but as the ice recedes, there will first be floods, and some time later, water supply will cease to be available, potentially leading to famine and disease.

1. *Climate Change, 2001, The Scientific Basis. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK, 1032 pp., http://www.grida.no/climate/ipcc_tar/. [Hereafter referred to as IPCC 2001, WG2]. Section 4.3.11.

2. M.B. Dyurgerov and M.F. Meier, 2000, *Twentieth Century Climate Change: Evidence from Small Glaciers*, Proceedings of the National Academy of Sciences, 97(4), pp.1406-1411.

3. IPCC 2001, WG1, op. cit., Summary for Policy-Makers.

4. J. Oerlemans, B. Anderson, A. Hubbard, Ph., Huybrechts, T. Jóhannesson, W.H. Knap, M. Schmeits, A.P. Stroeven, R.S.W. van de Wal, J. Wallinga, and Z. Zuo, 1998, *Modelling the Response of Glaciers to Climate Warming*, *Climate Dynamics*, 14, pp.267-274.

■ Besides these geological and hydrological impacts, mountainous ecosystems are also threatened with plant and animal species shifting ranges in order to adapt to the changing environment. Further details on this aspect are given in Chapter 3 (p. 40) on the impacts of climate change on terrestrial biodiversity.



Jungfrau-Aletsch-Bietschhorn
Switzerland

Sagarmatha National Park

Nepal

The Sagarmatha National Park was inscribed on the World Heritage List in July 1979 due to its superlative natural phenomena and areas of exceptional natural beauty and aesthetic importance. The 114,800 ha Park is buffered on its southern border by a 27,500 ha buffer zone created in 2002. The Park area is known by the local people as Khumbu. Khumbu is an exceptional high altitude landscape with dramatic scenery of high Himalayan mountain ranges dominated by Mount Everest (Jomo Langma-Sagarmatha), the world's highest mountain (8,848 m). Over 50% of the Park is constituted of high altitude landscape of snow, ice and rock. Besides alpine glaciers, the Park also includes alpine shrubs and deep river valleys covered with sub-alpine vegetation. Several rare species of wildlife such as the snow leopard, the musk deer and the red panda can be encountered in the Sagarmatha National Park.

The Park is also the home of the Sherpa People. The human settlements enclaves are legally considered as the buffer zone of the National Park. But in terms of management, these settlements are an integral part of the Park's overall landscape. There are nearly 6,000 resident people belonging to the Sherpa ethnic group. The presence of the Sherpa People, with their unique cultural traditions, adds further interest to this site.

The area began to attract international mountaineers and explorers after Mount Everest was successfully scaled by Sir Edmund P. Hillary and Sardar Tenzing Norgay Sherpa in 1953. The Park receives over 20,000 trekkers each year. The key attractions are the scenic beauty of the surrounding mountains, the local culture, and most importantly being close to Mount Everest. Tourism has contributed to improving the livelihoods of the local people. Yet, its impact on the local culture and environment continues to remain a management challenge.

The justifications for inclusion of the Sagarmatha National Park on the World Heritage List were geological, biological, aesthetic, and also humanity's interaction with its environment alongside the peculiar evolutionary relationship of the Sherpa People with their own natural environment.



The Pattar Glacier in the Sagarmatha National Park, Nepal. In the Himalayan and Tianshan Mountain Ranges, almost 67% of the glaciers have retreated in the past decade.

Impacts of climate change

Many of the features that constitute the outstanding universal values of the Sagarmatha National Park are the result of, or linked to, past climate variability. Up until the end of the Little Ice Age, snow accumulated in the Sagarmatha National Park, inciting the formation of glaciers. The action of these glaciers contributed to the geological features of the Park, since, as ancient rivers of compressed snow, they crept through and shaped the landscape.

It is now feared that the Himalayan glaciers are rapidly retreating because of climate change. Since the mid-1970s, the average air temperature rose by 1°C in the Himalayan region, i.e. almost twice as fast as the global average warming of 0.6 °C reported by the IPCC, this trend being most pronounced at high altitude sites.⁵ And almost 67% of the glaciers in the Himalayan and Tianshan mountain ranges have retreated in the past decade⁶ – by as much as 30 m per year for the Gangotri glacier.

The most visible impact of this trend is related to the aesthetic values of the mountains. Melting of the snow will turn the snow-covered mountains into bare, rocky mountains. The Himalayas will no longer be the 'abode of snow'. The dynamic glaciers will turn into lifeless rubble without their icy core. And in addition to the visual degradation for tourism and culture, the lack of snow will also have unfavourable consequences on the climbing experience.

The most devastating impact will concern the hydrological regime. Rapid melting of glaciers is already increasing the magnitude and frequency of catastrophic floods downstream. The continued melting will eventually affect the availability of life-giving water for drinking, food production, and ecosystem maintenance. Changes in the atmospheric temperature and in the rate of rainfall will affect the equilibrium between the amount of precipitation stored in winter and the melt away during summer. The melting season of snow coincides with the rainy season in the Himalayas. Consequently, any intensification of rainfall is likely to contribute to the rapid disappearance of snow and ice.⁷ It is therefore expected that the Himalayan region will gradually lose its ability to serve as water towers for billions of people living downstream of its lofty summits. And scarcity of water will not only impoverish lives but may breed conflicts at the local and regional scale.



The Phevi Valley, Nepalese scenery in the Sagarmatha National Park.

5. J. Thomas and S. Rai, 2005, *An Overview of Glaciers, Glacier Retreat, and Subsequent Impacts in Nepal, India and China*, WWF Nepal Program, Executive Summary, http://www.panda.org/downloads/climate_change/glacierssummary.pdf

6. IPCC, 2001, *WG2, op. cit.*, Section 11.2.1.2

7. IPCC, 2001, *WG2, op. cit.*, Section 11.2.3.1.

Glacial lake outburst floods

The melting of glaciers leads to the formation and rapid expansion of glacial lakes whose banks are made of loose glacial debris and unstable remnant ice. Glacial lakes are often located at the base of mountains with hanging ice. While the lake at the base continues to fill up, ice blocks from the mountain slope above detach (usually triggered off by earthquakes) and plunge into the lake, creating waves that break the loose moraine dam, causing a sudden discharge of large volumes of water. Floods of this kind are referred to as Glacial Lake Outburst Floods (GLOF) and have disastrous consequences for the population and for the biodiversity of the entire watershed. GLOFs are a natural phenomenon in the Khumbu region,⁸ but this threat is exacerbated in the context of climate change.

Within the span of two decades, three major GLOF events were experienced in the Khumbu. A damaging GLOF event in 1977 from the base of Mount Amadablam destroyed park facilities and a tourist lodge located along the riverbeds. A second GLOF in August 1985 from Digtso

Lake, completely destroyed the Namche Hydropower Station, trails, bridges, and washed away cultivated land, houses, livestock and killing at least 20 people along its 90 km downstream impact zone. The most recent GLOF in the eastern part of the Sagarmatha National Park occurred on 3 September 1998, in the Hinku Valley. Today, the Imja Lake in Sagarmatha National Park is identified as one of the largest and most threatening lakes needing urgent monitoring and risk assessment and preparedness.

In the eastern Himalayan region, in general, more than 15 major GLOF events have been recorded since 1995. Recently, the International Centre for Integrated Mountain Development (ICIMOD), with the support of the United Nations Environment Programme (UNEP), released the results of an inventory of glaciers, glacial lakes, and GLOF in Nepal and Bhutan. The study mentioned 3,252 glaciers and 2,323 glacial lakes in Nepal among which twenty were potentially dangerous.⁹

Water supply

Half of the freshwater used by humankind originates from mountain glaciers. If glacier melting continues at its current pace, the winter snowfall will not be sufficient to replenish the amount of snow and ice lost through melting, leading to a deficit in water storage in the form of snow and ice. This could cause many rivers to run dry, inducing shortages of water for drinking, agricultural irrigation, and affecting fisheries and wildlife. This is confirmed by numerical models which show that, in the context of climate change there will be an increase in river discharge in the short term causing widespread flooding.¹⁰ But in the medium term (a few decades), steady negative trends of water levels of glacial rivers will be observed.

The Himalayan region provides freshwater to one third of the world's population.¹¹ By supplying water to the Ganges, Indus, Brahmaputra, Salween, Mekong, Yangtze and Huang He rivers, glaciers in this area ensure a year-round water supply to 2 billion people. In the Ganges alone, the loss of glacier-melt water would reduce July-September flows drastically, impacting livelihoods of 500 million people and of 37% of India's irrigated land.^{12,13} In the northern Tianshan Mountains of Kazakhstan, more than 90% of the region's water supply is used for agriculture and up to 80% of river runoff is derived from glaciers and permafrost, which are melting at accelerated rates.

8. *Periodic Reporting of the Sagarmatha National Park to the World Heritage Committee, 2002*, <http://whc.unesco.org/en/list/120>

9. *Inventory of Glaciers, Glacier Lakes, Glacier Lake Outburst Floods Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region, Nepal and Bhutan, 2002*, International Centre for Integrated Mountain Development, UNEP, <http://www.ircap.unep.org/glofnepal/start.htm>

10. Thomas and Rai, 2005, *op. cit.*

11. *Going, Going, Gone! Climate Change and Global Glacier Decline*, WWF Report, 2003, <http://assets.panda.org/downloads/glacierspaper.pdf>

12. C.K. Jain, 2001, *A Hydro-Chemical Study of a Mountainous Watershed: the Ganges, India*, *Water Research*, 36(5), pp.1262-1274.

13. P.S. Singh, S.K. Jain, N. Kumar and U.K. Singh, 1994, *Snow and Glacier Contribution in the Ganges River at Deoprayag*, Technical Report, CS(AR)132, National Institute of Hydrology, Roorkee, India.

Biodiversity, geology, and cultural aspects

Climate change affects vegetation in a major way, for example with tree-line shifts towards higher elevation as a response to increased temperature. In that process, least-adapted vegetation and animal species may be squeezed out, and eventually disappear, because plants and animal populations respond to changing climates individualistically. Consequently, forest communities may not move upslope intact because some species will adapt and expand, while others will perish. These issues will be illustrated in detail in Chapter 3 (p. 40) on the impacts of climate change on terrestrial biodiversity.

Changes in disturbance regimes must also be taken into account. Assuming that the projected warming will be accompanied by sufficient moisture availability, the vegetative cover in the Sagarmatha National Park could increase, because currently the limiting factor for plant growth is the low temperature. But if the moisture does not increase, the warming trend may cause more forest fires. Also,

increased temperature will affect the incidence of invasive species, including pests and diseases.

Despite these changes in the environment, people will continue to reside in the Park and the interaction of the human race with nature will continue. The Little Ice Age cooling maintained humanity's well-being to a minimum. The warming may bring the reverse effect. Population growth, settlement expansion and encroachment are likely to become a major management challenge. And the integrity of the indigenous Sherpa People's culture will erode further under growing external influences.

Nevertheless, some of the outstanding universal values such as the wonderful geological formation of the Park – and status of Mount Everest as the highest mountain in the world – would not be affected, even if its scenic and cultural values would diminish due to lack of snow-covered protection.

Additional sources of stress

World Heritage sites, such as the Sagarmatha National Park, are fragile properties. Climate change is a serious external threat to the long-term conservation of their values. But this threat must be considered as one of many issues. The Park is also vulnerable to a series of locally triggered pressures, and requires active management solutions at the local level:

■ **Resource pressure:** The number of trekkers and mountaineers visiting the Park continues to remain high. And the population of Sagarmatha National Park is growing steadily. The movement of economic migrants into the Park has increased significantly, although the growth is somewhat offset by the out-migration of local residents.

■ **Development pressure:** As the Park continues to attract large numbers of trekkers and climbers the pressure in terms of development of tourism infrastructure is increasing.

Possible responses

Monitoring and early warning

In terms of possible responses, the solution to the problem of global warming lies beyond the boundary of the Sagarmatha National Park. The Park however provides an ideal laboratory for studying the impact of global warming and some research, information, and mitigation measures could be integrated into management plans and implemented to avoid further damage to ecosystems and people.

An effective monitoring and early warning system embedded in an appropriate risk preparedness strategy can greatly reduce the loss of lives and properties induced by GLOF events downstream of potentially dangerous glacial lakes.¹⁴

Appropriate measures include the use of remote-sensing tools such as the Land Observation Satellite (LANDSAT), over-flight

reconnaissance with small format cameras, telecommunication and radio broadcasting system integrated with on-site installed hydro-meteorological and geophysical instruments. In this regard, the methods of the World Glacier Monitoring Service¹⁵ provide state-of-the-art guidance for efficient monitoring of the state of conservation of glaciers.

Adaptation

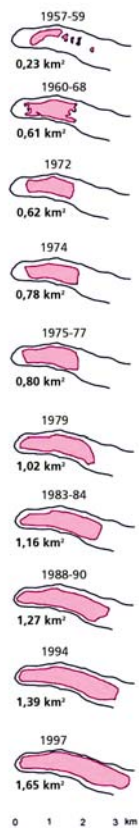
In many instances, immediate disaster may also be averted, by artificially draining potentially dangerous glacial lakes to avoid such outbursts of flooding. Such a measure is being implemented on the Tsho Rolpa Lake in the Rolwaling Valley in the western part of the Sagarmatha National Park. The possible strategies available to prevent a glacial lake outburst flood are: (i) controlled breaching; (ii) construction of an outlet control structure; (iii) pumping or siphoning out the water from the lake; (iv) tunnelling through the moraine wall to, or under, an ice dam to release water; (v) dam construction; and (vi) reducing the risk of avalanches into the lake.

The Tsho Rolpa GLOF management project was conducted between 1998 and 2002.¹⁶ The lake was storing approximately 90 to 100 million m³ held by a 150 m tall moraine.

A breach in this moraine would have caused at least a third of the lake to flood the valley. This threat led to a collaborative action by the Government of Nepal and the Netherlands Development Agency (NDA), jointly with the technical assistance of Reynolds Geo-Sciences Ltd., supported by the Department for International Development (DFID), United Kingdom. The project consisted in draining the lake and lowering its level by 3 m and installing early warning systems in villages downstream. The Project was completed in December 2002, leading to GLOF risk reduction by 20% but complete prevention of such an event would require further draining, perhaps as much as 17 m. The cost would, of course, be high but much less than the cost of damages caused to the infrastructures, biodiversity, and most importantly the loss of lives from an uncontrolled GLOF.



The Glacial Lake of Tsho Rolpa is expanding as a result of glacier melting and its fragile moraine banks threatened with collapse. The risk of Glacial Lake Outburst Flood (GLOF) was reduced by 20% by artificially lowering the water level by 3 m in 2002.



14. Inventory of Glaciers, Glacier Lakes, Glacier Lake Outburst Floods Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region, Nepal and Bhutan, 2002, International Centre for Integrated Mountain Development, UNEP, <http://www.rrcap.unep.org/glofnepal/start.htm>

15. <http://www.geo.unizh.ch/wgms/about.html>

16. S. Agrawala, V. Raksakulthai, M. van Aalst, P. Larsen, J. Smith and J. Reynolds, 2003, Development and Climate Change in Nepal: Focus on Water Resources and Hydropower, OECD, <http://www.oecd.org/dataoecd/6/51/19742202.pdf>

Huascarán National Park

Peru

Situated in the Cordillera Blanca, the world's highest tropical mountain range, Mount Huascarán rises to 6,768 m above sea level. The deep ravines watered by numerous torrents, the glacial lakes and the variety of the vegetation make the Huascarán National Park a site of spectacular beauty. It is also the home of rare species such as the spectacled bear and the Andean condor. The Huascarán National Park was inscribed on the World Heritage List in 1985 because of the significant on-going ecological and biological processes and its superlative natural phenomena and areas of exceptional natural beauty and aesthetic importance.

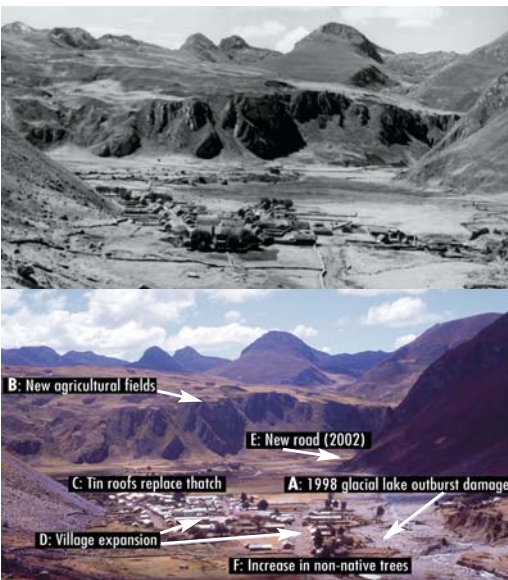
It is estimated that, in the Cordillera Blanca (white mountain range), about 22% of the mass volume of glaciers has disappeared since the late 1960s.¹⁷ And today, the livelihood of the two million people living within the immediate vicinity of the Huascarán National Park is threatened by high-altitude glacial lakes with the combination of climate change, local seismic activity and increased glacier and hill slope instability. Another very important climatic phenomenon that impacts on the Park is the variability of rain patterns during the El Niño events. Should this tendency continue, scientists predict that in less than 50 years there will no longer be any glacier mass in the Cordillera Blanca and that there will be a scarcity of water.

These climatic features are posing threats to local communities and their heritage:

- Two million people rely on water originating from the Huascarán National Park and the demand on water resources is increasing. The short-term risk of catastrophic floods, and the long-term decrease of the water supply, threaten these communities.

- As described in detail in Chapter 3 (p. 40), global warming is also affecting the terrestrial biodiversity. In the Huascarán National Park, this trend may impact the protected area as a whole, as well as traditional agricultural practices. Diseases of potatoes such as the fungus 'Rancha' (*phytophthora infestans*) used to be endemic to the lower parts of the Andes. Now, 'Rancha' has been reported at higher altitudes (3,700 to 4,000 m) in the Huascarán National Park.

- The melting of glaciers and the ablation of the ice mass also poses an important threat on cultural values in the Park and in its immediate vicinity. The vestiges of past cultures, such as the archaeological site of Willcahuain, are in the path of potential landslides induced by the instability of the soil and debris that becomes exposed once the ice melts. As described in Chapter 4 (p. 52) on Archaeological World Heritage, such an event occurred in 1945 at the World Heritage site of Chavín, located at the top of two river basins (Mosna and Huacheksa). Not to mention that similar events could completely wipe out the City of Huaraz and other towns in the region.



Repeat photographs illustrate the changes that are taking place in the region of the Huascarán National Park. The photograph of the Queropalca Village in the Huayhuash Cordillera (at the top) was taken in 1936, and other one (at the bottom) was taken in 2003 under similar circumstances*. Many differences between these two photographs can be related to climate change, such as the impact of a glacial lake outburst flood that partly destroyed the Village in 1998 (point A), or the increase of the altitude range of crops (point B).

* A.C. Byers, 2007, *Impacts of Climate Change in the Mountains*, in G. Braasch, (ed.), *Earth under Fire: How Global Warming Is Changing the World*, Berkeley, University of California Press, USA.

17. Byers, A.C., 2009, *A comparative study of tourism impacts on alpine ecosystems in the Sagarmatha (Mt. Everest) National Park, Nepal and the Huascarán National Park, Peru*. In: Hill, J. and Gale, T. (eds.), *Ecotourism and Environmental Sustainability*. London, Ashgate, in press.

1 Ilulissat Icefjord

Denmark

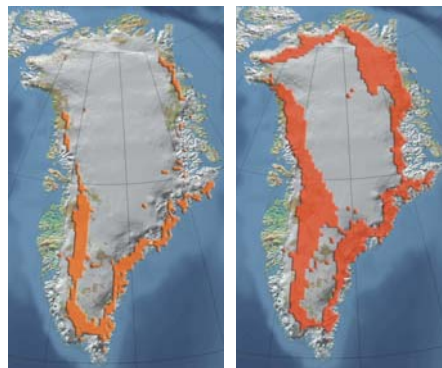
The Ilulissat Icefjord (Denmark) is one of the most active glaciers in the world. The Greenland ice sheet hosts the longest ice cores of the Northern Hemisphere that reveal past temperature and precipitation trends. But the glacier has receded during the twentieth century and climate change threatens the conservation of these scientific evidences.



Located on the west coast of Greenland, 250 km north of the Arctic Circle, the Ilulissat Icefjord (40,240 ha) is the sea mouth of Sermeq Kujalleq, one of the few glaciers through which the Greenland ice cap reaches the sea. Sermeq Kujalleq is one of the fastest flowing glaciers in the world (19 m per day). It is annually calving over 35 cubic km of ice, i.e. 10% of the production of the Greenland calf ice and more than any other glacier outside Antarctica. Studied for over 250 years, it has helped develop our understanding of ice cap glaciology and climate. The combination of a huge ice sheet and the dramatic sounds of a fast-moving glacial ice stream calving into a fjord covered by icebergs constitute a dramatic and awe-inspiring natural phenomenon.

The Ilulissat Icefjord was nominated under natural criteria in 2004. It is an outstanding example of a stage in the Earth's history: the last ice age of the Quaternary Period and the wild and highly scenic combination of rock, ice and sea, along with the dramatic sounds produced by the moving ice, combine to present a memorable natural spectacle. However, the outstanding universal values of this site will be affected by climate change, especially because the current rate of increasing atmospheric temperature is most pronounced in Polar Regions. According to the recent Arctic Climate Impact Assessment (ACIA), the local warming above Greenland could be one to three times as large as the average rate of global warming.¹⁸

The Ilulissat Icefjord plays a central role in the study of glaciology and climate variability. The first descriptions of the huge inland ice field were published by H. Rink in the second part of the nineteenth century. He provided the basis



The extent of melting of the Greenland ice sheet is rapidly increasing (left: in 1992 and right: 2002) as noted by the Arctic Climate Impact Assessment (ACIA).

for theories on the past ice ages when ice sheets covered large areas of the world. Today, the remnants of the ice age (ice sheets in Greenland and Antarctica) are essential for investigations of past climate. Of particular importance is the information retrieved from the 3 km long ice cores which reveal past temperatures and precipitations trends in

Greenland almost 250,000 years back in time. No other glacier or ice cap in the Northern Hemisphere provides such a long and continuous record of past climate.¹⁹ And the current impacts of climate change on this World Heritage site are threatening the conservation of this unique record.

