THE **ARGUMENTS FOR PROTECTION** SERIES

Natural**Security**

Protected areas and hazard mitigation

A research report by WWF and Equilibrium

Arguments for Protection

Natural Security
Protected areas and hazard mitigation

A research report by WWF and Equilibrium

Written by Sue Stolton, Nigel Dudley and Jonathan Randall

Published 2008, WWF – World Wide Fund for Nature

ISBN: 978-2-88085-280-1

Cover design: HMD, UK

Cover photographs: *Top*: Tornado building in Indonesia © WWF / Albrecht G. Schaefer
Bottom: The debris following Hurricane Mitch. Tegucigalpa, Honduras © WWF-Canon / Nigel Dickinson

Acknowledgements

We would like to thank WWF, and in particular Liza Higgins-Zogib, Alexander Belokurov and Duncan Pollard for asking us to prepare this report and through them for the funding provided by the DGIS-TMF Programme (Project No: C8F0014.01): Poverty Reduction through Improved Natural Resource Management and by the World Bank.

Anita van Breda from the WWF-US Humanitarian Partnerships Program has provided guidance and comment throughout the development of the report. Surin Suksuwan from WWF-Malaysia worked with us throughout the final stages of the report providing comment and fantastic support in ensuring the WWF Network were aware of and able to comment on the draft. We would also like to thank L N Silva, M Bugalho and A Do Ó for contributing the case study on Portugal.

Kathy MacKinnon from the World Bank provided insightful comments on the final draft for which we are particularly grateful. Others who commented on the text include Arjan Berkhuysen, WWF-Netherlands; Richard Beilfuss, Department of Scientific Services (Gorongosa Research Center), Mozambique; Dr. Christine Bratrich, WWF Danube-Carpathian-Programme, Austria; Anurag Danda, WWF Sundarbans Coordinator, India; Finn Danielsen, NORDECO, Denmark; Pushpam Kumar, University of Liverpool, UK; Rizwan Mahmood, Freshwater and Toxics Programme, WWF-Pakistan; Musonda Mumba, Freshwater Programme, WWF-Eastern Africa Regional Programme Office; Prakash Rao, WWF-India Climate Change and Energy Programme; Dr Robbie Robinson, IUCN-WCPA; Asae Sayaka, Wetlands International, Thailand Office; Kirsten Schuyt, WWF-Netherlands, Tony Whitten, World Bank and Clive Wilkinson, Reef & Rainforest Research Centre, Australia.

Foreword

The International Strategy for Disaster Reduction (ISDR) welcomes this report as a concrete response to its call for work to promote understanding that: *protection of vital ecosystem services is fundamental to reducing vulnerability to disasters and strengthening community resilience*.

Although there is a growing recognition that natural habitats can help to mitigate disasters caused by vulnerability to hazards, we still have a great deal to learn about how to maximise the potential benefits and about what this means in terms of landscape-scale management approaches. Clear evidence linking habitat degradation to a series of so-called “natural” disasters have added urgency to the need for further research and monitoring efforts. These problems are likely to increase as a result of the disturbance caused by climate change. Research shows that the poorest members of society consistently fare worst when disaster strikes.

At the same time, natural ecosystems continue to be degraded at an alarming rate, so that in many countries we can no longer assume they exist in good enough condition to provide the environmental services upon which many people depend. In response, governments and local communities are setting aside and where necessary restoring natural habitats deliberately for their protective role. Although protected areas such as national parks and nature reserves are primarily designed to conserve biodiversity, most also supply important environmental services, including disaster mitigation. Whilst this is understood and acted upon by many protected area managers, it has never been systematically assessed and the current report makes a first attempt to provide a global overview.

By focusing the case studies on major disasters in the new millennium, the authors have deliberately chosen a fairly narrow data set rather than choosing “best case” examples. They have found cases where protected areas clearly play a major role in disaster mitigation and cases where the links are not so clear cut or where changes in management approaches within protected areas are needed.

One clear result of this study is a need for specialists in disaster risk reduction, environmental management and protected areas to work together far more closely than they have in the past. There is already much that could be done through better collaboration to increase the role of natural habitats in disaster mitigation and these opportunities will continue to increase as we learn more. We call on both communities to develop talks and to take the necessary steps to ensure that natural safety measures are maintained and enhanced.

Sálvano Briceño

Director, International Strategy for Disaster Reduction

Contents

Summary

This is the fifth volume in the WWF series of reports developed as part of the *Arguments for Protection* project which is assembling evidence on the social and economic benefits of protected areas to widen and strengthen support for park creation and management.

In this volume we explore the increasing number and severity of so-called natural disasters, review how environmental degradation is contributing to this trend, look at how conservation through protection is currently mitigating the impacts of hazards and disasters and discuss the options for further developing the role of protected areas in disaster prevention and mitigation strategies.

The 21st century has already seen the impact of some truly horrific and record-breaking disasters such as the Indian Ocean Tsunami and Hurricane Katrina in the US. Are these really the 'one hundred year' events policy makers tell us they are, or is the increasing destruction and fragmentation of biodiversity and the consequent decline in ecosystem services making the impact of such events more extreme? After all, the Millennium Ecosystem Assessment estimates that approximately 60 per cent of the world's ecosystem services (including 70 per cent of regulating and cultural services) are being degraded or used unsustainably, and notes that: "*Changes to ecosystems have contributed to a significant rise in the number of floods and major wild fires on all continents since the 1940s*" [1].

Economic losses from weather and flood catastrophes have increased ten-fold over the past 50 years, partially as the result of climate change. And with more than half of the world's population exposed to at least one hazard that has the potential to become a disaster this is a subject matter that none of us can afford to ignore. Disaster reduction strategies have many elements but this report focuses on two of the most important: prevention and mitigation.