The case of Ilulissat Icefjord illustrates well the increasing concern about climate change issues in the context of the World Heritage Convention. This site was nominated very recently, and potential climate change impacts on this property were already mentioned in the Nomination Dossier and the International Union for the Conservation of Nature (IUCN) evaluation report, in which the Advisory Body recognized that a glacial recession has occurred during the twentieth century. In 1851, the ice front across the fjord was 25 km east of the sea. By 1950 it had retreated some more 26 km eastward.²⁰ And in the future, climate change will further affect the rate of the glacial flow and the position of the Sermeq Kujalleq ice front.

18. ACIA, 2004, *Impact of a Warming Arctic: Arctic Climate Impact Assessment*. Cambridge University Press, 2004, <http://www.acia.uaf.edu>

19. N. Mikkelson, and T. Ingerslev, (eds.), 2002, *Nomination of the Ilulissat Icefjord for Inclusion in the World Heritage List*, Geological Survey of Denmark and Greenland (GEUS).

20. IUCN Evaluation Report of the Site, 2003, http://whc.unesco.org/archive/advisory_body_evaluation/1149.pdf

Kilimanjaro National Park

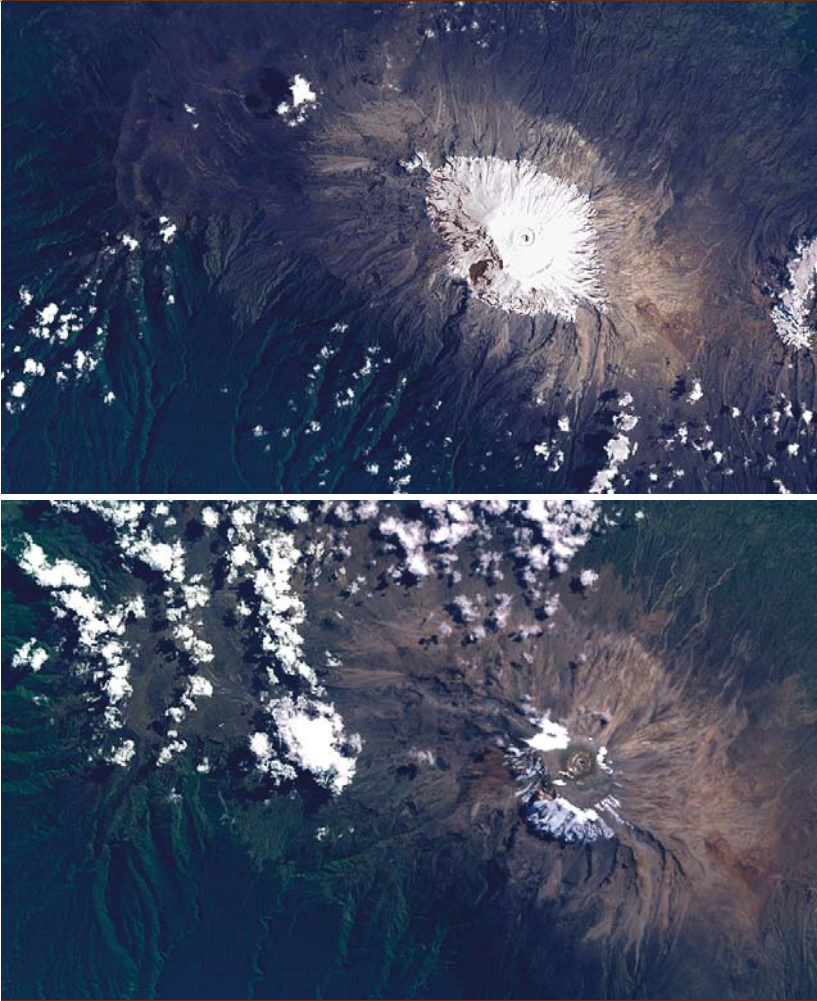
United Republic of Tanzania

25

At 5,895 m, Mount Kilimanjaro is the highest mountain in Africa. This volcanic massif stands in splendid isolation above the surrounding plains with its snowy peak looming over the savannah. The mountain is encircled by mountain forest. Numerous mammals, many of which are endangered species, live in the Park. The Kilimanjaro National Park was inscribed on the World Heritage List in 1987 because of its outstanding natural beauty.

The glaciers on Mount Kilimanjaro have been persisting for over at least 10,000 years. But as a result of the combined effect of global climate change and modification of local practices (including changes of land use), they lost 80% of their area during the twentieth century.²¹ At the Kibo cone of Kilimanjaro, the total ice cover diminished from 12,058 m², 6,675 m², and 4,171 m² to 3,305 m² between the years 1912, 1953, 1976, and 1989²² respectively. If the current trends are not inflected, losing more than half a meter in thickness each year will likely lead to the complete disappearance of the Kilimanjaro ice fields in less than 15 years.²³

In the same geographic region, the glaciers on Mount Kenya (Kenya) and in the Rwenzori Mountains (Uganda), both World Heritage sites, are also projected to disappear completely in 20 years time.²⁴



Snow and ice on Mount Kilimanjaro in 1993, and in 2002. The ice cap on the summit of Mount Kilimanjaro has dwindled down by 82% over the past century.

21. G. Kaser, D.R. Hardy, T. Mölg, R.S. Bradley, and T.M. Hyera, 2004, *Modern Glacier Retreat on Kilimanjaro as Evidence of Climate Change: Observations and Facts*, *International Journal of Climatology*, 24, pp. 329-339.

22. S. Hastenrath, and L. Greischar, 1997, *Glacier Recession on Kilimanjaro, East Africa, 1912-89*, *Journal of Glaciology*, 43(145), pp. 455-459.

23. L.G. Thompson, E. Mosley Thompson, M.E. Davis, K.A. Henderson, H.H. Brecher, V.S. Zagorodnov, T.A. Mashiotta, P.N. Lin, V.N. Mikhailenko, D.R. Hardy, and J. Beer, 2002, *Kilimanjaro Ice Core Records: Evidence of Holocene Climate Change in Tropical Africa*, *Science*, 298, pp. 589-593.

24. R.G. Taylor, L. Mileham, C. Tindimugaya, A. Majugu, A. Muwanga and B. Nakileza, 2006, *Recent Glacial Recession in the Rwenzori Mountains of East Africa Due to Rising Air Temperature*, *Geophysical Research Letters*, 33, L10402, doi:10.1029/2006GL025962.

1 Jungfrau-Aletsch-Bietschhorn

Switzerland

26

The Jungfrau-Aletsch-Bietschhorn area is the most glaciated part of the Alps, containing Europe's largest glacier and a range of classic glacial features such as U-shaped valleys, cirques, horn peaks and moraines. It provides an outstanding geological record of the uplift and compression that formed the High Alps. The area is home to a range of Alpine and sub-Alpine habitats and species. Plant colonization in the wake of retreating glaciers provides an outstanding example of plant succession. The impressive vista of the North Wall of the High Alps, centred on the Eiger, Mönch and Jungfrau peaks, has played an important role in European art and literature.

Glaciers in eight out of the nine European glacier regions are in retreat. Between 1850 and 1980, glaciers in the European Alps lost approximately one third of their area and one half of their mass, and since 1980 another 20 to 30% of the ice has melted. Also, during the heat wave of 2003, about 10% of European glacier mass melted. If this trend continues – which is very likely – by 2050, 75% of the glaciers in the Swiss Alps are likely to have disappeared.²⁵

More specifically, the Aletsch glacier has retreated 3.4 km since it reached its maximum length (23 km) at the end of the Little Ice Age (nineteenth century). About 1.4 km of this retreat has occurred over the past 56 years.²⁶ By 2050, it is highly probable that the Aletsch glacier may have shrunk to its smallest size since the late Bronze Age. Indeed, regional climate models show that, for a scenario of doubled atmospheric CO₂ concentrations, the Alps



are likely to experience, in the future, slightly milder winters with more precipitation; but summers much warmer and drier than today. These changes will have important impacts on Alpine glaciers.²⁷

Since the mid-nineteenth century, the Aletsch Glacier has retreated 3.4 km. In 1979, the end of the Aletsch glacier reached far down the slope of the mountain. By 1991 and 2002, a considerable retreat is visible and new vegetation is covering the slopes.

25. European Environment Agency, 2004, *Impacts of Europe's Changing Climate: An Indicator-Based Assessment*, at http://reports.eea.europa.eu/climate_report_2_2004/en/tab_content_RLR

26. H. Holzhauser, M. Magny, H.J. Zumbühl, 2005, *Glacier and Lake-Level Variations in West-Central Europe Over the Last 3,500 years*, *The Holocene*, 15(6), pp. 879-891.

27. IPCC, 2001, *WG2, op. cit., Section 13.2.1.4.*



The Eggishorn in the Jungfrau Region (Switzerland). Between 1850 and 1980, glaciers in the Alps lost about one half of their masses.

Glacier melting in the Alps will affect important European rivers such as the Rhine, the Rhone or the Danube and thus pose a threat to Europe's freshwater supply. In the years to come, discharge from glacier melting will increase – possibly causing more frequent floods. But in the long term, with a widespread retreat of Alpine glaciers, some regions in Europe may face a significant decrease in freshwater supply.

The tourism industry in the Alps is also concerned by the consequences of climate change, although this threat does not have direct influence on the Jungfrau-Aletsch-Bietschhorn World Heritage site. Nominal winter sports activities are said to be 'secured' if an area is guaranteed 100 uninterrupted days of satisfactory snow fall. Today about 85% of ski resorts in Switzerland present a sufficient snow cover. But a 300 m rise of the snow line would reduce this ratio to 63%.²⁸ In Switzerland about 100,000 jobs rely on tourism, but many of these face an uncertain future in the context of climate change.

Adaptation measures to limit glacier melting have been explored in Switzerland. For instance, the Tortin ice field has been covered with a protective 2,500 m² light-blue insulated sheet to reduce glacier melting in summer. This kind of measure can help in stabilizing the glacier in the short term, but this option is not relevant for the Jungfrau-Aletsch-Bietschhorn World Heritage site and it cannot ensure an appropriate conservation in the long term to guarantee that glaciers will be saved for future generations.

28. H. Elsasser, P. Messerli, 2001, *The Vulnerability of the Snow Industry in the Swiss Alps*, Mountain Research and Development, 21(4), pp. 335-339.

2

World Heritage

Marine Biodiversity

Any change in climate affects the physical, biological, and biogeochemical characteristics of the oceans on different spatial and temporal scales. Such changes have crucial consequences for the conservation of marine ecosystems, and thus for their role as suppliers of goods and services, including for fisheries on which billions of people rely for their subsistence.

28

But the oceans are also an integral and responsive component of the climate system and they feedback on the climate itself. The IPCC emphasizes that global warming will affect the oceans through changes in sea-surface temperature, sea level, sea-ice cover, salinity, alkalinity, ocean circulation, and large-scale climate oscillations.¹ The role of oceans as climate regulators, especially through the circulation of water redistributing heat and salinity through the global conveyor belt (or thermohaline circulation system) could thus be dramatically modified. But these changes would also have adverse consequences for biogeochemical cycles as well as for the sequestration of greenhouse gases such as carbon dioxide.

The main features of observed and projected changes are:²

- An increase of the global ocean heat content since the late 1950s.
- A global average sea-level rise between 0.1 m and 0.2 m during the twentieth century due to the thermal expansion of ocean waters and the loss of mass from glaciers and ice caps. This rise is projected to reach 0.09 m to 0.88 m between 1990 and 2100.
- A decrease of the extent of sea ice in the Northern Hemisphere of more than 10% since the 1950s in spring and summer, and a likely decrease of 40% in recent decades of sea-ice thickness in late summer to early autumn.
- An increase in the frequency, persistence and intensity of warm episodes of

the El Niño-Southern Oscillation (ENSO) events since the mid-1970s, compared with the previous 100 years. Current projections show a small increase in amplitude of ENSO over the next 100 years.

- A weakening of the thermohaline circulation system.

Coastal ecosystems are sensitive to these physical and chemical changes, especially in relation to:³

- The increased level of flooding, loss of wetlands and mangroves, and sea-water intrusion into freshwater sources.
- The increase in extent and severity of storm impacts such as shore erosion because of sea-level rise, especially in high latitude areas where the

1. IPCC, 2001, WG2, op. cit., Technical Summary.

2. IPCC, 2001, WG1, op. cit., Summary for Policy-Makers.

3. IPCC, 2001, WG2, op. cit., Summary for Policy-Makers.

protective role of permafrost and sea-ice decreases.

Marine ecosystems will be affected by changes in sea water temperature, global oceanic circulation patterns and salinity, with a wide range of effects such as changes in migratory patterns, shifts in community composition, and changes in ecosystem functioning. The resilience of these ecosystems will depend upon the rate and magnitude of climate change. Their adaptive capacity

(such as space for, and obstacles to, migration) plays also an important role.

In addition, the increased amounts of atmospheric CO₂ absorbed by the oceans are beginning to change the delicate equilibrium of the acidity of ocean waters. Increasing carbonate under-saturation and acidity in the oceans are predicted to have widespread effects on marine animals with calcareous shells or structures, such as zooplanktons and a large number of

seabed groups (e.g. corals, molluscs), by impairing their growth and dissolving their skeletons. It is predicted that these effects, combined with the rise of sea water temperatures, will disrupt the marine food webs with devastating effects on open water and seabed communities throughout the oceans, from the deep seas to shallow waters. The predicted changes in ocean chemistry are expected to affect around 70% of the world's deep sea corals by 2100.⁴



Great Barrier Reef
Australia

4. UNEP, IUCN, 2006, *Ecosystems and Biodiversity in Deep Waters and High Seas*, UNEP Regional Seas Reports and Studies, No. 178, http://www.iucn.org/en/news/archive/2006/06/16_unep_high_seas_lr.pdf

Great Barrier Reef

Australia

2

The Great Barrier Reef is a marine site of remarkable beauty off the north-eastern coast of Australia. It is the largest coral reef ecosystem in the world, 2,100 km in length, and covering an area of 344,400 km². The Great Barrier Reef Lagoon contains 2,900 individual reefs with 400 species of corals, 1,500 species of fish and several thousands species of molluscs. It also holds great scientific interest as the habitat of species such as the dugong ('sea cow') and the green and loggerhead turtles, which are threatened with extinction. For these reasons it was listed in 1981 under all four natural World Heritage criteria.

Impacts of climate change

The ecology of this World Heritage site is sensitive to any change in the following climate parameters: sea-level rise, sea temperature increase, storm frequency and intensity, precipitation patterns, drought, land run-off, oceanic circulation, and ocean acidity. One of the most dramatic and serious effects of observed and projected climate change is the physiological consequences of coral bleaching, which has already caused long-term damage to many coral reefs worldwide.

Coral bleaching

Many corals live close to their upper temperature tolerance levels, and increasing sea surface temperature is a serious threat for coral reef ecosystems. Although its rate of increase is less than atmospheric temperatures, the global average heat content of the oceans is increasing.⁵ The observed increase in the frequency, persistence, and intensity of warm episodes of the El Niño Southern Oscillation (ENSO) poses an additional threat to affected regions. In addition, the oceans constitute an important sink of atmospheric carbon dioxide. Increasing dissolution of carbon dioxide levels acidifies the water, leading to a decrease of carbonate ions (CO₃²⁻) and thus a decrease of CaCO₃ saturation state, causing the corals to either grow more slowly or have weaker



5. IPCC, 2001, WG1, op. cit., Summary for Policy-Makers.



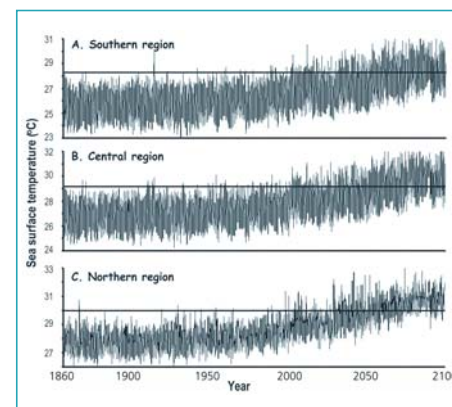
The Great Barrier Reef is the largest coral reef ecosystem in the world.

skeleton frames. According to the IPCC, the increase of sea surface temperature and dissolved CO₂ levels in the oceans will represent the most serious threats to coral reefs in the twenty-first century.⁶

In response to abrupt changes in temperature, light, salinity or turbidity, corals tend to bleach, i.e. turn pale in colour, because of the loss of symbiotic algae, which are essential to the corals as nutrient providers. Coral bleaching may occur at a local scale (a few 100 m) but mass bleaching events have begun to affect thousands of km² of reefs. Such large-scale events were unknown in scientific literature prior to 1979.⁷ Mass bleaching events occur when sea surface temperature exceeds seasonal maximums by 1.5 °C to 2 °C. Mortality becomes extensive if temperature anomalies reach more than 3 °C over several months.⁸ After a moderate event, when environmental conditions return to normal, corals can survive and the impacts of bleaching events are often temporary. However, decreased growth and reproductive capacity often occur in corals that survive bleaching consequences.⁹

Sea surface temperature in the Great Barrier Reef Lagoon measured during the past century shows a positive upward trend of approximately 1 °C,

which is similar to the trends reported at other tropical locations. The rate of warming has increased over the past 30 years. The year 1998 was the warmest in ninety-five years of instrumental data and the current rate of warming is now considered to be well over a degree per



Sea surface temperature trends in the Great Barrier Reef region generated by the global coupled atmosphere-ocean-ice model (ECHAM4/OPYC3) forced by greenhouse warming that conforms to the IPCC scenario IS92a. Horizontal lines indicate the thermal thresholds of corals at each site. (Hoegh-Guldberg, 1999)*

* O. Hoegh-Guldberg, 1999, *Climate change, Coral Bleaching and the Future of the World's Coral Reefs*, Marine and Freshwater Research, 50, pp.839-866.



Bleached coral at Keppel Island in January 2006. Bleached coral is white due to the loss of the symbionts that normally populate its tissues.

6. IPCC, 2001, WG2, op. cit., Section 6.4.5.

7. O. Hoegh-Guldberg, 2003, *Coral Reefs, Thermal Limits and Climate Change*, in M. Howden, L. Hughes, M. Dunlop, I. Zethoven, D. Hilbert and C. Chilcott, *Climate Change Impacts On Biodiversity, in Australia, Outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1-2 October 2002, Canberra, Commonwealth of Australia*.

8. IPCC, 2001, WG2, op. cit., Section 6.4.5.

9. A.H. Baird and P. Marshall, 2002, *Mortality, Growth and Reproduction in Scleractinian Corals Following Bleaching on the Great Barrier Reef*, Mar. Ecol. Prog. Ser., 237, pp.133-141.

century.¹⁰ The consequence of this environmental change is a drastic shrinkage of appropriate habitats for coral reefs in the region.¹¹

In addition, sea surface temperature oscillations associated with the ENSO compound impacts on this positive temperature trend. The ENSO is part of natural climate variability, but according to the IPCC, the frequency, persistence, and intensity of warm episodes of this oscillation is increasing.¹²

In 1998, the regional summer warming induced by the El Niño event combined with the global warming trend caused the sea surface temperature to exceed bleaching thresholds.¹³ About 65% of inshore reefs suffered high levels (above 10%) of coral bleaching, whereas extreme levels (above 70%) were reported in 25% of inshore reefs; about 14% of offshore reefs were also affected by severe bleaching. Fortunately, most corals in the Great Barrier Reef survived this bleaching event. In some places, however, over 50% of corals died.¹⁴ Increased sea surface temperatures associated with positive phases of ENSO are far from being limited to the Great Barrier Reef, and it is estimated that 16% of the world's coral reefs died in 1998. In some areas, such as the Western Indian Ocean, more than 50% of corals have died.¹⁵

The estimated time-scale for recovery of a coral reef following a severe bleaching-induced mortality event ranges from 10 to 30 years. Therefore, the return interval and intensity of such events is a crucial issue.

In that context, it must be noted that the 1998 bleaching event was followed, as soon as in 2002, by the largest bleaching occurrence on record for the Great Barrier Reef.¹⁶ Two periods of several weeks of hot weather resulted in seawater temperatures several degrees centigrade higher than long-term seasonal averages. And aerial surveys conducted in March and April 2002 revealed that 60% of reefs surveyed were bleached.



Great Barrier Reef.

According to model projections, warming in the Great Barrier Reef Region would be in the range of 2 °C to 5 °C by 2100. The most likely outlook is that mass bleaching events, leading to widespread death of corals, will become more frequent on the Australian coast in the coming decades.¹⁷ Current projections show that the frequency of bleaching events is increasing at a rate of about 1.6% more each decade. Consequently, coral reefs will face temperatures above the bleaching threshold, on an annual basis, before the end of the twenty-first century – even under the most optimistic scenarios.¹⁸

Adaptation and acclimation are the two broad ways for marine biota to respond to temperature change. Marine species shall acclimate by changing their physiology to become more tolerant to higher temperatures. Adaptation corresponds to a selection of more robust species, while others do neither survive nor breed. The occurrence of adaptation or acclimation depends strongly on the timescale of the predicted changes. The time required for acclimation is of the order of days but adaptation is much slower.

10. J.M. Lough, 1999, *Sea Surface Temperatures on the Great Barrier Reef: A Contribution to the Study of Coral Bleaching, Final Report*, Great Barrier Reef Marine Park Authority.

11. J.M. Guinotte, R.W. Buddemeier, J.A. Kleypas, 2003, *Future Coral Reef Habitat Marginality: Temporal and Spatial Effects of Climate Change in the Pacific Basin*, *Coral Reefs*, 22, pp.551-558.

12. IPCC, 2001, WG1, *op. cit.*, Summary for Policy-Makers.

13. IPCC, 2001, WG2, *op. cit.*, Section 12.4.7.

14. O. Hoegh-Guldberg, 1999, *op. cit.*

15. C. Wilkinson, (ed.), *Status of Coral Reefs of the World 2004*, Australian Institute of Marine Science, Australia.

16. *The State of the Great Barrier Reef On-line*, Great Barrier Reef Marine Park Authority, http://www.gbrmpa.gov.au/corp_site/info_services/publications/sot

17. IPCC, 2001, WG2, *op. cit.*, Section 12.4.7.

18. O. Hoegh-Guldberg, 1999, *op. cit.*

Consequences on marine biodiversity

As far as the Great Barrier Reef is concerned, the temperature tolerance of coral reefs is geographically variable.¹⁹ The apparent threshold for coral bleaching is higher in the northern part of the Reef. This latitudinal variability suggests that some very long-term adaptation through the selection of more heat-tolerant hosts and symbiotic species has occurred following previous bleaching events.²⁰

Coral reefs have a crucial role in shaping ecosystems. They are the primary habitat for hundreds of thousands of species of fish and other organisms and the source of primary production in otherwise typically nutrient-poor tropical oceans. Sometimes, levels of productivity are as much as many thousand times more important within the reefs than in the nearby open sea.²² This high level of productivity makes coral reefs a major element of the food web in tropical areas.

Prediction of the consequences of coral bleaching for coral reef ecosystems is a complex topic with possible positive or negative consequences on the marine biodiversity. For the majority of reef organisms that are not directly linked to coral colonies, the result of coral bleaching is very difficult to predict. Overall, more frequent coral bleaching events will lead to less attractive reefs. But the diversity of some marine groups and the abundance of invertebrates could increase in the short term, as new habitats become available.²³ After the major bleaching occurrence of 1998 that killed 88% of corals on Tanzanian reefs plots, fish diversity appeared to be unchanged and fish abundance rose by 39%, because of an increase in herbivores responding to a greater availability of macro-algae.²⁴ Nevertheless such observations are very limited in space and valid

However, the timescale of such evolution of corals is far from being compatible with the timescale of the current rate of increase of the sea surface temperature, and field measurements show that coral colonies are just as close to their thermal limits as they were at the beginning of the 1980s. This suggests that neither acclimation nor adaptation has occurred to any extent in the recent past.²¹

only in the short term for the time being. In the long term, coral bleaching would reduce rates of coral reproduction, recruitment, and calcification, resulting in an overall degradation of reef habitat. The effects of reducing the productivity of reef ecosystems are thus expected to be substantial. In many other examples, fish species are found to be coral obligates (feed and breed only around coral) and disappear quickly after the coral is lost.²⁵ Consequently, fishing yields will be reduced, with dramatic consequences for a region's biodiversity and dependant local population.²⁶

Reef-building corals provide most of the primary productivity of coral reefs and an important shelter for the coral reef organisms. Reduction of abundance and diversity of reef-building corals is thus very likely to have a major influence on the surrounding biodiversity. Tropical fishery yields are on the decline worldwide and it is now clear that the conditions may become critical for the local, often poor, populations. Very few studies were conducted on the topic of the long-term consequences of coral bleaching on coral reef organisms. Nonetheless, a correlation has been established between ENSO variability and negative conditions for seabirds, turtle and marine mammals.²⁷

19. O. Hoegh-Guldberg, 1999, *op. cit.*

20. IPCC, 2001, WG2, *op. cit.*, Section 12.4.7.

21. O. Hoegh-Guldberg, 1999, *op. cit.*

22. *Ibid.*

23. S.L. Coles, 2001, *Coral Bleaching: What Do We Know And What Can We Do?* in R.V. Salm, and S.L. Coles, (eds.), 2001, *Coral Bleaching and Marine Protected Areas, Proceedings of the Workshop on Mitigating Coral Bleaching Impact Through Marine Protected Areas Design*, Bishop Museum, Honolulu, Hawaii, 29-31 May 2001, *Asia Pacific Coastal Marine Program Report # 0102*, The Nature Conservancy, Honolulu, Hawaii, USA. 118 pp. <http://conserveonline.org/docs/2001/10/CoralBleachingMPAsWorkshop.pdf>

24. U. Lindahl, M.C. Ohman, and C.K. Schelten, 2001, *The 1997/1998 Mass Mortality of Corals: Effects on Fish Communities on a Tanzanian Coral Reef*, *Marine Pollution Bulletin*, 422, pp. 127-131.

25. O. Hoegh-Guldberg, 2004, *Marine Ecosystems and Climate Change*, Chapter 20, in T. Lovejoy and L. Hannah (eds), *Climate Change and Biodiversity*, Yale University Press, USA, 34 pp.

26. IPCC, 2001, WG2, *op. cit.*, Section 6.4.5.

27. Hoegh-Guldberg, 1999, *op. cit.*

Consequences on tourism

2

34

Coral bleaching also has implications for the tourist industry in the Great Barrier Reef Marine Park.²⁸ The marine tourist industry is a major contributor to the Australian economy. Tourism is the largest commercial activity in the Great Barrier Reef region, attracting approximately 1.8 million visitors per year and generating over AU\$5.1 billion. In 2005 there were approximately 820 authorized tourist operators and 1,500 vessels and aircrafts permitted to operate in the Park.

Many tourists visit the reefs that are closest to the coast and can be reached by boat within a couple of hours. These inshore reefs are located in relatively shallow water, thus potentially more exposed to the impacts of climate

change.²⁹ In addition they are more exposed to pollutants entering the reef via river discharges into near shore areas. In the context of climate change, flood events are expected to become less frequent but more intense,³⁰ increasing the sediment and nutrient loads, as well as increasing the distance that flood waters extend into the reef tract.³¹

Climate change in the Great Barrier Reef would thus have direct consequences for the local economy. But this threat is also valid for other reefs around the globe, and it has been estimated that the cost would reach as much as US\$90 billion in tourism alone³² for loss of 58% of the world's coral reef.

Additional sources of stress

At the global scale, as much as 58% of coral reefs are considered at risk from episodic natural events (storms or cyclones) and from human activities such as industrial development and pollution, tourism and urbanization, agricultural runoff, sewage pollution, increased sedimentation, excessive fishing, coral mining, land reclamation, predation and disease.³³

In the Great Barrier Reef, several sources of stress threaten the conservation of coral reefs, in addition to climate change. Anthropogenic eutrophication with run-off from the land containing suspended solids, herbicides, pesticides, nutrients, etc. can have an effect on the reef.³⁴ Studies in the Great Barrier Reef indicate that significant increases in phytoplankton concentrations have occurred over the last 65 years.

Increasing use of the Reef may also be considered as a stress with the accompanying discharge of vessel waste, physical damage

to reefs from anchors, people snorkelling, diving and reef walking, disturbance of island fauna (especially seabirds), excessive fishing and/or collecting. This threat is now spreading across the whole Great Barrier Reef World Heritage Area with the operation of speedboats allowing access to almost 80% of the park on day-trips.³⁵ However, tourism is particularly well-controlled through a 'permitting system'. Thus, while particular sites are at risk, tourism and recreational activities are not a significant source of damage to the Great Barrier Reef on an ecological scale.

28. H. Hoegh-Guldberg and O. Hoegh-Guldberg, 2004, *Biological, Economic and Social Impacts of Climate Change on the Great Barrier Reef*, World Wide Fund for Nature, 318 pp.
29. S. Crimp, J. Balston, A. Ash, L. Anderson-Berry, T. Done, R. Greiner, D. Hilbert, M. Howden, R. Jones, C. Stokes, N. Stoeckl, B. Sutherst and P. Whetton, 2004, *Climate Change in the Cairns and Great Barrier Reef Region: Scope and Focus for an Integrated Assessment*, Australian Greenhouse Office. <http://www.greenhouse.gov.au/impacts/publications/pubs/gbr.pdf>
30. CSIRO, 2001: *Climate Change Projections for Australia*, CSIRO Atmospheric Research, 8 pp.
31. B. King, M. Zapata, F. McAllister, and T. Done, 2002, *Modelling the Distribution of River Plumes on the Central and Northern Great Barrier Reef Shelf*, Interactive CD and Technical Report No.44 to the Cooperative Research Centre for the Great Barrier Reef World Heritage Area from Asia-Pacific Applied Science Associates and the Australian Institute of Marine Science, <http://www.reef.crc.org.au/discover/threats/king10rivers/index.html>
32. D. Bryant, L. Burke, J. McManus, and M. Spalding, 1998, *Reefs at Risk: a Map-Based Indicator of Threats to the World's Coral Reefs*. World Resources Institute, Washington, D.C.
33. IPCC, 2001, WG2, op. cit., Section 6.4.5.
34. P.R.F Bell, and I. Elmetri, 1995, *Ecological Indicators of Large-Scale Eutrophication in the Great Barrier Reef Lagoon*, *Ambio*, XXIV (4), 208-15.
35. S. Hillman, 1996, *The State of the Great Barrier Reef World Heritage Area*, Report, Reef Research, 6(1).

Possible responses

There are many actions that can be taken to help coral reefs cope with climate change.³⁶ A Climate Change Response Programme (2004-2008) has been developed to better understand and respond to the threats of climate change to the Great Barrier Reef. Key outputs of this programme, which is jointly funded by the Great Barrier Reef Marine Park Authority and the Australian Greenhouse Office, include a Coral Bleaching Response Plan and a Climate Change Action Plan.

The Coral Bleaching Response Plan aims at detecting and measuring bleaching and other short- and long-term impacts (through satellite imagery, underwater surveys and monitoring) and has received worldwide recognition (it has been adapted for the Florida Keys and Indonesia, for example). The Climate Change Action Plan aims at sustaining ecosystems, industries, and communities by identifying and implementing relevant management actions, adapting policy and fostering collaborations. A Great Barrier Reef Climate Change Vulnerability Assessment is also being conducted, which will provide a comprehensive analysis of the observed and projected impacts of climate change on all parts of the Great Barrier Reef's social and ecological system.

The resilience of coral reefs to climate change can be greatly improved by reducing the effects of other stresses on the ecosystem. Corals weakened by other stresses (such as water quality, abundance of herbivores and connectivity to sources of coral larvae) may be more susceptible to bleaching, less likely to survive and slower to recover. Initiatives such as the Reef Water Quality Protection Plan, various fisheries management plans, and the Representative Areas Programme were developed in order to maximize the resilience of the Great Barrier Reef to future pressures, such as climate change.³⁷ In 2004 the Great Barrier Reef

Marine Park Authority increased the percentage of no-take areas from 5% to 33% to improve the resilience of the Great Barrier Reef Marine Park by protecting regions of unique biodiversity, including areas crucial to fish and other organisms. The Australian Government is working closely with the Queensland Government on the Reef Water Quality Protection Plan, which aims to halt and reverse the decline in water quality entering the Marine Park by 2013. The Great Barrier Reef Marine Park Authority is also working with fisheries managers to ensure the ecologically sustainable use of resources within the Great Barrier Reef Marine Park.

These management actions being implemented are recognized as the world's best practice and the site has experienced relatively low bleaching impacts to date, though further events will be inevitable. The main challenge is to increase the resilience of the Great Barrier Reef system, incorporating key species, habitats and processes, as well as the industries and regional communities that depend upon the Reef. This will require continuation and enhancement of current management efforts, cooperation between government agencies and active partnerships with stakeholders and individual community members.³⁸

36. P.A. Marshall, and H.Z. Schuttenberg, 2006, *A Reef Manager's Guide to Coral Bleaching*, Great Barrier Reef Marine Park Authority, Townsville, Australia.

37. Natural Resource Management Ministerial Council, 2004, *National Biodiversity and Climate Change Action Plan 2004-2007*, Australian Government, Department of the Environment and Heritage, Canberra, Australia, <http://www.deh.gov.au/biodiversity/publications/nbccap/index.html>.

38. Marshall, P., and H.Z. Schuttenberg, 2006, *Adapting Coral Reef Management in the Face of Climate Change*. In: J.T. Phinney, A. Strong, W. Skyring, J. Kleypas, O. Hoegh-Guldberg (Eds.), *Coral Reefs and Climate Change: Science and Management* (pp. 244). American Geophysical Union Coastal and Estuarine Series, Volume 61.

Sundarbans

India, Bangladesh

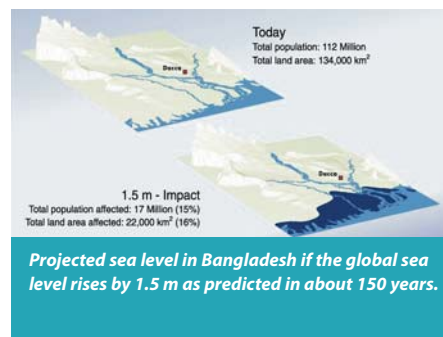


The Sundarbans mangrove forests, the largest of such forests in the world (over 10,000 km² of land and water, more than half situated in India, the rest in Bangladesh), lie within the delta of the Ganges, Brahmaputra and Meghna rivers on the Bay of Bengal. The site is intersected by a complex network of tidal waterways, mudflats, and small islands of mangrove forests.

Mangroves are made up of salt-adapted evergreen trees. They are restricted to the inter-tidal zone along the vast coastlines of tropical countries and extend landward along tidal rivers. Mangroves act as natural buffers against tropical cyclones and also as filtration systems for estuarine and fresh water. They also serve as nurseries for many marine invertebrate species and fish.

The Sundarbans mangrove forests are well-known for their biodiversity, including 260 bird species, Indian otters, spotted deer, wild boar, fiddler crabs, mud crabs, three marine lizard species, and five marine turtle species. But they also host threatened species such as the estuarine crocodile, Indian python and the most iconic Bengal tiger. For these reasons, the Sundarbans National Park, India, and the Bangladesh part of the Sundarbans were inscribed on the World Heritage List in 1987 and 1997, respectively.

According to the IPCC, sea-level rise is the greatest threat and challenge for sustainable



adaptation within south and southeast Asia.³⁹ The consequences in terms of flooding of low-lying deltas, retreat of shorelines, salinization and acidification of soils, and changes in the water table raise serious concerns for the well-being of the local population.

In addition to global sea-level rise (or eustatic sea-level rise, i.e. the change in global average sea level brought about by an alteration of the volume of the world ocean), there is a continuous natural subsidence in the Sundarbans,⁴⁰ which causes a sea-level rise of about 2.2 mm

per year. The resulting net sea-level rise rate is 3.1 mm per year at Sagar.

Additional sources of stress*, not related to climate change, include the diversion of upstream freshwater inflow of the Ganges by the Farraka Barrage in India since 1974 to alleviate the rapid siltation in the Port of Calcutta. This barrage diversion induced a decrease of 40% of the dry season flow.^{41,42}

The joint action of sea-level rise, increased evapotranspiration, and lower freshwater flow in winter will also result in increased salinity in the area threatening the conservation of the Sundarbans mangroves.⁴³ In the Sundarbans, as in many protected areas worldwide, conservation is threatened by several external factors and, again, climate change should be viewed as one source of stress among others. Altogether these factors could lead, in the case of a 45 cm rise in global sea level, to the destruction of 75% of the Sundarbans mangroves.⁴⁴

39. IPCC, 2001, WG2, *op. cit.*, Section 11.3.2.4.

40. P. Sanyal, 2002, *Sea-Level Rise and Sundarban Mangrove*, in G. Quadros, (ed), Proceedings of the National Seminar on Creeks, Estuaries and Mangroves – Pollution and Conservation, 28-30 November 2002, Thane, India, pp. 47-50.

41. IUCN Evaluation Reports for the World Heritage Sites #452 (1987) and 798 (1997), http://whc.unesco.org/archive/advisory_body_evaluation/452.pdf, http://whc.unesco.org/archive/advisory_body_evaluation/798.pdf

42. J.C. Pernetta, (ed.), 1993, *Marine Protected Area Needs in the South Asian Seas Region, Vol. 2, India, A Marine Conservation and Development Report*, IUCN, Gland, Switzerland, vii+ 77 pp., http://www.uicn.org/themes/marine/pdf/mpan_v2.pdf

43. S. Huq, A. Rahman, M. Konate, Y. Sokona, and H. Reid, 2003, *Mainstreaming Adaptation to Climate Change in Least-Developed Countries (LDCs)*, International Institute for Environment and Development, 40pp., <http://www.iied.org/pubs/pdf/full/9219IIED.pdf>

44. IPCC, 2001, WG2, *op. cit.*, Section 19.3.3.5.



Mangroves are made up of salt-adapted evergreen trees that act as protective buffers against tropical cyclones, filtration system for estuarine, and fresh water and nursery for many marine invertebrate species and fish. The Sundarbans is the largest of such forests in the world.



The delta of the Ganges River covered with the mangrove forests of the Sundarbans.

Further destruction of the Sundarbans mangroves would diminish their critical role as natural buffers against tropical cyclones. The Bay of Bengal is heavily affected by tropical storms: about 10% of the world's tropical cyclones occur in this area and 17% of these sweep the land in Bangladesh.⁴⁵ No matter whether the frequency or intensity of cyclones change in the future due to climatic disturbances, exposure of the region to the devastating effects of storms will increase if the mangroves cannot be conserved successfully.⁴⁶

Sea-level rise is typically a process that cannot be entirely prevented through site level strategies. However, the following measures could help in increasing the adaptive capacity of the Sundarbans mangroves against the adverse effects of sea-level rise:

- conservation of remaining mangrove forests in protected areas;

- restoration or rehabilitation of mangrove forests through re-planting selected mangrove tree species, for example along freshwater canals of reclaimed land (successfully practiced on Sagar Island).^{47,48}

Such measures make sense both ecologically and economically. A project of the United Nations Development Programme (UNDP) has evaluated the cost of building 2,200 km of protective storm and flood embankments that would supposedly provide the same level of protection as the Sundarbans mangroves. The capital investment was estimated at about US\$294 million with a yearly maintenance budget of US\$6million⁴⁹ – much more than the amount currently spent on the conservation of the mangrove forests in the area.

**The Government of India have indicated that this statement is not acceptable to them on the basis of scientific study results that will be available in the future.*

45. L.J. Hansen, J.L. Biringer, J.R. Hoffmann, (eds.), 2003, *Buying Time: A User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems*, WWF, 246pp., http://assets.panda.org/downloads/buyingtime_unfe.pdf

46. IPCC, 2001, WG2, *op. cit.*, Section 11.2.4.5.

47. Sanyal, 2002, *op. cit.*

48. S. Saha, and A. Choudhury, 1995, *Vegetation Analysis of Restored and Natural Mangrove Forest in Sagar Island, Sundarbans, East Coast of India*, *Indian Journal of Marine Sciences*, 24(3), pp. 133-136.

49. UNDP, FAO, Government of Bangladesh, 1995, *Integrated Resource Development of the Sundarbans Reserved Forest, Draft Report*, Vol. 1.

2 Komodo National Park

Indonesia

The Komodo National Park was inscribed on the World Heritage List in 1991. The rugged hillsides of dry savannah and pockets of thorny green vegetation contrast starkly with the brilliant pink sandy beaches and the blue waters surging over coral. A place of exceptional natural beauty, which features some of the world's most diverse coral reefs, Komodo National Park is famous for the last remaining habitat of the world's largest lizard, the Komodo dragon (*Varanus komodoensis*), which exists nowhere else in the world, and is also of great interest to scientists.

Climate change threatens several features of this site. Increased CO₂ concentrations and sea surface temperature threaten coral reefs. Sea-level rise may affect sea turtle nesting beaches, and changes in atmospheric temperature may impair successful hatching of sea turtle eggs. Furthermore, sea-level rise could threaten the conservation of mangrove forests if these forests do not have the space to recede with the progressing shoreline. As far as the Komodo dragon is concerned, to date neither evidence, nor hint, of possible climate change impacts on this endemic population have been reported.

Increased sea surface temperature causes coral bleaching and increased mortality of coral polyps, possibly resulting in the loss of biological diversity and ecosystem services that reefs provide (e.g., coastal protection, fisheries, tourism). In addition, increased atmospheric CO₂ levels modify the concentrations of carbonic acid and bicarbonate ions in the ocean, causing a decrease in carbonate ions necessary for coral calcification,⁵⁰ resulting in weaker skeleton frames, reduced growth rate, dimin-

ished ability to compete for space on the reef, and increased susceptibility to breakage and bio-erosion. Temperature related mass bleaching has already occurred in 1998-99, though this event was confined to the northern part of the Komodo National Park, where currents are

weaker and mixing of temperatures through the water column is minimal.

The resilience of coral reefs in the Komodo National Park could be highly improved by enforcing the already established no-take



50. C. Langdon, 2003, Review of Experimental Evidence for Effects of CO₂ on Calcification of Reef Builders, Proceedings of the 9th International Coral Reef Symposium, Bali, Indonesia, 23-27 October 2000, Vol.2, pp. 1091-1098.



The Komodo National Park is famous as the last remaining habitat of the world's largest lizard (the Komodo dragon). It is also home of some of the world's most diverse coral reefs as well as turtle nesting beaches and mangroves. This aerial view of Pulau Sebayor (to the north of the Komodo National Park) shows a variety of coastal and marine habitats (reefs, sea grass, mangroves, channels, and beach).

zones. No-take zones ensure a healthy fish population, including herbivorous fish such as surgeons and parrotfish, which help to keep the growth of macro-algae under control after a mass bleaching event. Hence, the grazing pressure of herbivorous fish will increase the recovery efficiency of coral reefs by keeping the competition for space between macro-algae and settling corals in favour of the latter. A tailored coral monitoring programme should also be implemented, including indicators related to mass bleaching to improve our understanding of this phenomenon.

A diver encounters a giant sea fan over 12 feet across. This coral reef is home to many fish and invertebrates, truly a world within a world on a coral reef. A tailored reef monitoring programme in the Komodo National Park would greatly improve our understanding of mass bleaching events.

Increased temperature will affect sea turtles as incubation temperature of eggs co-determines the sex of hatchlings. Higher temperatures skew the sex ratio towards a predominance of females hatchlings.^{51,52} A higher fraction of females may enhance the fertility of the sea turtle population, but this beneficial effect will be nullified if nesting opportunities decrease through a loss of nesting beaches due to sea-level rise. The outcome of

the combined effects of sea-level rise and increased temperature is unsure.

Considering the uncertainties in the outcome of climate change for sea turtle populations, management options must increase their likelihood of survival by focusing on abatement of other threats, such as poaching of turtles and eggs, and predation by wild boar and Komodo dragons. In addition, monitoring the incubation temperature ranges and trends in hatching success will help to shed more light on the effects of climate change on sea turtles. Such a monitoring programme is a long-haul activity because of the long maturation of turtles.

Regarding the threat of rising sea level,⁵³ the morphology of turtle nesting beaches and of the neighbouring terrain should be used to assess the vulnerability of the beaches to flooding and erosion. Egg clutches on eroding or regularly flooded beaches could be moved to the more stable beaches and reburied. Retrieval and burial of these egg clutches should be guided by detailed standard protocols concerning timing and handling of eggs for translocation.

Increased sea level is the most significant climate change threat to mangroves, resulting in erosion, inundation, and loss. Fringing

mangroves backed by high relief terrain which typically have limited input of ferruginous sediment are more likely to suffer loss through erosion and inundation than mangroves backed by salt flats and low-lying coastal flats. Mangroves in the latter locations will have greater inputs of sediments and silt from both land and sea and have the space to expand inland as the sea-level rises. Similarly, mangroves on low-lying islands may be rapidly inundated as they have nowhere to move and limited sources of sediment on which to build.

Mapping of the extent and distribution of mangroves and of the local topography will help the assessment of potential impacts of sea-level rise. Mangroves bordered on their landward margins by salt flats or low-lying land should be afforded greatest levels of protection from encroachment, harvest, or any interference with the hydrology of the area. Such mangroves should also be monitored for inland expansion as part of a general monitoring programme that would include fringing mangroves to determine their response to sea-level rise.

51. R.R. Carthy, A.M. Foley, Y. Matsuzawa, 2003, *Incubation Environment of Loggerhead Turtle Nests: Effects on Hatching Success and Hatchling Characteristics*, in *Loggerhead Sea Turtles*, A.B. Bolten and B.E. Witherington, (eds.), pp. 144–153, Smithsonian Institution, Washington, DC, USA.
 52. F.J. Janzen, 1994, *Climate Change and Temperature-Dependent Sex Determination in Reptiles*, Proc. Nat. Acad. Sci., 91, pp. 7487–7490.
 53. M.R. Fish, I.M. Côté, J.A. Gill, A.P. Jones, S. Renshoff, and A.R. Watkinson, 2005, *Predicting the Impact of Sea-Level Rise on Caribbean Sea Turtle Nesting Habitat*, Conservation Biology, 19 (2), pp. 482–491, doi: 10.1111/j.1523-1739.2005.00146.x.

3

40

World Heritage

Terrestrial Biodiversity

Terrestrial biodiversity will be affected by a very wide range of geophysical changes resulting from climate change: rising atmospheric temperatures, increasing atmospheric CO₂ concentrations, changes in precipitation patterns and hydrological cycles, increased frequency of extreme weather events, etc. In temperate latitudes, according to climate models, it is projected that spring will arrive on average 2.3 days earlier per decade in the years to come. During the twentieth century, a survey of 1,700 biological species found a pole ward displacement of species of about 6 km per decade.¹ These changes have far-reaching implications on the biodiversity of the planet so that, according to the Convention on Biological Diversity,² climate change has been identified as one of the main drivers of the biodiversity loss that will be felt over the coming decades.

The following impacts of climate change on terrestrial biodiversity are expected:^{3,4}

- Species distributions. Individualistic species (including invasive alien species, pathogens and parasites) respond to warmer/cooler and drier/moister condi-

tions, with possible migration in latitudinal and altitudinal directions. Local, regional, and global extinction of species due to range expansions, contractions and eliminations.

- Community composition and configuration. Changes in relative and

1. C. Parmesan and G. Yohe, 2003, *A Globally Coherent Fingerprint of Climate Change Impacts Across Natural Systems*, *Nature*, 421, pp. 37–42.

2. Statement by Dr Ahmed Djoghlaif, Executive Secretary of Convention on Biological Diversity, on the Occasion of the High Level Segment of the 14th session of the Commission on Sustainable Development on 15 May 2006, Available at <http://www.biodiv.org/doc/speech/2006/sp-2006-05-15-csd14-en.pdf>

3. L. Hannah, G.F. Midgley, T.E. Lovejoy, W.J. Bond, M. Bush, J.C. Lovett, D. Scott, and F.I. Woodward, 2002, *Conservation of Biodiversity in a Changing Climate*, *Conservation Biology*, 16, pp. 264–268.

4. L. Hannah, G.F. Midgley and D. Millar, 2002, *Climate Change-Integrated Conservation Strategies*, *Global Ecology and Biogeography*, 11, pp. 485–495.

absolute abundance of each species within the community and formation of non-analogue communities built on new assemblages of species.

- Ecosystem functioning. Changes in the phenology (the timing of biological events such as flowering); in the nutrient cycling and availability of

natural resource such as freshwater; in predator-prey, parasite-host, plant-pollinator and plant-disperser relationships; in pest control, pollination, and soil stabilization.

- Disturbance regimes. Changes in the intensity, frequency and seasonality of extreme events such as wildfires, floods,

droughts and synergies with global change, including modifications of anthropogenic land-use pressures.

- Provision of ecosystem goods and services, with significant impacts on human livelihoods, through socio-economic activities including agriculture, fishery, and tourism.



Panamanian golden frog
Central America

3 Cape Floral Region Protected Areas

South Africa⁵

The Cape Floral Region represents less than 0.5% of the area of Africa but it is home to nearly 20% of the continent’s floral biodiversity. As such it is one of the richest areas for plants in the world. It displays the highest levels of endemism at 32% and it has been identified as one of the world’s 18 biodiversity hot spots, and due to its unique floristic values it is recognized as one of the world’s six floral kingdoms. The site displays outstanding ecological and biological processes associated to the Fynbos biome, which is unique to this region. Of unique character are also the reproductive strategies of some plants including their adaptive responses to fire and the patterns of seed dispersal by ants and small mammals (rodents). The pollination biology and nutrient cycling are other distinctive ecological processes found on the site. The Cape Floral Region forms a centre of apparently active speciation where interesting patterns of endemism and adaptive radiation are found in the flora.

Impacts of climate change

The Cape Floral Region has probably experienced mild climate changes with mostly cooler and wetter conditions during glacial times for at least the past 2 million years. This has resulted in the persistence of many range-restricted, locally rare species with limited dispersal ability, and of climate sensitive relict species, especially in wetland areas.

In addition, as a result of this relative climate stability, highly specialized mutualisms have evolved in the flora and fauna of the region.⁶

According to the IUCN,⁷ experiments, observations and modelling show that climate change might be the most significant threat facing biodiversity in the Cape Floral Region over

the next 50 to 100 years. The most threatening aspects of climate change for the conservation of this area are (1) shrinking of optimal bioclimatic habitats with warming and potential drying; (2) ecosystem changes in response to modification of environmental conditions; and (3) increase of fire frequency.

Projected climate change

Climate change projections have been performed by downscaling global climate models, i.e. interpolating coarse model outputs to derive finer scale data, yet accounting for the variability of current climate, altitude, topography, and continental situation. This work shows that by the year 2050 the Cape Floral Region will face generally warmer and drier conditions with an increase in mean annual

temperatures of about 1.8 °C under a scenario of doubled atmospheric CO₂ concentrations.⁸ But in some areas the direction of change in rainfall is still uncertain. The general future warming and drying, most likely unprecedented in the past 20,000 years or more, will intensify the already significant water stress across the region and impact on biodiversity and people in many ways.

5. B. Bomhard and G. Midgley, 2005, *Securing Protected Areas in the Face of Global Change: Lessons Learned from the South African Cape Floristic Region, A Report by the Ecosystems, Protected Areas, and People Project, IUCN (Bangkok) and SANBI (Cape Town)*, www.iucn.org/themes/wcpa/pubs/theme.htm#climate

6. Communication of B. Bomhard and G. Midgley at the Meeting on Climate Change and World Heritage held at UNESCO, 16-17 March 2006, in Document WHC06-30COM7.1, <http://whc.unesco.org/archive/2006/whc06-30com-07.1e.pdf>

7. Report to the World Heritage Committee on the Prediction and Management of the Impacts of Climate Change on World Heritage, Document WHC06-30COM7.1 <http://whc.unesco.org/archive/2006/whc06-30com-07.1e.pdf>

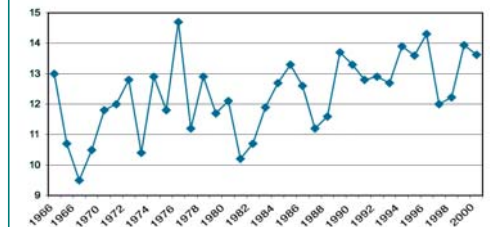
8. R.E. Schulze and L.A. Perks, 1999, *Assessment of the Impact of Climate. Final Report to the South African Country Studies Climate Change Programme, School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg, South Africa.*



Fynbos biome in the Cape Floral Region. The Cape Floral Region is one of the world's biodiversity hotspots with a level of endemism above 30%.

Consequences on the biodiversity

As a result of these physical changes, four out of five protected areas in South Africa are predicted to lose 10% to 40% of their plant species by the year 2050.⁹ The first impacts of climate change on the biodiversity of the Cape Floral Region are already becoming apparent and many more impacts are expected.



Observed minimum temperatures in January at an interior site (de Keur, Koue Bokkeveld) in the Cape Floral Region show a clear positive trend (South African Weather Service).

Global sea-level rise

Some coastal lowlands are threatened by sea-level rise in the area, which will further reduce the remaining natural buffer between the ocean and human developments at the expense of coastal species and ecosystems.

species.¹⁰ This is a matter of concern for an area of very high endemism such as the Cape Floral Region. However, it is difficult to represent such species in bioclimate models in order to predict their overall response, partly because these invasive alien species have been introduced only recently. Consequently, they have not yet reached their equilibrium distribution in the area, which is a necessary assumption in bioclimate models.

Invasive alien species

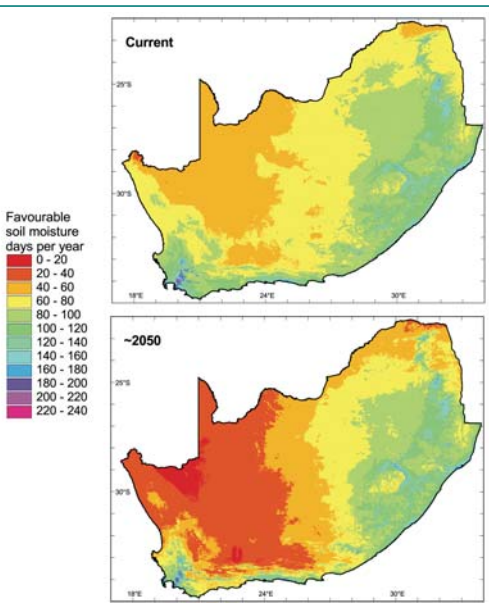
Trees and shrubs from other Mediterranean-type climates (Australia, California or the Mediterranean basin) were introduced to the region prior to the twentieth century. Currently 70% of the Cape Floral Region is classified as natural vegetation, either free of woody invasive alien species or with low-density stands of invasive alien shrubs and trees. Of this proportion, about 20% is in pristine condition, being free of invasive alien plants and subject to appropriate fire regime. The remainder (about 30%) has been transformed by agriculture, urbanization and dense stands of invasive alien plants altering freshwater supply and fire frequency.

Shifting, shrinking, and dislocating ranges in response to global warming

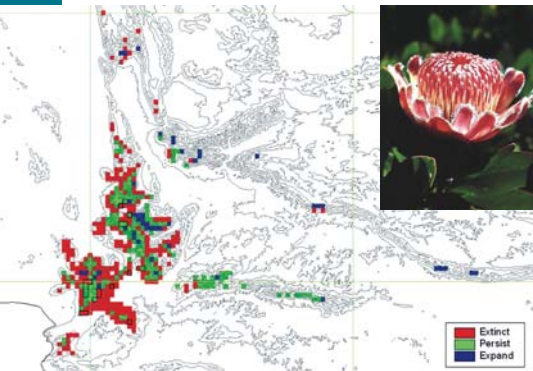
Projected changes in soil moisture and winter rainfall will modify species distributions. In the Cape Floral Region, the hostile landscape matrix might prove to be a key obstacle for species migrations in response to climate change. In the heavily transformed and fragmented coastal lowlands there is little scope for latitudinal or altitudinal range adjustments. Furthermore, species that occur currently on mountain tops would have no place to go in the context of future warming, and habitat-specialist species might suffer greater impacts compared to habitat-generalist species.

It has been shown that five plant species that represent an important life form in South Africa's invasive alien flora are generally less sensitive to climate change than indigenous

9. M.C. Rutherford, L.W. Powrie and R.E. Schulze, 1999, *Climate Change in Conservation Areas of South Africa and its Potential Impact on Floristic Composition: A First Assessment, Diversity and Distributions*, 5, pp. 253-262.
 10. D.M. Richardson, W.J. Bond, W.R.J. Dean, S.I. Higgins, G.F. Midgley, S.J. Milton, L.W. Powrie, M.C. Rutherford, M.J. Samways, R.E. Schulze, 2000, *Invasive Alien Species and Global Change: A South African Perspective*, in H.A. Mooney, R.J. Hobbs, (eds.), *Invasive Species in a Changing World*, Island Press, Washington DC, USA, pp. 303-349.



The projected effects of climate change on biodiversity in South Africa can be inferred from these charts that show the current and projected number of days when both soil moisture and temperature are suitable for plant growth. Projections account for an equivalent increase in atmospheric CO₂ levels of 50% compared to current levels (Midgley, 2001).



Optimum range will shift and shrink for *Protea laticolor*. The areas where this iconic plant will persist are displayed in green, while in many areas it will become extinct (red). (Hannah et al., 2005)*

* L.Hannah, G.F. Midgley, G.O. Hughes, B. Bomhard, 2005: The view from the Cape: extinction risk, protected areas, and climate change, *BioScience*, 55, pp. 231-242.

Consequences on disturbance regimes

Consequently, climate change would affect the range restricted and locally rare species with limited dispersal ability. Some 40% of the species are expected to lose up to one third of their current range, whereas only 5% will retain more than two thirds of their current ranges in the Cape Floral Region.

Bioclimatic modelling, accounting for both projected climate changes and biological species responses show that the envelope of the Fynbos biome vegetation will contract significantly by 2050 with an estimated overall loss of area of up to 65%.¹¹ This shrinkage depends on the latitude with a maximum in the northern part of the domain. In the south of the Cape Floral Region, the Fynbos biome will contract onto higher altitudes.¹² In contrast, plains and low altitudes areas are not expected to retain suitable bioclimates for Fynbos vegetation. Overall, about 10% of the 330 Proteaceae taxa have ranges restricted to the biome area predicted to be lost by 2050 and are therefore most likely to become extinct.¹³

If suitable ranges shift or contract, some species could adapt by natural migration. But another matter of concern is the dislocation of such ranges, which implies the absence of overlap between their current and future extension. If these species cannot disperse and establish rapidly enough to their future ranges, all of them could face extinction. Based on the research work on the iconic Proteaceae family,

Wildfire

Projected warming and drying will also affect fire regimes, with potentially devastating effects on biodiversity and people. In addition, in the Fynbos biome, the increasing number of incendiary events caused by humankind is important, leading to more frequent and less intense fires.¹⁶ Consequently, both global change (through direct changes induced by human activities) and climate change (because of the warming and drying in the area) will affect fire regimes in the Cape Floral Region.

it is estimated that this phenomenon could affect up to 30% of the species by 2050.

Ecosystems responses

The shifting, shrinking, and dislocating of ranges of species threatens unique highly-specialized mutualisms in the Cape Floral Region such as plant-pollinator and plant-disperser interactions. By impacting on species distributions, these changes will affect community composition and configuration, and in turn impair the whole ecosystem functioning, services and states. At worst, extinctions of species that are not able to adapt to a rapidly changing climate may occur. Consequently, many protected areas may lose species through prompt cascading extinctions and migrations interrupting vulnerable mutualisms.¹⁴

Increased CO₂ concentrations

Increased CO₂ concentrations in the atmosphere impact on the biodiversity in two ways. The indirect impacts are those listed earlier in the context of increased greenhouse effect (species migration, changes in the phenology etc.). But CO₂ availability also directly influences the growth of plants. However, as far as the Cape Floral Region is concerned, the direct effect should be limited. Indeed the response of Fynbos vegetation to elevated CO₂ would be counteracted by the frequency of fires that generally limits the extent to which mature individuals compete for resources.¹⁵

Many rare species in the region are fire-sensitive and thus at risk. In particular, changes in the complex interaction of indigenous and invasive alien plants, fuel loads, fire seasonality, frequency and intensity, local wind and weather patterns, and water balance will play a key role in changing biodiversity patterns and processes.¹⁷ For more details on the impacts of wildfires on the biodiversity, see also the following case study on the Greater Blue Mountains Area (Australia), p. 46.

11. G.F. Midgley, L. Hannah, D. Millar, M.C. Rutherford and L.W. Powrie, 2002, *Assessing the Vulnerability of Species Richness to Anthropogenic Climate Change in a Biodiversity Hot Spot*, *Global Ecology and Biogeography*, 11, pp. 445-451.
12. G.F. Midgley, L. Hannah, D. Millar, W. Thuiller and A. Booth, 2003, *Developing Regional and Species-level Assessments of Climate Change Impacts on Biodiversity in the Cape Floristic Region*, *Biological Conservation*, 112, pp. 87-97.
13. Midgley et al. (2002), *op.cit.*
14. W.J. Bond, 1994, *Do Mutualisms Matter? Assessing the Impact of Pollinator and Disperser Disruption on Plant Extinctions*, *Philosophical Transactions of the Royal Society of London*, B, 344, pp. 83-90.
15. W.D. Stock and G.F. Midgley, 1995, *Ecosystem Response to Elevated CO₂: Nutrient Availability and Nutrient Cycling*, in J.M. Moreno and W.C. Oechel, (eds.), *Global Change and Mediterranean-Type Ecosystems*, Springer, New York, pp. 326-342.
16. S.I. Higgins, D.M. Richardson, 1998, *Pine Invasions in the Southern Hemisphere: Modelling Interactions Between Organism, Environment and Disturbance*, *Plant Ecology*, 135, pp. 79-93.
17. H.A. Mooney, M.T.K. Arroyo, W.J. Bond, J. Canadell, R.J. Hobbs, S. Lavorel and R.P. Neilson, 2001, *Mediterranean-Climate Ecosystems*, in Chapin III, F.S. Sala, O.E. Huber-Sannwald, (eds.), *Global Biodiversity in a Changing Environment: Scenarios for the twenty-first century*, Springer, New York, pp. 157-199.

Possible responses

Although there has been no unified response strategy to climate change in the Cape Floral Region, different stakeholders have started to address the issue in many ways on different spatial and temporal scales. In so doing, some principles and practices have emerged that are now widely applied in biodiversity conservation in the region and beyond. The paragraphs below summarize the actions that are undertaken or contemplated.

Monitoring and risk assessment

Bioclimatic modelling provides an excellent risk assessment but key knowledge gaps need to be bridged by experimental and observational studies, including monitoring. A monitoring system is already in place to detect the possible effects of climate change.¹⁸ It includes survey of native species as well as exotic (or invasive) species that are already present. But screening other potentially invasive alien species which are so far absent from the region could help to prevent future invasions in the Fynbos biome.

Increasing resilience

In a similar way as for the protection of the Great Barrier Reef World Heritage site (see Chapter 2, p. 30), reducing or removing external sources of stress on the ecosystem would greatly help the Cape Floral Region to cope with the potential, or ascertained adverse impacts of climate change.

Risk preparedness

The threat posed by natural or anthropogenic wildfires could be relieved by strengthening the risk preparedness to such incidences. An improved network for the detection and prevention of wildfires would be most efficient in protecting this biome from the frequency and intensity of fires. Fire management strategies are currently being carefully reconsidered by national and provincial agencies in their managing, mapping, and monitoring activities.¹⁹

Design of protected areas

One of the specificities of the activities conducted in the domain of climate change adaptation planning at the Cape Floral Region is the

extensive bioclimatic modelling research used to predict potential effects of climate change. Such models can also be used to test possible adaptation scenario, more specifically to explore possible re-definition of the design of protected areas and to focus on migratory corridors that could help alleviate the effects of climate change by allowing the species to shift ranges.

Indeed by comparing current and projected ranges of species, and assuming that they will adapt fast enough to shift ranges, it is possible to suggest modifications that would allow the conservation of these fragile species by:

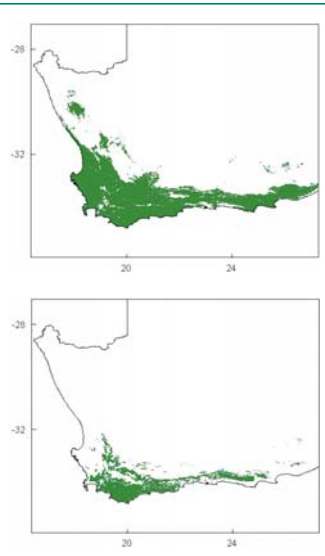
- moving or extending the boundaries of the protected area and of buffer zones;
- increasing the habitat heterogeneity and topographic diversity;
- increasing landscape connectivity of current and future protected areas in the design of migratory corridors, if the overlap of current and future boundaries cannot be ensured.

Also, the areas with no, or little, projected changes under various climate change scenarios should be identified and prioritized for conservation.

Translocation of exceptionally threatened species

Lastly, for species that are expected to face the most pronounced threats, translocation could be contemplated. Either toward safer habitats in the wild, or by storing genetic resources in gene or seed banks, or in protected ex-situ conservatories. However, these strategies are very sensitive and their impacts on biodiversity in target areas must be carefully assessed.

Current modelled range of the Fynbos biome (top) and modelled contraction of optimum bioclimatic conditions as a consequence of climate change (bottom). Projections account for an equivalent increase in atmospheric CO₂ levels of 50% compared to current levels. (G. Midgley)



18. IUCN, 2003, *Evaluation of the Cape Floral Region for the World Heritage Committee, 2003*, available at: http://whc.unesco.org/archive/advisory_body_evaluation/1007rev.pdf

19. Bomhard and Midgley, 2005, *op. cit.*

Additional Case Studies

Greater Blue Mountains World Heritage Area

Australia

3

46

The Greater Blue Mountains World Heritage Area (GBMWA) consists of over 1 million ha of sandstone plateaux, escarpments and gorges covered largely by temperate eucalypti forests. The site, comprised of eight protected areas, is inscribed on the World Heritage List for its representation of the evolutionary adaptation and diversification of the eucalyptuses in post-Gondwana isolation on the Australian Continent. More than 100 eucalypt taxa have now been recorded within the Greater Blue Mountains Area which is also outstanding for its exceptional expression of the structural and ecological diversity of the eucalyptuses associated with its wide range of habitats. Among the justification for inscription on the World Heritage List is also the presence of species of flora and fauna of conservation significance and their habitats, as the Greater Blue Mountains World Heritage Area hosts 120 rare or threatened species, including 114 endemic taxa and evolutionary relict species.

Australia has seen a 0.7 °C average increase in temperature between 1910 and 1999 with most of that increase occurring since 1950.^{20,21} Climate model projections of the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) indicate an increase of average annual temperature ranging from 0.4 to 2.0 °C by 2030, and as much as 1 to 6 °C by 2070.^{22,23} Evaluation of future trends in rainfall is much more challenging for the state-of-the-art climate models.²⁴ This change in climate regime raises a special concern for forests, where the impacts of increased temperatures could lead to an increased risk of more frequent, intense, and destructive wildfires.



The eucalypti forests of Australia, including those of the Greater Blue Mountains Region of New South Wales, are amongst the most fire-dependent forest ecosystems in the world. The blue haze of the region, from which it derives its name, is caused by the highly flammable eucalyptus oil being released into the atmosphere in response to heat. Many species of eucalypt, banksias and other native flora have

20. N. Plummer, Z. Lin and S. Torok, 1995, *Trends in the Diurnal Temperature Range Over Australia Since 1951*. Atmospheric Research, 37, pp. 79–86.

21. S.J. Torok and N. Nicholls, 1996, *A Historical Annual Temperature Data Set for Australia*. Australian Meteorological Magazine, 45, pp. 251–260.

22. M. Howden, 2003, *Climate Trends and Climate Change Scenarios*, in *Climate Change Impacts on Biodiversity in Australia* (ed.), M. Howden, L. Hughes, M. Dunlop, I. Zethoven, D. Hilbert and C. Chilcott), pp. 8–13. Canberra, Commonwealth of Australia, <http://www.deh.gov.au/biodiversity/publications/greenhouse/pubs/climate-change.pdf>

23. *Climate Change Projections for Australia*. Climate Impact Group, CSIRO Atmospheric Research, Melbourne. 8 pp., <http://www.cmar.csiro.au/e-print/open/projections2001.pdf>

24. L. Hughes, 2003, *Climate Change in Australia: Trends, Projections and Impacts*, Austral Ecology, 28, pp. 423–443.



Temperate eucalypti forest in the Greater Blue Mountains (Australia) is among the most fire-dependent forest ecosystems in the world. The potential effects of climate change on wildfire regimes in this area should thus be carefully assessed.

become so adapted to fire that they only release their seeds after burning has taken place, the ash compensating for the often nutrient-poor soils.

There is usually a high rate of re-growth of eucalypti and banksias within the first three years following a major fire. However, a second hot fire, during that stage in the regeneration process, can lead to severe stress and a loss of species diversity by killing plants before they have matured sufficiently to produce seeds. Consequently, if the interval of intense bush fires moves from long cycles of ten to twenty years to below six years there would be a significant decline in the diversity of the major eucalypti species and other flora of the region,²⁵ a change which would have serious consequences for the World Heritage values and ecosystem integrity of the area.²⁶

The aforementioned (p.42) impacts of climate change on community composition for the Cape Floral Region (South Africa) could also apply to the Greater Blue Mountains World Heritage Area. Increasing temperatures may threaten flora and fauna of the very limited wetter, higher altitude parts of the area, by forcing species to move up the mountains in

response to rising temperatures and by reducing availability of water. One of the attributes of the GBM WHA relevant to its listing under natural criteria is the variability of the vegetation in response to decreasing temperature across an altitude range from 100 m to 1,400 m.

For example, the upland swamps of the Greater Blue Mountains World Heritage Area contain some unique species that are adapted to seasonally waterlogged soils. These species are at risk of displacement by species tolerant of drier soils. Upland swamps also provide habitat for the endangered skink *Elamprus leuraensis* and the Giant Dragonfly. Their ability to retain and slowly release water also contributes to the survival of threatened plants, such as *Microstrobos fitzgeraldii* and *Epacris hamiltonii*, which have adapted to permanently moist habitats. Swamps that are currently at the lower end of the suitable rainfall spectrum would be most vulnerable to contraction due to changes in rainfall and/or evaporation associated with climate change.

Several research projects regarding the impacts of climate change on the Greater Blue Mountains World Heritage Area are being conducted under the auspices of the Australian Greenhouse Office, the New South

Wales Department of Environment and Conservation and the Blue Mountains World Heritage Institute. The topics under study include impacts on biodiversity and ecosystem functions (terrestrial and aquatic), synergistic effects on other threats such as invasive species, and risks posed by bushfires to people and properties.

Several strategies are being developed to protect the Greater Blue Mountains World Heritage Area from the adverse impact of wildfires in the context of a changing climate. The first is to implement more informed policies through increased research into fire behaviour and its ecological impacts, especially following the very destructive fires of 2002 that led to the establishment of a Bushfire Cooperative Research Centre in December 2003.²⁷ The second concerns the use of controlled or mosaic burning to limit the risk of intense and ecologically destructive fires, appropriately designed to take into account the specific ecosystems involved. As the Greater Blue Mountains World Heritage Area borders Sydney's rapidly expanding suburban boundaries, there is a real risk of conflicting policy priorities between the protection of urban property and that of biodiversity conservation.

25. J. Merson, 2004, *Climate Change and Ecosystem Stress: The Impact of Increased Forest Fire Frequency and Intensity on Australian Protected and World Heritage Areas*, in *Proceeding of the 3rd IUCN World Conservation Congress*, Geneva, Switzerland.

26. R.A. Bradstock and B.J. Kenny, 2003, *An Application of Plant Functional Types to Fire Management in a Conservation Reserve in South Eastern Australia*, *Journal of Vegetation Science*, 14, pp. 345-354.

3 Ichkeul National Park

Tunisia

The Ichkeul National Park (Tunisia) is a major stopover point for hundreds of thousands of migrating birds in northern Africa.



The wide range of climate change impacts on wetlands, in general, is a subject of growing attention. Wetlands cover nearly 10% of the Earth's surface. They are critically important ecosystems that provide globally significant social, economic, and environmental benefits. It is estimated that the total global value of services provided by coastal areas and wetland ecosystems reach US\$15.5 trillion per year, i.e. 46% of the total value of services that global ecosystems are estimated to offer.²⁸ The Ramsar Convention of 1971 provides an international framework for the study and management of wetlands worldwide, including with regard to climate change issues.²⁹

Increasing temperatures, changes in precipitations, and sea-level rise will affect wetland distributions and functions. At the same time, wetlands and peat lands contribute significantly to the global carbon cycle. Therefore, if climate change affects wetlands, in turn they also feed back on the climate. It is thus necessary to consider how the twin forces of change in land use and climate change may affect the role of wetlands in the global carbon cycle, and thus how these biomes are affected by, or affect themselves, the climatic equilibrium of the planet.

A wide range of climate change impacts will affect wetlands worldwide:

- Sea-level rise. Increased sea level will have several adverse effects on coastal wetlands including: coastal erosion, coastal flooding, loss of habitats, augmentation in the salinity of estuaries and freshwater aquifers, change in tidal ranges in rivers and bays, transport of

sediments and nutrients, patterns of contamination in coastal areas, etc. As a result, individualistic responses and changes in ecosystem composition and functioning can be expected which will, in turn, affect the productivity and functions of wetlands.³⁰

- Hydrological cycle. Climate change is projected to lead to an intensification of the global hydrological cycle accompanied with major changes in the spatial and temporal water distribution and availability. Changes in precipitation, evaporation, transpiration, runoff and groundwater recharge and flow pose an obvious threat on wetlands by affecting both surface and groundwater systems.

- Increased temperature of water bodies. Although their response is slower than for the atmosphere (because of higher inertia), important effects of rising temperature are expected on the biological productivity within water bodies. Changes in wetland surface temperature will also modify their static stability,

and thus impact on vertical mixing regimes between surface and deep waters.

- Storm activity. In many areas, winds play an important role in the mixing of wetlands. Changes in storm activity may thus impair the mixing of stratified water bodies.³¹

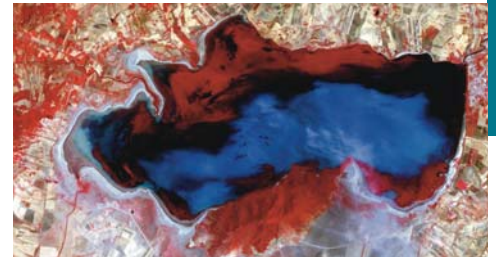
- Increased atmospheric temperature. Even a small rise in atmospheric temperature can result in the melting of large areas of permafrost. Permafrost is defined as perennially frozen ground that occurs wherever the temperature remains below 0 °C for several years, and is considered as wetland. This melting will also modify the processes that contribute to the methane (CH₄) emissions from these wetland areas.³²

The Ichkeul Lake and marsh constitute a remarkable wetland system in northern Africa. It is a major stopover point for hundreds of thousands of migrating birds, such as pochards, wigeons, coots, and greylag geese

28. R. Costanza, R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton and M. van den Belt, 1997, *The Value of the World's Ecosystem Services and Natural Capital*, Nature, 387, pp. 253-260.
29. G. Bergkamp and B. Orlando, 1999, *Wetlands and Climate Change, Exploring Collaboration Between the Convention on Wetlands (Ramsar, Iran, 1971) and the United Nations Framework Convention on Climate Change*, http://www.ramsar.org/key_unfccc_bkgd.htm#2
30. R.S. Warren and N.A. Niering, 1993, *Vegetation Change on a Northeast Tidal Marsh: Interaction of Sea-Level Rise and Marsh Accretion*, Ecology, 74, pp. 96-103.
31. J. Talling and J. Lamoalle, 1998, *Ecological Dynamics of Tropical Inland Waters*. Cambridge University Press, Cambridge, 441 pp.
32. T.A. Clair, B.G. Warner, R. Robarts, H. Murkin, J. Lilley, L. Mortsch and C. Rubec, 1997, *Executive Summary - Impacts of Climate Change to Inland Wetlands: A Canadian Perspective*.



Composite images of the ASTER satellite showing the vegetation in shades of red. The photograph of the Ichkeul Lake and marsh taken in 2001 (at the top) shows that *potamogeton pectinatus* have disappeared from the lake. In 2005 (at the bottom), after a tailored adaptation plan was implemented and climatic conditions improved, the vegetation recovered in the lake.



which come to feed and nest there. Ichkeul is also the last remaining lake in a chain that once extended across North Africa. As such, it was inscribed in 1980 on the World Heritage List.

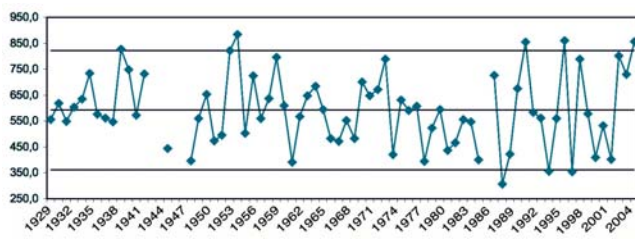
The specificity of the lake and marsh system of Ichkeul relies on the seasonal cycle of the water inflow: freshwater from six rivers flowing from the catchments upstream in winter and salted water from the sea in the summer. This peculiar hydrology led to the development of an adapted flora used as a primary source of nutrient by thousands of migratory birds: the massive beds of the pondweed called *potamogeton pectinatus* in the lake and the bulrush *scirpus maritimus* in the marshes.

resulted in the increase of the saltwater inflow. In addition, a slight decrease of precipitation has been observed since the 1930s with a higher year-to-year variability of annual precipitations, i.e. an increased frequency of very wet and very dry years in the recent past.

As a consequence, an increase in the salinity of the lake and drying of the marshes has been observed. The *potamogeton pectinatus* disappeared from the lake and the scirpus, reed beds, sedges and other fresh-water plant species of the marshes were replaced by halophytic plants, with a consequent sharp reduction in the migratory bird populations dependent on the habitat that the lake formerly provided.

area. These changes will probably affect the functioning of the catchments and thus increase the existing pressure on the Ichkeul National Park. The droughts of the 1990s (although attributed to climate variability rather than climate change for the time being) give an insight of what would happen if the projected trends were confirmed.

Adaptation measures have been developed to face these impacts and water supply planning now accounts for the consumption of freshwater by the Ichkeul Lake and marsh. Freshwater inflow from the dams upstream is regulated as well as exchanges of salted water with the sea downstream. A tailored scientific monitoring programme has been implemented. In addition, since 2002 climatic conditions have improved and with the implementation of these management measures the site recovered quickly, showing the high resilience of this biome. Consequently, the site was removed from the List of World Heritage in Danger in July 2006. But if the projected trends of climate change are confirmed during the twenty-first century, the Ichkeul wetland is likely to face conditions similar to, or worse than, those of the 1990s. Consequently, it will be crucial to develop and refine these adaptation measures.



Annual rainfall (in mm) recorded at the Tinja station (Ichkeul Region) between 1929 and 2004. A slight negative trend is observed but most importantly, the variability (frequency of extremely wet and dry years) increased in the recent past. Current climate models project that this trend of variability will be confirmed over the twenty-first century (ANPE Tunisie, 2006).*

* Agence nationale de protection de l'environnement, Tunisie, 2006 : Rapport sur le suivi scientifique au Parc national de l'Ichkeul - Année 2004/05.

In 1996 this site was inscribed on the List of World Heritage in Danger. The construction of three dams on the rivers supplying Lake Ichkeul and its marshes led to long periods of drought between 1993 and 2002 which cut off a significant amount of freshwater inflow; and

would reach 2 °C to 4 °C. The sea level is also expected to rise, possibly as much as 0.88 m. The projected precipitation trends show a slight decrease, but most importantly an increased spatial and temporal variability – as was observed in the recent past in the Ichkeul

33. H. Kraiem, 2002, Biophysical and Socio-economic Impacts of Climate Change on Wetlands in the Mediterranean, in Mediterranean Regional Roundtable on Water, Wetlands and Climate Change – Buildings Linkages for their Integrated Management, UICN GWP med-MedWet, Athens, Greece, 10-11 Decembre 2002.

3

Wet Tropics of Queensland Australia



The Wet Tropics of Queensland hosts a particularly extensive and varied array of tropical terrestrial flora and fauna. But even a 1 °C increase in mean air temperature will lead to a significant decline in range size for almost every endemic vertebrate in the region.

The Wet Tropics of Queensland World Heritage site stretches along the north-eastern coast of Australia for some 450 km. It is made up of tropical lowland and upland rainforests and thickets, vegetation complexes, mangroves and sclerophyll forests and woodlands. These ecosystems host a particularly extensive and diverse array of plants and animals, including a high proportion considered as endemic, evolutionarily significant, rare or threatened. These features justified its inscription on the World Heritage List in 1988 under all four natural criteria.

Impacts of climate change on the Wet Tropics of Queensland

This remarkable ecosystem is threatened by rapid changes in temperature and rainfall, as many species in this area are unable to keep pace with rapid climate change. Even with a 1 °C increase in mean air temperature, significant declines in range size for almost every endemic vertebrate of the Wet Tropics bioregion are predicted by bioclimatic modelling.³⁴

For about half of the species modelled, a warming of 3.5 °C (corresponding to the average projected scenario) may lead to the total loss of their core environment; for the remaining species, range sizes are likely to be reduced on average to 11% of the current area.³⁵ Vertebrates living in these isolated tropical mountain rain-

forests may become trapped in, with nowhere to go, in response to the projected changes in climate. Therefore, many species including a number of frogs, mammals, birds and skinks, could be lost in the Wet Tropics of Queensland within 50 to 100 years, depending on the rate and timing of climate change.³⁶

Possible responses³⁷

Australia's Marine and Tropical Scientific Research Facility (MTSRF), with substantial funding from the Australian Government, is conducting a programme of research to formulate feasible proactive regional-scale management initiatives in response to projected climate change. The research programme will refine present climate change models and scenarios to verify the following:

- species and ecological communities most at risk;
- long-term effects of these threats;
- geographical distribution of the threats;
- how climate change might interact with other threats such as clearing, fragmentation, fire, weeds and feral animals; and
- as to whether, or where, some areas may provide continued habitat, or new areas of habitat, in the future.

More specifically, concerning the Wet Tropics World Heritage Area, the James Cook University in Townsville, Queensland has established a Centre for Tropical Biodiversity and Climate Change Research that will focus its efforts on climate change impacts on the biota of the Wet Tropics of Queensland.

34. S.E. Williams, E.E. Bolitho, and S. Fox, 2003, *Climate Change in Australian Tropical Rainforests: an Impending Environmental Catastrophe*. Proceedings of the Royal Society London, 8, 270, pp. 1887-1892.
35. S.E. Williams, 2003, *Impacts of Global Climate Change on the Rainforest Vertebrates of the Australian Wet Tropics*, in *Climate Change Impacts on Biodiversity in Australia* (ed.), M. Howden, L. Hughes, M. Dunlop, I. Zethoven, D. Hilbert and C. Chilcott, pp. 50-52. Canberra, Commonwealth of Australia. <http://www.deh.gov.au/biodiversity/publications/greenhouse/pubs/climate-change.pdf>
36. Allen Consulting Group, 2005, *Climate Change: Risk and Vulnerability. Promoting an Efficient Adaptation Response in Australia*. Report to the Australian Greenhouse Office, Department of the Environment and Heritage, Department of the Environment and Heritage, Canberra, Commonwealth of Australia.
37. Wet Tropics Management Authority. *Annual Report and State of the Wet Tropics Report, 2005-2006*.

Area de Conservación Guanacaste

Costa Rica

This World Heritage site contains important natural habitats for the conservation of biological diversity, including some of the best dry forest habitats in Central America and other key habitats like rainforest and cloud forest for endangered or rare plant and animal species. The site hosts unique ecological processes in both its terrestrial and marine-coastal environments and, therefore, it was inscribed on the World Heritage List in 1999.



In Central America, the impacts of climate change on biodiversity loss are already visible. The Panamanian golden frog is one of more than 100 species of disappearing harlequin frogs.

However, the cloud forests and rainforests of Costa Rica have seen a dramatic biodiversity loss in the recent past. Over the past twenty years, 110 endemic frog species (approximately 67%) in the American tropical mountain have become extinct, including the Monteverde Harlequin frog and the golden toad. After a debate on whether these extinctions were caused by global warming

or deforestation, recent research has shown the critical role of pathogen *chytrid* fungus and climate change in the extinction of Harlequin frogs: increased air temperatures creates optimum conditions for the fungus, while increased daytime cloudiness prevents the frogs from finding thermal refuges from the pathogen.³⁸

38. J.A. Pounds, M.R. Bustamante, L.A. Coloma, J.A. Consuegra, M.P. Fogden, P.N. Foster, E. La Marca, K.L. Masters, A. Merino-Viteri, R. Puschendorf, S.R. Ron, G.A. Sanchez-Azofeifa, C.J. Still and B.E. Young, 2006, Widespread Amphibian Extinctions from Epidemic Disease Driven by Global Warming, *Nature*, 439, pp. 161-166.

4

World Heritage

Archaeological Sites

52

Climate change will be accompanied by a number of changes in environmental conditions that may threaten buried evidences by exacerbating decay mechanisms at archaeological sites. Archaeological evidences are preserved in the ground because they have attained a balance with the hydrological, chemical and biological processes of the soil. Changes to these parameters may result in a poorer level of survival of sensitive classes of material.

Any changes of temperature or water content of the soils will impact on the conservation of these sites. This threat must be addressed for such properties inscribed on the World Heritage List. But of special concern for archaeological evidence, compared to any other type of properties, is the fact that climate change may jeopardize the conservation of precious evidences whose existence is even not known today.

Several changes in climate will impact on the conservation of archaeological heritage:

- The modification in precipitation regimes and the increased year-to-year variability in many areas worldwide reported by the IPCC.¹ No matter whether the trend is toward an increased frequency of droughts or floods, the changes in water-table levels, in humidity cycles, in time of wetness, in ground water, and in soil chemistry will impact on the conservation of archaeological remains.
- The increased soil temperature, in response to increased atmospheric

temperature will also play an important role, especially in polar regions where large areas of permafrost are melting. In temperate areas, shifts in the regions exposed to seasonal freeze-thaw cycles are projected which could affect subsoil instability, ground heave and subsidence, not to mention the more dramatic massive landslides.

- Sea-level rise also threatens coastal areas with the subsequent coastal erosion and permanent submersion of low lying areas, and the increase in the sea salt chlorides load of coastal soils.
- Changes in sediment moisture are expected to affect data preserved in

1. IPCC, 2001, WG1, op. cit., Summary for Policy -Makers.

waterlogged, anaerobic, or anoxic conditions. It will also lead to the loss of stratification integrity due to cracking and heaving.

■ Changes in wetting and drying cycles will induce crystallization and dissolu-

tion of salts and thus affect buried archaeology as well as wall paintings, frescos and other decorated surfaces, including rock art.



*The Chavín Archaeological Site
Peru*

Chan Chan Archaeological Zone

Peru

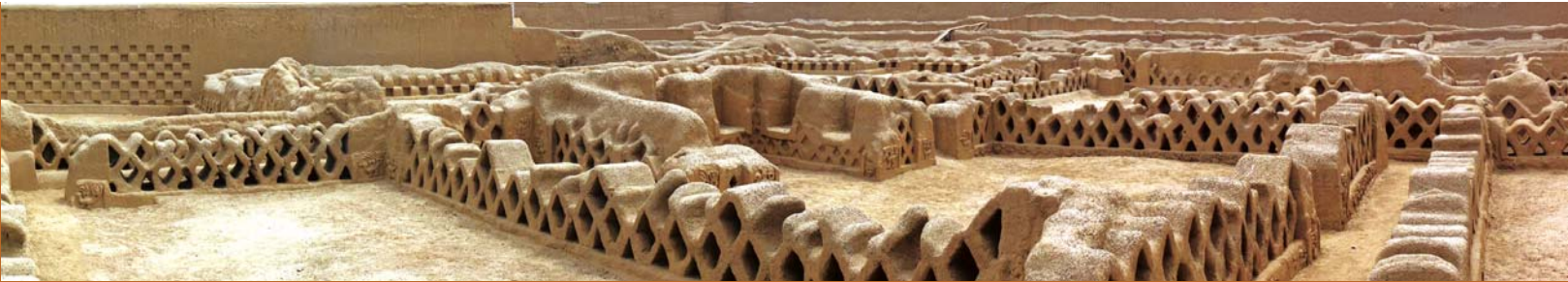
Chan Chan, capital of the ancient Chimú Kingdom, is one of the largest and most important prehispanic earthen architecture cities in the Americas.² The architectural ensembles and the complexity of the urban design reflect the high political, social, technological, and economic levels attained by the Chimú society between the ninth and fifteenth centuries, just before falling into the hands of the Incas. The archaeological complex, therefore, synthesizes the historical evolution of ethnic groups in northern Peru that contributed to the development of the Andean culture. The City of Chan Chan is also a symbol of the cultural identity at the local, regional and national levels.

At the height of its expansion, the city spread for over 20 km² out of which only 14 km² are preserved today. In the central urban zone, there are nine palaces, thirty-five architectural units and semi-monumental ensembles, six temples (*Huacas*), ceremonial roads and four extensive popular neighbourhoods (where there are evidences of wood, gold and silver working and weaving). Outside of the central area, diverse *Huacas*, agricultural units (*Huachaques*), and a road system that connected all the different components of the city can be found. The earthen architecture walls are decorated with raised friezes in which abstract motifs, anthropomorphic, and zoomorphic subjects add to the exceptional splendour of these large arrays of ruins.

The criteria that justified its inscription in 1986 on the World Heritage List stemmed from the fact that Chan Chan bears a unique testimony to the ancient Chimú Kingdom and is the largest city in pre-Columbian America. It is an absolute masterpiece in terms of town planning with rigorous zoning and differentiated use of inhabited space, and its hierarchical construction also illustrates a political and social ideal which has rarely been expressed with such clarity.

The vast and fragile site of Chan Chan was inscribed on the List of World Heritage in Danger the same year it was inscribed on the World Heritage

2. ICOMOS, 1985, *Evaluation of the Chan Chan Archaeological Zone for the World Heritage Committee*, 1985, available at: http://whc.unesco.org/archive/advisory_body_evaluation/366.pdf



General view of the Audiencias sector at Tschudi Palace. The Chan Chan Archaeological Zone is the largest city in pre-Columbian America and bears a unique testimony to the ancient Chimú Kingdom.

List. Its earthen structures are particularly vulnerable and thus quickly damaged by natural erosion as they become exposed to the environment, and they require continuous conservation efforts and substantial ancillary measures. The rapid and seemingly unstoppable erosion of the remains constitutes a serious obstacle to the in-depth knowledge of the site. Many of the structures excavated and surveyed in the past have suffered significant decay. Therefore, the World Heritage Committee recommended at the time of inscription that (1) appropriate measures be taken for the conservation, restoration and management of the site; (2) excavation work be halted unless accompanied by appropriate conservation measures; and (3) all possible steps be taken to control plundering of the site.



Grand courtyard at Tschudi Palace.

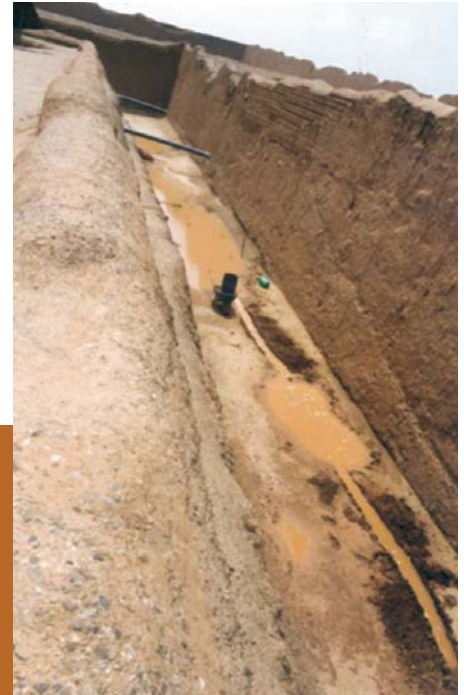
Impacts of climate change

4 Impact of El Niño events in northern Peru

The El Niño-Southern Oscillation (ENSO) phenomenon consistently affects regional variations of precipitation and temperature over much of the tropics, and sub-tropics.³ Over the northern coast of Peru, warm episodes of this oscillation (referred to as 'El Niño' events in opposition with 'La Niña' that correspond to the cold phases of the oscillation) are associated to large positive anomalies in precipitation.⁴ In coastal arid zones of northern Peru the historical average of annual precipitation is only 20 to 150 mm, but this area received up to 3,000 mm of rainfall during the El Niño event of 1997-98.⁵

The 1982-83 El Niño event is considered as one of the most intense of the twentieth century. The World Bank estimated the global losses at about US\$14 billion of which

US\$1 billion in Peru, mainly in relation to losses from fisheries revenue and destruction of infrastructure. In 1997-98, again, Peru suffered damages of the same order (of which 55% was transportation infrastructure, 15% agriculture, 14% energy, and 9% education).⁶



Partial flooding of the Tschudi Palace following the El Niño event of 1982-83.

Impact of extreme precipitations on Chan Chan Archaeological Zone

Intense precipitation is damaging the base of the earthen architecture structures. It leads to greater humidity in the lower parts of the buildings and, consequently, to an increase in salt contamination of the structures and to the growth of vegetation such as reeds and water lilies in the low lying *huachaques*.

A monitoring survey of the sixty-eight wells is underway since August 2000 and it has revealed a progressive rise of the water levels that had already reached alarming heights in

January 2003. This phenomenon is due to the combined effect of changes in the irrigation technology for extensive mono-cultures in the area, and the reduction of the use of water as the local population now obtains freshwater from a new system. But climate change poses an additional source of stress on this site and the intense precipitations during the 1997-98 El Niño events have also significantly contributed to the increase of the groundwater level.⁷

3. IPCC, 2001, WG1, op. cit., Summary for Policy-Makers.

4. IPCC, 2001, WG2, op. cit., Section 14.1.2.1.4.

5. IPCC, 2001, WG2, op. cit., Section 14.2.1.3.

6. World Bank, 1997, Annual Report, World Bank, Washington DC, USA.

7. IPCC, 2001, WG2, op. cit., Section 14.2.1.3.

Projected changes in El Niño events

In the recent past, a change in patterns of ENSO has been recorded according to the IPCC. Warm phases of the oscillation have been more frequent, intense and persistent since the 1970s compared to the previous 100 years.

The representation of El Niño events in climate models remains a challenge. Current

projections show little or small increase in amplitude of El Niño events over the next century. But the IPCC stresses that, even with little or no change in El Niño amplitude, global warming is likely to lead to greater extremes of drying and heavy rainfall and to increase the risk of droughts and floods that occur, with El Niño events, in many regions.⁸

Possible responses

Since Chan Chan was inscribed on the List of World Heritage in Danger, a Master Plan has been designed with support of the World Heritage Fund and the training for conservation and management has improved.

The first Pan-American Course on the Conservation and Management of Earthen Architectural and Archaeological Heritage, which directly benefits the preservation and management planning for the site, was held in Chan Chan in 1996, jointly organized by the Government of Peru, the International Organization for Conservation of Cultural Heritage (ICCROM), the International Centre for Earthen Construction (CRATerre-ENSAG) and the Getty Conservation Institute (GCI).

In September 1997, an emergency assistance fund was allocated to implement immediate measures to protect the most significant and

vulnerable parts of Chan Chan against the devastating impacts of the El Niño event that were projected to occur in 1998. Consequently, the impacts on the site were relatively modest, which shows that the protective measures were effective.

Long-term adaptation is also underway with the reinforcement and stabilization of the foundations and structures for the main buildings and the architecture surrounding the Huachaque of the Tschudi Palace. These works are carried out combining the use of traditional materials and skills, as well as modern engineering techniques.⁹



The Chan Chan Archaeological Zone.

8. IPCC, 2001, WG1, op. cit., Summary for Policy-Makers.

9. State of Conservation of the Chan Chan World Heritage Site, 2003, <http://whc.unesco.org/archive/2003/whc03-27com-07ae.pdf>

4 Ivvavik/Vuntut/Herschel Island

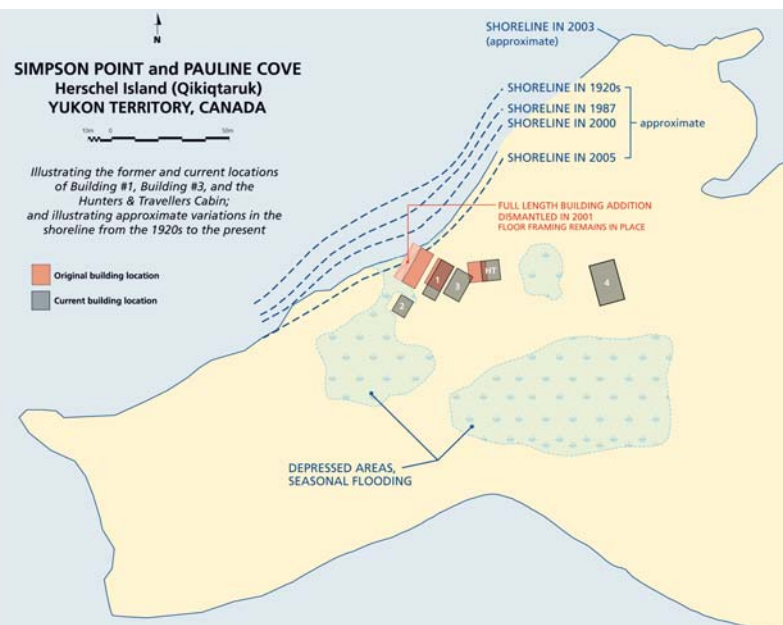
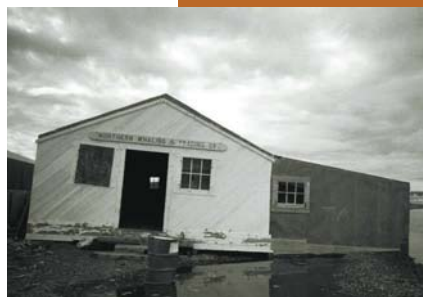
(Qikiqtaruk) Canada

Ivvavik/Vuntut/Herschel Island (Qikiqtaruk)¹⁰ is currently on the Canadian World Heritage Tentative List and being considered for nomination on the World Heritage List under both cultural and natural criteria. In this area, high mountains, boreal forest, tundra, expansive wetlands, coastal plains and an arctic island come together to form the living fabric of the arctic wilderness. Culturally, this land illustrates the very early human occupation of northwest North America via the Bering Yukon Refugium, the traditional land use adaptation of aboriginal cultural traditions to extreme environments, and the nineteenth-century whalers' settlement of Herschel Island. But it also possesses scenic beauty and outstanding natural phenomena, with mountains, wetlands, wild rivers and migrating wildlife species. It illustrates geological processes relating to Pleistocene events and Beringia and includes significant biological diversity, with a wide range of species including caribou, bear, waterfowl and marine life.

The values that could justify the inscription of this site on the World Heritage List are however currently under stress:

- The decrease of sea ice leads to a higher exposure of coastal areas to storms, therefore enhancing coastal erosion. Consequently, on Herschel Island, the Yukon Government authorities have been forced to undertake salvage archaeology of ancient Thule dwellings and move buildings inland to keep them dry and thus avoid flooding of low-lying areas. But if the shoreline erosion

On the Herschel Island Territorial Park (Canadian World Heritage Tentative List), the nineteenth-century whalers' settlement had to be relocated inland due to the progression of the shoreline, as a result of faster erosion when the sea-ice melts.



10. D. Olynyk, 2004, *Canada's Yukon Territory – Heritage at the Edge, Cultural Heritage in the Arctic and Antarctic Regions, ICOMOS Monuments and Sites VII, International Polar Heritage Committee.*



The destabilization of frozen ground threatens archaeological buried evidences of nineteenth-century whalers' settlements on Herschel Island Territorial Park.

progresses another move may be needed and abandonment of structures will need to be taken into consideration as the context and values of the whaling settlement site may become irreversibly compromised.

■ The deterioration of the Herschel Island permafrost is leading to ground slumping, which also threatens archaeological resources. This is posing an important source of stress on the historical grave markers and even caskets buried in graveyards around Pauline Cove. Some caskets are tumbling with the slumping soil and are being broken into pieces and pushed out. Some archaeological evidence of early human occupation has already been lost due to ground destabilization and erosion influenced by melting permafrost, wave action, and storm surges.

The fact that evidences of climate change threats appear on a site that is not yet listed as World Heritage raises an important concern regarding archaeological heritage. It means that such threats may also apply to other buried evidence whose existence we may not even be aware of currently.

Another striking example of this issue in the Yukon Territory was highlighted recently in and around the World Heritage site of Kluane/Wrangell-St. Elias/Glacier Bay/Tatshenshini-Alsek (Canada-USA).¹¹ This site was listed under all four natural criteria in 1979. But recently, culturally modified pieces of wood dating more than 9,000 years' old were discovered in a nearby, isolated alpine ice patch¹² (although such archaeological evidences are not related to the inscription of this site on the World Heritage List). In this area of North America, alpine ice patches are melting quickly as a result of rising atmospheric temperature. Consequently, we are facing a paradoxical situation where, on the one hand, if this ice patch was not melting we may never have discovered these evidences but on the other hand the conservation of these materials was guaranteed by the ice and is now under threat.

11. D. Olynyk, 2005, *Climate Change in the Western Canadian Arctic Threatens Cultural Resources, Heritage at Risk, ICOMOS World Report 2004/2005 on Monuments and Sites in Danger.*

12. P.G. Hare, et al., 2004, *Ethnographic and Archaeological Investigations of Alpine Ice Patches in Southwest Yukon, Canada, Journal of the Arctic Institute of North America, 57(3), pp. 259-271.*

The site of Chavín is the most significant and representative site of the Formative period (1500 to 300 BC) in the Peruvian Central Andes. It consists of stone-faced platform mounds, terraces, and sunken plazas and is characterized by a series of subsurface galleries. This former place of worship is one of the earliest and best-known pre-Columbian sites. Its appearance is striking, with the complex of terraces and squares, surrounded by structures of dressed stone, and the mainly zoomorphic ornamentation. Therefore, it was inscribed on the World Heritage List in 1985, as an exceptional testimony of a civilization which has ceased to exist.

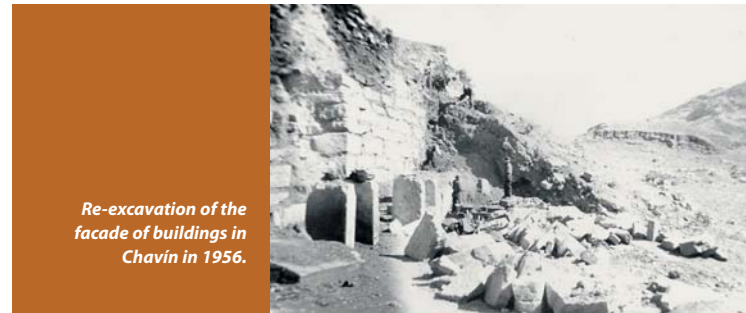
This site is located in the Province of Huari, Department of Ancash, at 3,150 m elevation in a high valley on the eastern side of Peru's Cordillera Blanca, at the confluence of the Mosna and Wacheqsa rivers.

Similarly to the site of Chan Chan (see p. 54) this site is exposed to extreme flooding events related to the important rainfall that occurs during warm phases of the El Niño Southern Oscillation. The Chavín site suffered from the adverse impacts of such floods in 1925, one of the most violent El Niño events in the twentieth century. The rain increased the flow of the Mosna River, and destroyed an important number of buildings on its banks.¹³

In addition, this site is located in the Cordillera Blanca (Peru), in the vicinity of the Natural World Heritage site of Huascarán National Park. As elsewhere in the world, glaciers are melting in this area, leading potentially to the formation of glacial lakes, and incidentally to glacial

lake outburst floods (see Chapter 1, p. 23).

On 17 January 1945, the archaeological site and part of the modern town were re-interred completely when a catastrophic debris flow – known in the Andes as an *aluvión* – swept over the monument. The phenomenon occurred when, near the headwaters of the Wacheqsa River (on the eastern slope of Central Peru's Cordillera Blanca) the waters of Laguna Ayhuinyaraju were disturbed by a landslide of snow and mud, causing the lake to breach the terminal moraine and empty into Laguna Carhuacocha. Like most lakes in this area, these lakes have a glacial origin. Their banks are made of accumulated moraine debris constituted by stone and clays and thus weak.¹⁴ In this particular case, the result was an estimated 900,000 m³ slurry of ice, rock, earth,



Re-excitation of the facade of buildings in Chavín in 1956.

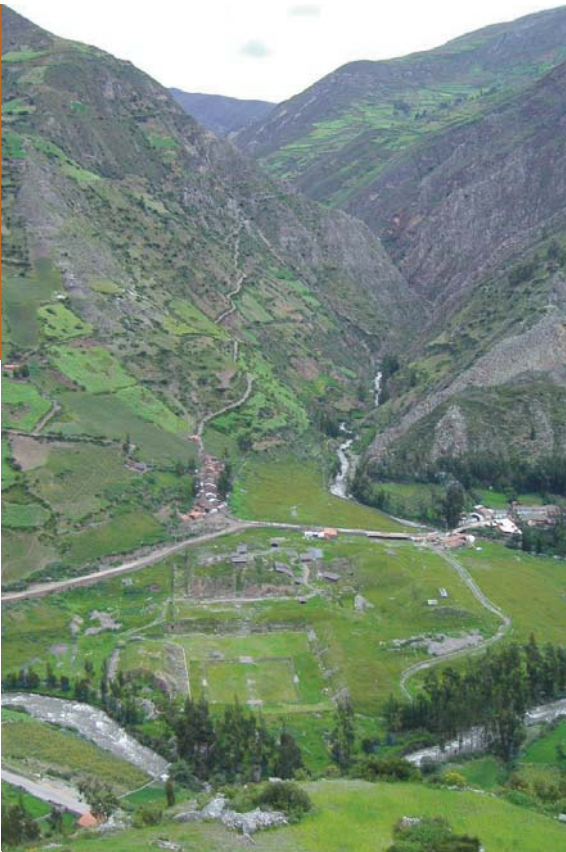
and water that descended the Quebrada Wacheqsa, at a speed of about 30 km per hour.¹⁵ At the Wacheqsa's terminus, where it feeds into the larger Río Mosna, the *aluvión* roared over the archaeological monument of Chavín de Huántar and a portion of the adjacent modern town of Chavín. The site was buried by up to 3.5 m of sediment, and the extensive underground galleries were largely filled by the pressurized injection of *aluvión* material.¹⁶

13. L.G. Lumbreras, *Excavaciones en Chavín de Huántar*, in press.

14. G. Indacochea and M. Iberico, 1947, *Aluvionamiento de Chavín de Huántar el 17 de enero de 1945*, Report for the Instituto Geológico de Perú, pp. 21-28.

15. Indacochea and Iberico, 1947, *op. cit.*

16. D. Contreras, 2005, *pers. comm.*, Stanford University.



Chavín is located in the Cordillera Blanca of Peru, at the confluence of the Mosna and Wacheqsa rivers.



Catastrophes associated with geological phenomena have affected populations in the Cordillera Blanca. Over the last sixty years notable modern geologic disasters have included debris flows that swept through the Cordillera Blanca towns of Chavín (1945), Huaraz (1962), and Yungay (1970). Impacts on the conservation of the archaeological site of Chavín are mentioned above, but such events have obviously dramatic consequences for the people living in this area. Catastrophic rock avalanches triggered by melting glacier headwalls are the most destructive type of landslides. Those of 1962 and 1970 resulted in 5,000 and 23,000 deaths respectively.¹⁷

Climate models project an increased rate of glacier melting in the future. It is thus critical to investigate further the geodynamics of glaciers, particularly in regard to the potential increase in the frequency and strength of landslides, so that preventive and emergency

measures can be adequately defined and, when possible, implemented.



The Chavín Archaeological Site is one of the earliest and best-known pre-Columbian places of worship.

17. G. Plafker and G.E. Ericksen, 1978, Nevados Huascarán Avalanches, Peru, in B. Voight, (ed.), *Rockslides and Avalanches*, Amsterdam, Elsevier, pp. 277–314.

Golden Mountains of Altai

Russian Federation

4

62

The Altai Mountains in southern Siberia form a major mountain range in western Siberia, with the total area covering 1,600,000 ha and representing the most complete sequence of altitudinal vegetation zones in Siberia, from steppe, forest-steppe, mixed forest, sub-alpine vegetation, to alpine vegetation. The site is also an important habitat for endangered animal species such as the snow leopard. The Altai Massif is spread across China, Kazakhstan, Mongolia, and the Russian Federation. Its Russian sector was inscribed on the World Heritage List under natural criteria in 1998.

Archaeological remains in the Golden Mountains of Altai: burial mounds (kurgans), Bronze-Age stelae and stone circles. The melting of permafrost threatens the conservation of unique grave articles and buried organic materials.



cultural characteristics but left few written records. And one of the only sources of information are the Scythian burial mounds, the so-called *kurgans*.

Situated in a permafrost zone, the grave contents (metal objects, gold pieces, etc.), and even organic materials (mummified and sometimes beautifully tattooed human bodies, sacrificed horses, objects in wood or leather, clothes, textiles, etc.), have been perfectly preserved.

The subtle equilibrium that enabled the formation and subsistence of the permafrost in the Altai Mountains, and therefore the preservation of the tombs, is now endangered by climate change.¹⁸ Over the past 100 years, there has been an increase in temperature of 1 °C in the vast area encompassing temperate Asia. The data from Barnaul, located in the foot slopes of the Altai, indicate an increase of 2 °C over the past 100 years, this increase being more pronounced in winter and spring. Hence, a significant reduction of the permafrost is

Although this site was not listed for its cultural values, it is worth noting that the Golden Mountains of Altai also bear a unique testimony to the Scythian culture that flourished in the Eurasian steppes during the 1st millennium BC. This nomadic civilization developed very particular

18. Workshop on The Frozen Tombs of the Altai Mountains: Strategies for the Future. Organized by UNESCO World Heritage Centre, the Gorno-Altai State University and the Ghent University, Gorno-Altai, Russian Federation, from 28 to 31 March 2006.



The Golden Mountains of Altai.

predicted for the middle of this century in the Altai Mountains. The remaining frozen kurgans are, therefore, extremely vulnerable to climate change and the conservation of valuable remains of the ancient nomadic cultures of the Eurasian steppes is threatened.

In addition, glacial lake outburst floods (see Chapter 1, p. 16) are also an issue in the Altai. The Sofiyskiy Glacier (Chuya Range) has retreated at a rate of 18 m per year during the twentieth century.¹⁹

Therefore UNESCO, in close co-operation with Ghent University (Belgium), has initiated a project²⁰ to carry out a complete survey of the

area, using satellite techniques in addition to traditional field investigations. When the survey will be completed the project will enter a phase of monitoring of the tombs located in a geographically discontinuous permafrost zone. The result of this initiative will provide a better understanding of the potential climate change consequences on the permafrost zone of the Altai Mountains, which will assist the relevant authorities in establishing a conservation strategy on how to preserve this unique cultural heritage.

19. F. Pattyn, B. DeSmedt, S. DeBrabander, W. Van Huele, A. Agatova, A. Mistrukov and H. Declair, 2003, *Ice Dynamics and Basal Properties of Sofiyskiy Glacier, Altai Mountains, Russia based on DGPS and Radio-Echo Sounding Surveys*, *Ann. Glaciol.*, 37, pp. 286–292.

20. *Preservation of the Frozen Tombs of the Altai Mountains, Flemish/UNESCO Cultural Trust Fund (2005-2006)*, <http://www.archaeology.ugent.be/altai/>

5

World Heritage

Historic Cities and Settlements

The adverse impacts of climate change will have consequences for humanity as a whole including the products of human creativity. In the case of built cultural World Heritage these consequences will be manifest in at least two principal ways: (1) the direct physical effects on the buildings or structures and (2) the effects on social structures and habitats that could lead to changes in, or even the migration of, societies which are currently maintaining the sites.

The character of cultural heritage is closely related to the climate. The rural landscapes have developed in response to the plant species that are able to flourish in different climatic regimes. The urban landscapes and the built heritages were designed with the local climate in mind. The stability of cultural heritage is, therefore, closely tied to its interactions with the environment. And where World Heritage sites are in daily use and occupied by local communities, significant adaptive changes may possibly be needed.

Climate change is expected to have a number of direct physical impacts on built heritage:

- Historic buildings have a greater intimacy with the ground than modern ones. They are more porous, draw water from the ground into their structures and lose it to the environment by surface evaporation, thereby causing corrosion or salt weathering as secondary effects. Their wall surfaces and floors are the point of exchange for these reactions. Increase in soil moisture might result in greater salt mobilization and subsequent damaging crystallization on decorated surfaces but also to a greater soil instability, ground heave

and subsidence. An increasing rate of heavy rainfall can cause severe problems for the historic rainwater systems that are not capable of handling heavy rain and are often difficult to access, maintain, and adjust.

- Shocks (extreme and sudden variations) or changes in the amplitude of the diurnal or seasonal variation of temperature and humidity can cause the splitting, cracking, flaking and dusting of materials and surfaces. For instance, special attention needs to be given to changes in the annual number of freeze/thaw cycles that put an important pressure on outdoor built structures.

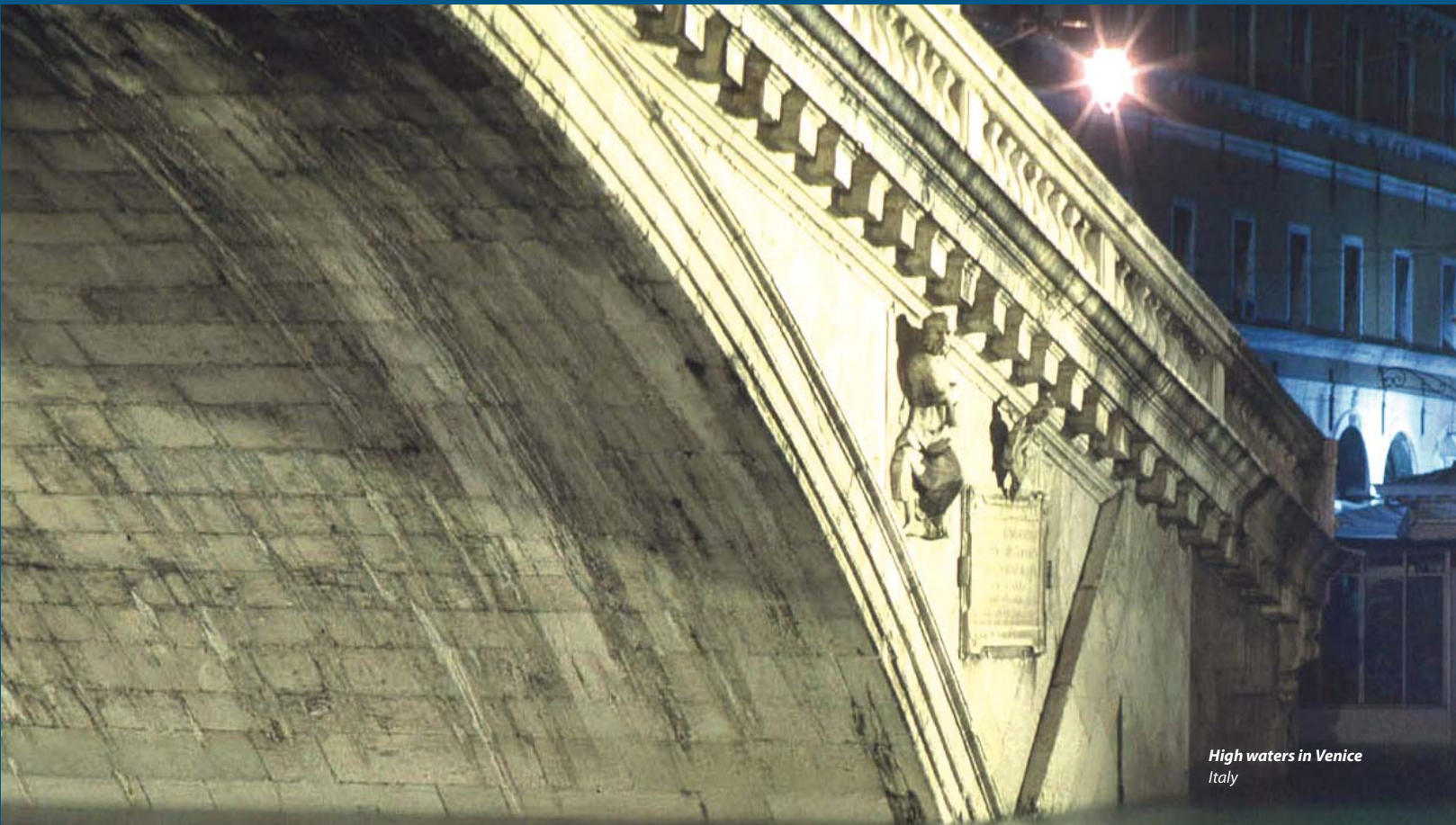
- Timber and other organic building materials may be subject to increased biological infestation as a result of migration of pests in altitudes and latitudes towards areas that were not concerned by such threats in the past.
- Flooding, with the invariably dirty water and the erosive character of rapid flowing water, will damage building materials not designed to withstand prolonged immersion. In addition, post flooding drying may encourage the growth of damaging micro-organisms such as moulds and fungi and staining.
- Coastal erosion, leading to a significant retreat of the shoreline can threaten coastal properties with total loss.
- Increases in storminess and wind gusts can lead to structural damage of whole structures as well as vulnerable elements.

- Desertification, salt weathering and erosion threatens cultural heritage in desert areas.

Climate change is primarily a threat that has physical impacts. But, in turn, these effects have societal and cultural consequences. When it comes to cultural 'dynamic' heritage – i.e. buildings and landscapes where people live, work, worship, and socialize – it is important to underline the cultural consequences. These consequences can be derived from the degradation of the property under consideration. But climate change can also force populations to migrate (under the pressure of sea-level rise, desertification, flooding, etc.) leading to the break-up of communities and to the abandonment of property, with

the eventual loss of rituals and cultural memory. As far as the conservation of cultural heritage is concerned, this abandonment raises an important concern in contexts where traditional knowledge and skills are essential to ensure a proper maintenance of these properties. In this respect, biological changes (with species shifting ranges) can also have an impact on conservation issues, with the reduction of availability of native species to repair structures and buildings.

The assessment of the impacts of climate change on cultural World Heritage must, therefore, account for the complex interactions among natural, cultural and social aspects.



*High waters in Venice
Italy*

World Heritage sites of the City of London

United Kingdom

There are three World Heritage sites located in, or in the immediate vicinity of, the City of London and on the banks of the River Thames, reflecting its erstwhile role as a major communication artery.

Westminster Palace, rebuilt as from the year 1840 on the site of important medieval remains, is a fine example of neo-Gothic architecture. This site – which also comprises the small medieval Church of St Margaret, built in Perpendicular Gothic style, and Westminster Abbey, where all the sovereigns since the eleventh century have been crowned – is of great historic and symbolic significance. These buildings were inscribed on the World Heritage List as one single site in 1987.

The Tower of London was inscribed in 1988. Focused originally on the central tower called the White Tower, built by William the Conqueror to protect London from invaders – and assert his strength and authority – it grew into a massive fortress with many layers of history, which has become one of the symbols of royalty, whose influence was strongly felt throughout the Kingdom.

The ensemble of buildings at Greenwich – an outlying district of London – and the Park in which they are set, symbolize English artistic and scientific endeavours of the seventeenth and eighteenth centuries. They were listed





Several World Heritage sites are threatened by tidal flooding in the City of London (United Kingdom), here: the Tower of London.

under four cultural criteria in 1997. The Queen's House by the architect Inigo Jones, was the first Palladian-style villa in England, while the complex that was until recently the Royal Naval College was designed by Sir Christopher Wren. The Park, laid out on the basis of an original design by the French landscape architect André Le Nôtre, contains the Old Royal Observatory, the work of Sir Christopher Wren and the scientist Robert Hooke.

Impacts of climate change

Climate change may lead to more frequent and intense flooding of the River Thames which flows through the City of London. The most significant flood threat to London arises from a combination of high tides and storm surges caused by low pressure systems travelling over the North Sea, and the funnelling of water from the southern North Sea into the Thames Estuary.¹

Consequently, the combination of rising sea level and changes in storm patterns will pose a significant threat to the World Heritage sites located on the banks of the River Thames. For a scenario of unmitigated future emissions,

climate models project that the conjunction of a rise in mean sea level and changes in storminess patterns will increase the incidence of flooding by storm surges.²

National Maritime Museum, formerly Royal Naval College, Greenwich.

1. London Climate Change Partnership, 2002, *Climate Change Impacts in a London Evaluation Study, Final Report*, 311 pp., http://www.london.gov.uk/gla/publications/environment/londons_warming_tech_rpt_all.pdf
2. J. Lowe, 2003, *The Effects of Climate Change on Storm Surges Around the UK*, in *The Big Flood: An International Scientific Meeting on North Sea Storm Surges*.



Westminster Abbey and St Margaret's Church.

rapidly than mean sea levels, partly because of the reclamation of inter-tidal areas and the deepening of channels.³

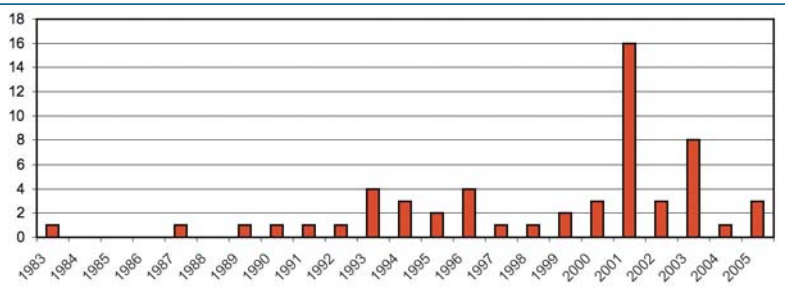
The City of London is protected to a high standard with tidal defences such as the Thames Barrier, designed and built in the 1970s in response to the catastrophic floods of 1953.



Observations in the Thames Estuary show that the mean and extreme water levels have been rising over the last two centuries. A long-term rising trend of 0.4 mm per year during the nineteenth century and 2.2 mm per year in the twentieth century has been observed at Sheerness (in the direction of the Thames Estuary). Extreme water levels have risen more

London and the Thames Estuary currently have one of the best tidal defence systems in the world which should have provided a high standard of protection to beyond 2030. But historical trends of extreme water levels were used for their design and now the effects of climate change present an unwelcome picture for flood risk in the future.⁴ The Thames Barrier was expected to function two to three times per year, but this number has been exceeded several times in the recent past.

Annual number closures of the Thames Barrier due to tidal flooding during the winter flood season. (Thames Estuary 2100)

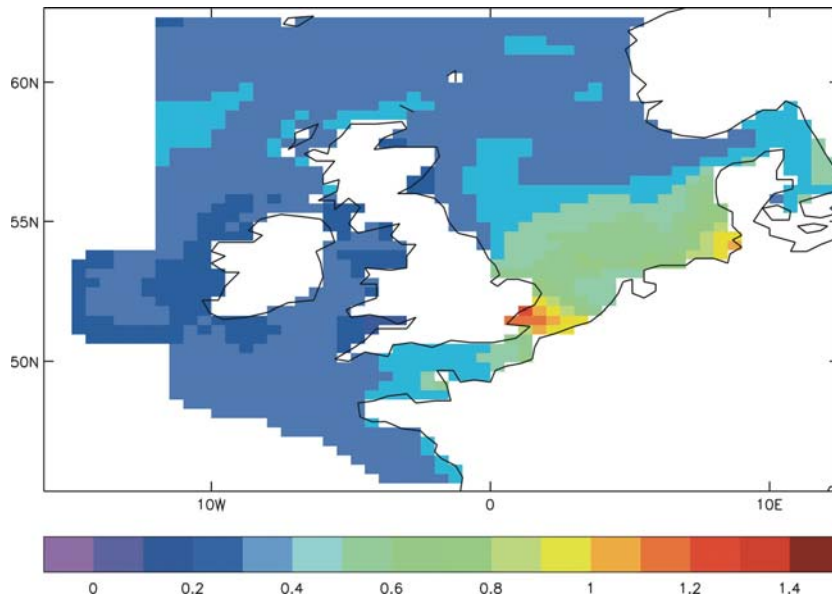


Projected global sea-level rise will pose an important threat to London. The United Kingdom Climate Impacts Programme (UKCIP) has suggested that the sea-level rise in the Thames Estuary will reach between 0.26 and 0.86 m by the 2080s compared to its average level between 1961 and 1990.⁵

3. K. Lonsdale, T.E. Downing, R.J. Nicholls, A.T. Vafeidis, D. Parker, R.J. Dawson and J.W. Hall, 2005, A Dialogue on Responses to an Extreme Sea-Level Rise Scenario in the Thames Region, United Kingdom, in ATLANTIS Atlantic Sea-level rise, Adaptation to Imaginable Worst Case Climate Change. <http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/annex13.pdf>
 4. S. Lavery, 2003, Planning for Flood Risk Management in the Thames Estuary: Looking Ahead 100 years, in The Big Flood: An International Scientific Meeting on North Sea Storm Surges.
 5. M. Hulme, G.J. Jenkins, X. Lu, J.R. Turnpenny, T.D. Mitchell, R.G. Jones, J. Lowe, J.M. Murphy, D. Hassell, P. Boorman, R. McDonald and S. Hill, 2002, Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK, 120pp, Chapter 6. http://www.ukcip.org.uk/scenarios/ukcip02/documentation/documents/UKCIP02_Ch6.pdf

Change in storm surge height (m) with a 50 year return period projected for 2080 with a scenario of medium-high greenhouse gases emissions. (UKCIP 2002)*

* UKCIP 2002 Climate Change Scenarios (funded by Defra, produced by Tyndall and Hadley Centres for UKCIP).



The Thames Barrier protects the City of London against tidal floods, but its design in the 1970s did not take into consideration the impacts of climate change.

In addition, global warming could induce a reduction in the total number of mid-latitude cyclones, but an increase in the number of intense events.⁶ And the combination of intense mid-latitude cyclones and rising sea levels favours the flooding of Western European tidal areas such as the River Thames.

By the 2050s, a 34 cm rise in sea level at Sheerness changes the one-in-1,000-year flood level, to a one-in-200-year flood event. By 2100, it is estimated that the Thames Barrier will need to be closed about 200 times per year to protect London from tidal flooding.⁷

Possible responses

Over GB£80 billion worth of property lies within the Thames tidal flood plain, the majority in London. Just one overtopping of the Thames Barrier will have an indirect cost blow to the British economy of GB£30 billion and it can be predicted that flooding will inundate at least the three World Heritage sites closest to the Thames, namely the National Maritime Museum, Greenwich, the Tower of London and the Palace of Westminster. Rapid flowing waters will erode their walls, and post-flooding drying will favour the growth of damaging micro-organisms such as moulds and fungi.

The Thames Barrier can holdfast up until 2025 before the 1,000-year return flood event is exceeded and, consequently, it is now timely to take appropriate adaptation measures. Monitoring is conducted through the project of the British Environment Agency 'Thames

Estuary 2100 Project (TE2100)' in a joint initiative between the Anglian, Southern and Thames Regions, which aim to determine the appropriate level of flood protection needed for London and the Thames Estuary over the next 100 years.⁸

6. S.J. Lambert and J.C. Fyfe, 2006, *Changes in Winter Cyclone Frequencies and Strengths Simulated in Enhanced Greenhouse Warming Experiments: Results from the Models Participating in the IPCC Diagnostic Exercise*. *Climate Dynamics*, 26(7-8), pp. 713-728.

7. London Climate Change Partnership, 2002, *op. cit.*

8. Thames Estuary 2100 Project, (TE2100), http://www.thamesweb.com/page.php?page_id=60&topic_id=9

Venice and its Lagoon Italy

5

Founded in the fifth century and spread over 118 small islands, Venice became a major maritime power in the tenth century. The whole city is an extraordinary architectural masterpiece in which even the smallest palaces contain works by some of the world's greatest painters such as Giorgione, Titian, Tintoretto, Veronese and other artists.

The City and its Lagoon are directly associated with events and living traditions, with ideas, beliefs, and artistic and literary works of outstanding universal significance. Therefore, it was inscribed in 1987 on the World Heritage List under all six cultural criteria.

In its evaluation, ICOMOS, acting as Advisory Body to the World Heritage Committee, added that 'Venice symbolizes the victorious struggle of humanity against the elements, and the mastery men and women have imposed upon hostile nature'. But this statement could be read under a different perspective in the context of climate change.

According to archaeological records, in the past Venice has been sinking at a rate of about 10 cm per century as a result of natural subsidence, i.e. the rise of water level caused by delta propagation and the compactness of sediments. But during the twentieth century, it lost an extra 10 to 13 cm because neighbouring industries were pumping groundwater out of the deep aquifers. This process ended in the 1970s but irreversible damage has already been done.⁹



These factors contribute to the local sea-level rise that should be considered in a broader context with climate change causing the global sea level to rise. The expected increase of global sea level was mentioned several times earlier in this publication. The melting of glaciers and icecaps, and the thermal

expansion of warmer sea waters result in an increase of the average volume of the oceans, also referred to as 'eustatic sea-level rise' to be differentiated from the relative sea-level rise, i.e. the net increase of the sea level as a result of both global and local changes.¹⁰

9. A. Somers Cocks, 2005, *Venice in Peril*. The British Committee for the Conservation of Venice, <http://www.veniceinperil.org/news/news.asp?id=86>

10. IPCC, 2001, WG2, *op. cit.*, Glossary.



High waters in Venice are becoming more frequent and climate projections with moderate greenhouse gases emissions trends suggest that Venice could be flooded daily by the end of the century.



The IPCC reports that the global average sea level rose between 0.1 m and 0.2 m during the twentieth century and it is projected to rise by another 0.09 m to 0.88 m between 1990 and 2100.¹¹ But regional specificities must also be taken into account. On the one hand, in the Mediterranean, the increase of sea levels is moderated by the declining freshwater input (with the decrease of average precipitations) and subsequent seawater density increase.¹² But on the other hand, deltas, islands, coastal wetlands and estuaries are among the most threatened coastal environments in Europe.¹³ Also the tidal range is an important factor, with projected sensitivity to a given sea-level rise reaching maximum values in areas with a small tidal range. The Mediterranean is typically an area of limited tidal range, which suggests that its vulnerability to sea-level rise will be exacerbated.¹⁴

The combination of local and global sea-level changes results in a net rising of the sea level in Venice. In the recent past, the frequency of flooding and damage to this unique city has greatly increased and out of the ten highest

tides between 1902 and 2003 eight have occurred since 1960.¹⁵ As far as future projections are concerned, according to the moderate scenarios of climate change, the projected net altitude loss of Venice will reach 54 cm by 2100. Consequently, if nothing is done, Venice could be flooded daily.

Solutions to the problem of flooding in Venice are the subject of a continuing debate.^{16,17} Considering that (1) dynamic management approaches that harness natural processes to counter sea-level rise rather than move to hard defences should be explored,¹⁸ and (2) the development of appropriate responses must account for the environmental challenges for Venice and its Lagoon, the Italian Government eventually opted for the implementation of mobile barriers (the so-called MOSE system, Modulo Sperimentale Elettromeccanico, or Experimental Electromechanical Module) to defend the City of Venice from high waters. The works are thus being initiated for the protection of St Mark's Square and for the construction of breakwaters at the Malamocco inlet.¹⁹

11. IPCC, 2001, WG1, op. cit., Summary for Policy-Makers.

12. M.N. Tsimplis, and T.F. Baker, 2000, *Sea Level Drop in the Mediterranean Sea: An Indicator of Deep Water Salinity and Temperature Changes?* Geophysical Research Letters, 27, pp. 1731-1734.

13. IPCC, 2001, WG2, op. cit., Section 13.2.1.3.

14. R.J. Nicholls, and N. Mimura, 1998, *Regional Issues Raised by Sea-Level Rise and their Policy Implications*, Climate Research, 11, pp. 5-18.

15. M. Chown, 2004, *New Scientist*, 25 December 2005, 77. <http://www.veniceinperil.org/news/news.asp?id=52>

16. E.C. Penning-Rowsell, C.H. Green, P.M. Thompson, A.M. Coker, S.M. Tunstall, C. Richards, and D.J. Perker, 1992, *The Economics of Coastal Management: A Manual of Benefit Assessment Techniques*, Belhaven Press, London, United Kingdom.

17. *Consorzio Venezia Nuova, 1997, Measures for the Protection of Venice and its Lagoon, Consorzio Venezia Nuova (concessionary of Ministry of Public Works, Water Authority of Venice), Venice, Italy.*

18. A. Sanchez-Arcilla, J. Jimenez and H.I. Valdemoro, 1998, *The Ebro Delta: Morphodynamics and Vulnerability*, Journal of Coastal Research, 14, pp. 754-772.

19. Cambridge University and Churchill College (Cambridge) in Association with the Venice based Consortium for Co-ordination of Research Concerning the Venice Lagoon System (Corila) under An Initiative by the Venice in Peril Fund (the British Committee for the Preservation of Venice). <http://ccru.geog.cam.ac.uk/research/projects/venice2003/background.html>

5 Historic Centres of Český Krumlov and Prague

Czech Republic

72

The Historic Centre of Prague was inscribed on the World Heritage List under cultural criteria in 1992. The Old Town was built between the eleventh and eighteenth centuries; the Lesser Town and the New Town illustrate the great architectural and cultural influence enjoyed by this city since the Middle Ages. Most magnificent monuments, such as Hradčani Castle, St Vitus Cathedral, Charles Bridge and numerous churches and palaces, were built in the fourteenth century under the Holy Roman Emperor Charles IV.

In 1992, the World Heritage Committee also decided to inscribe the Historic Centre of Český Krumlov, a Czech city located south of Prague. Situated on the banks of the Vltava River, the town was built around a thirteenth-century castle with Gothic, Renaissance and Baroque elements. It is an outstanding example of a small central European medieval town whose architectural heritage has remained intact thanks to its peaceful evolution over more than five centuries.

But the sites remain exposed to natural hazards, such as the severe floods that affected Eastern Europe in the summer of 2002. The World Heritage sites of the Historic Centres of Prague and Český Krumlov suffered significant damages from these events.

In Prague, some buildings recorded flooding up to 2 m above ground level and many waterlogged buildings collapsed. In Český Krumlov, the Historic Centre was flooded up to 4 m and

about 150 buildings of the medieval Gothic and Renaissance periods suffered considerable damage. It was only for the preference of medieval builders in the Czech region to use stone, bricks and lime, instead of the less durable wood or raw bricks, which prevented the damage from being much worse.

The biggest challenges encountered in the recovery of these floods were how to dry the waterlogged walls and structures before the winter brought frost damage. Preserving the authenticity of the sites after the floods proved to be difficult because of several pressures to replace historic features by modern materials assumed to be more resistant to floods.

To some extent, these flooding events can be related to climate change. The IPCC reported that it is very likely that average precipitation has increased by 0.5% to 1% per decade in the twentieth century over most medium- and high-latitudes of the Northern Hemisphere





The Historic Centre of Český Krumlov.

The Historic Centre of Prague has been exposed in the past to catastrophic floods, and future precipitation trends must be integrated in the design of anti-flood protection measures and management plans.

continental areas.²⁰ Also, the frequency of heavy precipitation events has increased by about 2% to 4% over the latter half of the twentieth century in these areas. The accurate simulation of short-duration, high-intensity, localized rainfall remains a challenge for climate models, even if important developments are expected in the years to come.²¹

Considering that (1) the IPCC warns that the frequency of intense precipitations events is very likely to increase over most areas worldwide²² and (2) World Heritage sites in the Czech Republic have proved in the past to be particularly exposed, it is now timely to implement appropriate response strategies.

The emergency actions taken in 2002 could prevent the sites from suffering further damage. But a strategic shift from a reactive to a proactive (preventive) approach is needed. Regular maintenance is far more efficient than timely interventions, and strong risk analysis and risk management components would greatly help in the conservation of such sites. That is why the Czech Government is currently reinforcing anti-flood protection of these World Heritage sites.

20. IPCC, 2001, WG1, op. cit., Summary for Policy-Makers.

21. IPCC, 2001, WG2, op. cit., Section 4.3.8.

22. IPCC, 2001, WG1, op. cit., Summary for Policy-Makers.

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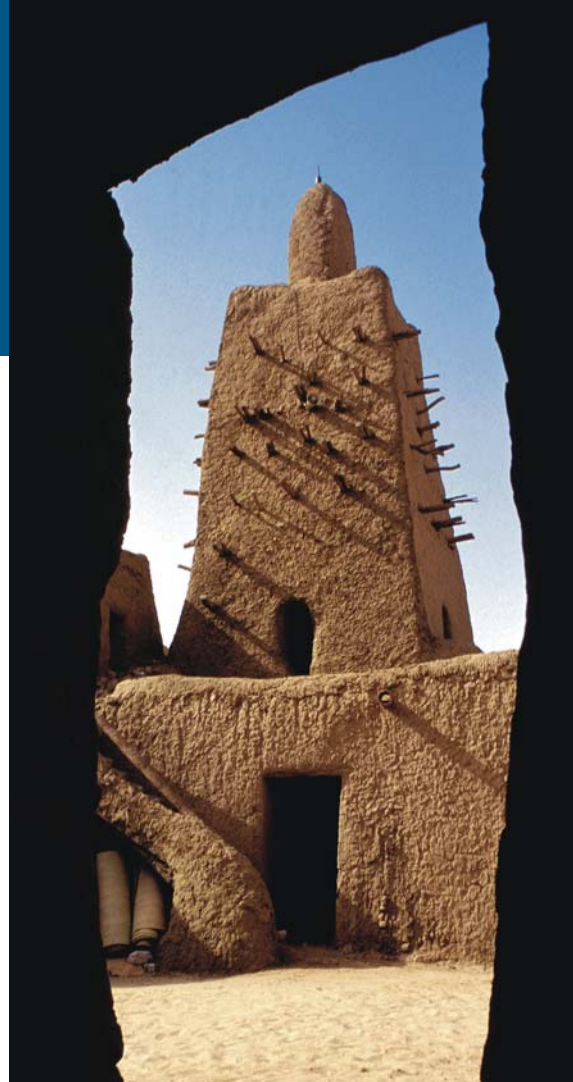
Timbuktu Mali

74

Home of the prestigious Koranic Sankoré University and other madrasas, Timbuktu was an intellectual and spiritual capital, and a centre for the propagation of Islam, throughout Africa in the fifteenth and sixteenth centuries. The three great mosques of Djingareyber, Sankoré and Sidi Yahia recall Timbuktu's Golden Age and were, therefore, inscribed in 1988 on the World Heritage List. But today, desertification threatens this World Heritage site.

The United Nations Convention to Combat Desertification (UNCCD) defines desertification as degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities.²³ It is estimated that in the recent past desertification in Africa has reduced by 25% the potential vegetative productivity of more than 7 million km², or one-quarter of the Continent's land area.²⁴

Desertification is also an important source of stress for the mosques of Timbuktu. In the past, the walls of the Sankoré mosque were continuously raised to combat sand encroachment. As a result, a difference of 1 m is observed between the current roof height and the height it reached in 1952. This threat of sand encroachment justified the inscription of Timbuktu on the List of World Heritage in Danger between 1990 and 2005 and a dedicated programme was set up to safeguard the site.



The threat of sand encroachment at the Sankoré mosque justified the inscription of Timbuktu on the List of World Heritage sites in Danger. Traditionally, the walls have been continuously raised in the past to compensate for sand encroachment – note here the difference between the height of drain-pipes in 1952 and today.

The identification of the factors responsible for the desertification in the region of Timbuktu is still debated among experts. As anywhere else in the world, the relative importance of climatic and anthropogenic (local) changes causing desertification remains unresolved.²⁵ Some scientists judge that anthropogenic practices outweigh climatic factors, while others argue that extended droughts remain the key factor. Also, it is worth mentioning the important feedback between climate change and desertification since land degradation subsequently affects the climate.

23. United Nations, 1994, *United Nations Convention to Combat Desertification (UNCCD)*. UN document No. A/AC.241/27, United Nations, New York, USA, 58 pp.

24. UNEP, 1997, *World Atlas of Desertification*, 2nd ed. United Nations Environment Program, E. Arnold, London, United Kingdom, 69 pp.

25. IPCC, 2001, *WG2, op. cit.*, Section 10.2.6.

Djingareyber is the largest and most complex of the Timbuktu mosques.



The restoration of the ancient mosques of Timbuktu was carried out by local craftsmen using traditional practices.

In the vicinity of the mosques of Timbuktu, the influence of anthropogenic desertification cannot be neglected because of traditional practices such as the renewal of fine sand inside houses before major religious holidays. However, climate change plays also an important role. Between 1901 and 1996, temperature increased by 1.4 °C in that area, and the impact of droughts is becoming significant. Projected changes show that in future the area will face a decrease in average rainfall, and an increase in atmospheric temperature, which will surely enhance desert encroachment and sand-blown damage in Timbuktu.

A second climate factor that deserves attention are the extreme precipitation events. In the recent past, the mud mosques in Timbuktu suffered severe damage from the heavy rains of 1999, 2001 and 2003 that caused the collapse of traditional earthen buildings, and also toppled down more recently-built structures. Modelling the changes in heavy precipitation patterns in the Sahelian Region is a real challenge. Nevertheless, the potential impacts that such events may have on the conservation on this unique site underline the need to address this important issue.

Several actions were undertaken to protect the City of Timbuktu from these impacts, including:

- the restoration of the mosques and damaged houses;
- the removal of the sand in the vicinity of the mosques;
- the creation of buffer zones to protect the mosques from sand encroachment;
- the improvement of the drainage systems of rainwater.

These activities were conducted by ensuring collaboration and active participation of all stakeholders (Imams, City of Timbuktu, Cultural Mission of Timbuktu, etc.). An important aspect of this project included the involvement of local craftsmen in the restoration process. And lessons learnt during this project constitute 'best practice examples' regarding the use of traditional practices, in ensuring the conservation of cultural heritage, in the face of climate change.

The success of these measures led the World Heritage Committee to withdraw Timbuktu from the List of World Heritage in Danger. But the emerging threat of climate change requires a close attention to be given to the conservation of this property.

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Ouadi Qadisha and (the Holy Valley)

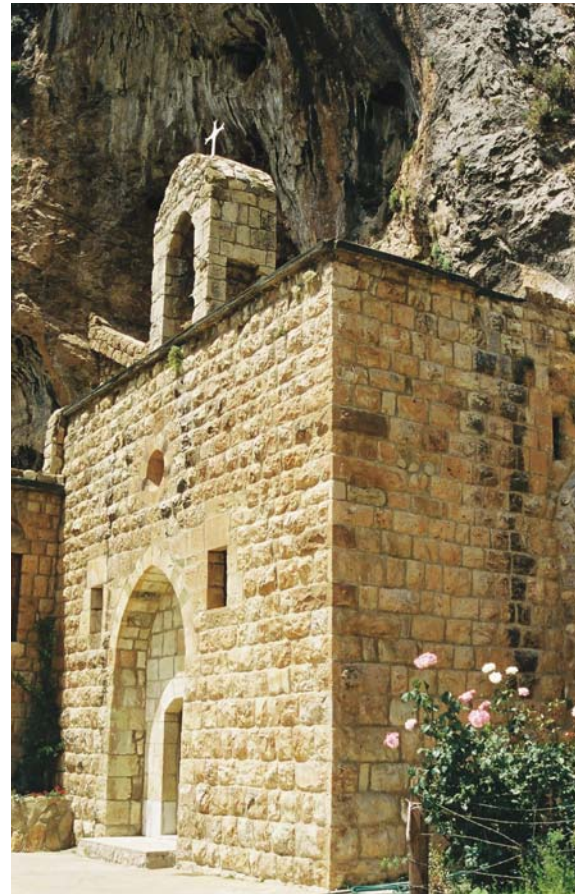
the Forest of the Cedars of God (Horsh Arz el-Rab)

Lebanon

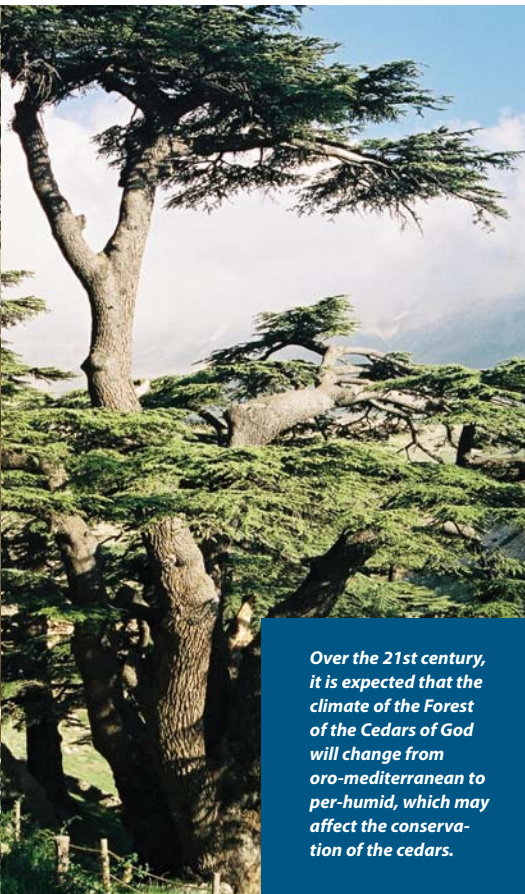
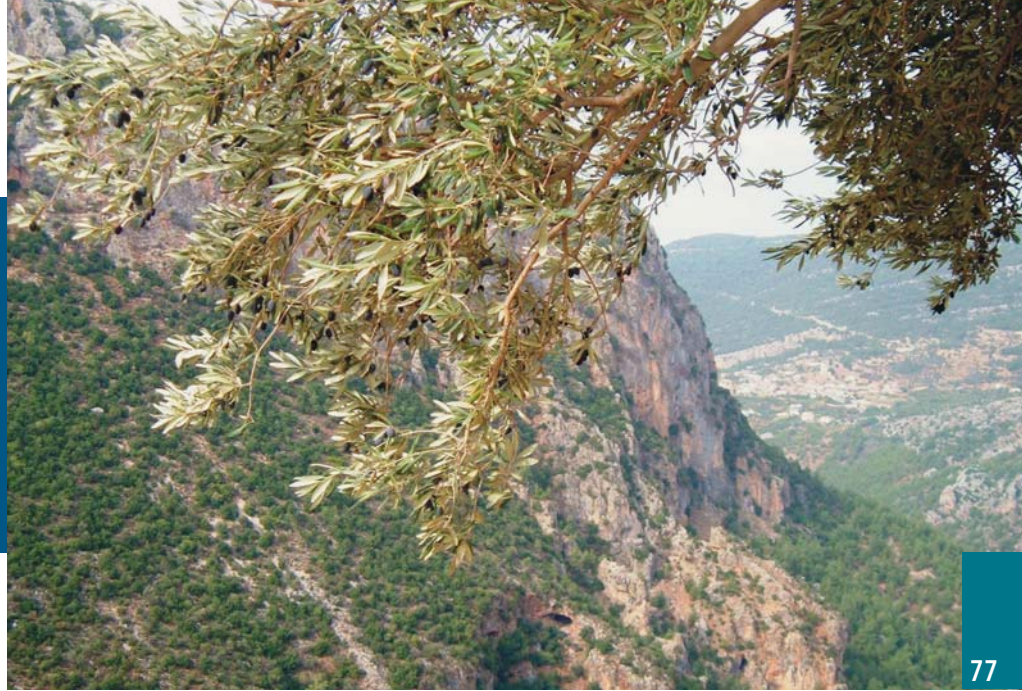
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Some World Heritage sites were inscribed under cultural criteria because of outstanding natural features that have a cultural importance. Therefore, if climate change affects the conservation of these natural characteristics, it may impair their outstanding cultural values as well.

The Ouadi Qadisha (the Holy Valley) is one of the most important early Christian monastic settlements in the world. Its monasteries, many of which are of a great age, stand in dramatic positions in a rugged landscape. Nearby are the remains of the well-known Forest of the Cedars of God of Lebanon, highly prized in antiquity for the construction of religious buildings. The cedar (*Cedrus libani*) is described in ancient works of botany as the oldest tree in the world. Due to its extra hard consistency and beautiful odour, it was used to build the ancient temples, palaces and armadas of the peoples of the area, including the Phoenicians, the Israelites and the early Christians.



Ouadi Qadisha.



Over the 21st century, it is expected that the climate of the Forest of the Cedars of God will change from oro-mediterranean to per-humid, which may affect the conservation of the cedars.

Current observed changes or threats on this World Heritage site relate more to direct interference of humanity than to climate change. However, there are already several indications that changes in the climate tending towards more aridity are taking place^{26,27} and may threaten the conservation of the Forest of the Cedars of God.

The Lebanese climate covers six bioclimatic zones: arid, semi-arid, sub-humid, humid, per-humid, and oro-mediterranean. Numerical experiments have been conducted to investigate future climate change over Lebanon by the years 2020, 2050 and 2080.²⁸ Model results show a significant change in percentage of areas representing the different bioclimatic zones. By the year 2080 a new zone will appear: 'extreme arid'. Some others will decrease, ranging between a shrinking of 18% for the humid zone to a complete loss for the oro-mediterranean zone by the year 2050. The arid area could increase possibly up to 13.2% by the year 2080.²⁹

The Qadisha Valley lies in the per-humid and humid areas and the Forest of the Cedars of God lies in the oro-mediterranean area. But the expected effect due to climate change for the Forest of the Cedars of God is to become per-humid, while the lower part of the Qadisha Valley would change to sub-humid.

These changes would imply a shift in climate-plant levels rendering some species unable to survive, as well as the invasion of other species at the expense of the native ones. Thus, spatial distribution, species composition and community structures would be affected,³⁰ which poses special concern for the conservation of the Forest of the Cedars of God.

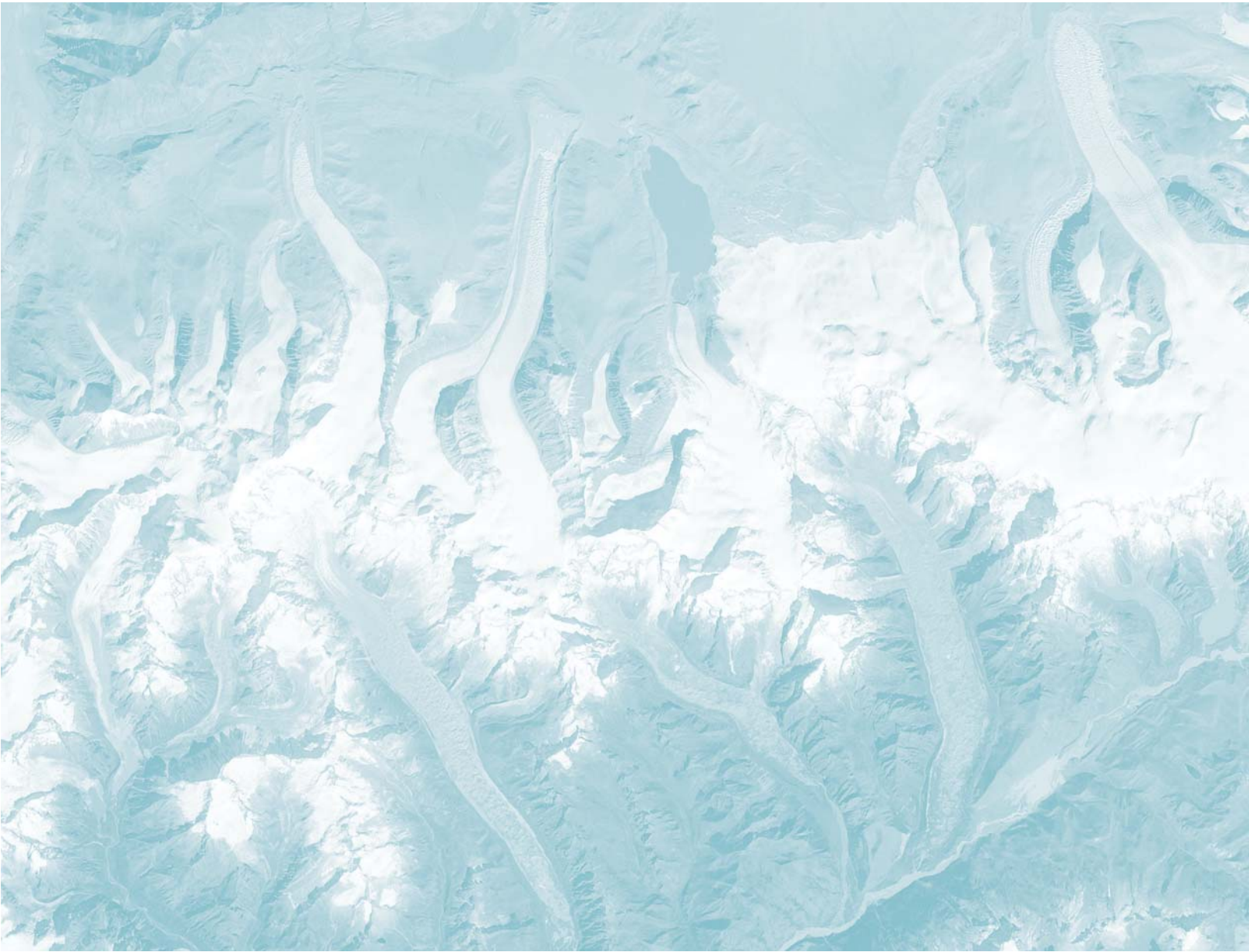
26. M. Khawlie, 1999, *Assessment of Lebanon's Vulnerability to Climate Change – Water Resources*, in *First National Communication on Climate Change*, Ministry of Environment, Lebanon, UNDP, GEF, B2, pp. 1-39.
27. M. Khawlie, 2003, *The Impacts of Climate Change on Water Resources of Lebanon – Eastern Mediterranean*, in C. Giupponi and M. Shechter, (eds.), *Climate Change in the Mediterranean – Socio-Economic Perspectives of Impacts, Vulnerability and Adaptation*, Edward Edgar Publication, UK, pp. 94-107.
28. Ministry of Environment, Lebanon, 1999, *Technical Annex to Lebanon's First National Communication on Climate Change*, Beyrouth, Lebanon.
29. S. Safi, 1999, *Assessment of Bioclimatic Change – Lebanon Case Study*, in *First National Communication on Climate Change*, Ministry of Environment, Lebanon, UNDP, GEF, B1, pp. 1-19.
30. R. Sadek, 1999, *Assessment of Terrestrial Ecosystems to Impacts of Climate Change*, in *First National Communication on Climate Change*, Ministry of Environment, Lebanon, UNDP, GEF, B4, pp. 9-38.

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There is general consensus that the climate of the planet is changing rapidly, and that human activities contribute significantly to this change. Climate change is now considered as one of the major environmental challenges of the twenty-first century.

The *Convention concerning the Protection of the World Cultural and Natural Heritage*, adopted by UNESCO in 1972, aims at ensuring that outstanding sites around the globe are effectively preserved and passed on to future generations. But this task becomes very challenging in a situation where, because of climate change, glaciers are melting; animal and plant species are migrating outside designated protected areas to adapt to their changing environment; pest infestation is spreading; coastal erosion is advancing with rising sea levels; frequency and intensity of storms is changing, and the Arctic Sea ice cover is reducing. Hence, World Heritage properties located in such environments are also threatened by these changes.

The UNESCO World Heritage Centre, in partnership with States Parties to the *Convention* and various international organizations, and under the guidance of the World Heritage Committee, is taking several initiatives to protect and promote management of World Heritage in the face of climate change: a dedicated strategy was endorsed by the World Heritage Committee in July 2006 and a report on predicting and managing the effects of Climate Change on World Heritage was prepared. A policy document on the subject was approved by the General Assembly of States Parties in 2007.

This publication presents several case studies from selected natural and cultural World Heritage sites around the globe in order to illustrate the impacts of climate change that have already been observed and those that can be expected in the future. For each of the featured sites, ongoing and planned adaptation measures are reviewed, to give an indication of what may be possible by way of management responses to the different situations.



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