At present, billions of dollars are spent on the aftermath of disasters even though experience shows that spending on pre-disaster mitigation is a far better value that can lessen the enormous suffering that disasters usually result in. The World Bank, for example, suggests that every dollar invested in effective disaster reduction measures saves seven dollars in terms of reduced losses from natural disasters. So, as in the other reports in the ***Arguments for Protection*** series, we argue that investment in a well-managed, ecologically representative, global system of protected areas can produce benefits far beyond the conservation of biodiversity. Therefore protected area professionals, need to consider the role of protected areas in disaster mitigation when planning, managing, and advocating the contribution protected areas make to society.

We recognise that there have been many international agreements and declarations linking the preservation of ecosystem services with the mitigation of disasters, but note that in many cases it is only the permanent and well-managed setting aside of land and sea as protected areas which can provide the stability and protection so often called for.

We find that protected areas can play three direct roles in preventing or mitigating disasters arising out of natural hazards:

- ✓ Maintaining natural ecosystems, such as coastal mangroves, coral reefs, floodplains and forest that may help buffer against natural hazards
- ✓ Maintaining traditional cultural ecosystems that have an important role in mitigating extreme weather events, such as agroforestry systems, terraced crop-growing and fruit tree forests in arid lands
- ✓ Providing an opportunity for active or passive restoration of such systems where they have been degraded or lost

Specifically we find that:
Natural or semi-natural habitats conserved in protected areas can help to mitigate flooding by:
- ✓ Providing space for floodwaters to go without causing major damage
- ✓ Absorbing the impacts of floods with natural vegetation

Protected areas retain natural vegetation, particularly forests, which can in certain circumstances, prevent and mitigate landslides and avalanches by:
- ✓ Stabilising soil and packing snow in a way that stops the slippage starting
- ✓ Slowing the movement and extent of damage once a slip is underway

Protected areas help to retain natural vegetation, reefs and landforms that can help block sudden incursions by seawater, with particular benefits from the stabilising effects of:
- ✓ Coral reefs
- ✓ Offshore barrier islands
- ✓ Mangrove forests
- ✓ Sand-dunes
- ✓ Coastal marshes

Protected areas can provide barriers against the impacts of drought and desertification by:
- ✓ Reducing pressure (particularly grazing pressure) on land and thus reducing desert formation
- ✓ Maintaining populations of drought resistant plants to serve as emergency food during drought or for restoration

Protected areas can protect against fire by:
- ✓ Limiting encroachment into the most fire-prone areas
- ✓ Maintaining traditional cultural management systems that have controlled fire
- ✓ Protecting intact natural systems that are better able to withstand fire

Protected areas can help address problems of hurricanes and typhoons through:
- ✓ Their role in mitigating floods and landslides
- ✓ Directly buffering communities and land against the worst impacts of a storm events (e.g. storm surge)

The main role of protected areas in the case of earthquakes is in:
- ✓ The prevention or mitigation of associated hazards including particularly landslides and rock falls
- ✓ Providing zoning controls to prevent settlement in the most earthquake prone areas

Protected areas can also play a role in addressing some of the underlying causes of disasters through, for example:
- ✓ Stabilising climate change through carbon sequestration
- ✓ Halting the loss of forest quality and quantity
- ✓ Protecting against river fragmentation and wetland loss
- ✓ Protecting coral reefs

However, discussing the role protected areas can play in disaster mitigation is, at least at present, not a wholly positive story. The under protection of some biomes, for example, coastal mangrove forests, and the exploitation rather than the conservation of forests and wetlands has left many areas extremely vulnerable to disaster; disasters which in reality are not ‘natural’ at all but are the consequence of our scant regard for the ecosystem services our natural environment provides.

We thus conclude this report with a 12 point **Action Plan for Integrating Disaster Mitigation Planning into Protected Areas** calling for:

Research

1. A great deal is already known about the role of natural ecosystems in mitigating disaster. Further research should now focus on the scale of disasters for which natural ecosystems can provide effective mitigation strategies. Appropriate natural resource management strategies should be identified.
2. Additional tools are needed to help planners identify the most valuable places where natural ecosystems need to be protected and/or restored to provide disaster mitigation services – through, for example, overlaying ecosystem data with hazard mapping in an opportunity analysis.

Planning

3. At a national and regional/transboundary scale opportunity analyses should be used to identify places where natural systems could mitigate disasters and to develop associated protection strategies, including the establishment of new protected areas.
4. At a protected area scale, some protected area authorities may consider revising their management objectives and management plans to better reflect and conserve the contribution of their protected areas in providing ecosystem services, including mitigating disasters.

Policy

5. The links between protected areas and disaster mitigation need to be made explicit when implementing or revising the various disaster reduction initiatives reviewed in Appendix 1.
6. Similarly, lending agencies and donors supporting protected area establishment and management should consider the disaster mitigation role of protected areas in project planning and implementation and facilitate the integration of environment and disaster management professionals.
7. Protected area managers and agencies need to build a working relationship with those working on disaster management before disasters happen to maximise synergies and opportunities.
8. Effective examples of where land and sea-use management are contributing to disaster mitigation need to be identified, application of management options field-tested and results disseminated to help other protected area mangers and agencies as well as disaster recovery agencies.
9. The underlying causes of the increase in hazard and disaster occurrence, such as climate change, forest loss and hydrological disturbance, should be addressed as part of a preventative strategy.

Funding

10. Further development is needed on economic evaluation of protected area contribution towards disaster mitigation and to investigate funding options for maintenance of natural defence systems, including innovative use of Payment for Environmental Services schemes and use of insurance premiums to maintain strategically important ecosystem services.
11. The effectiveness of protected areas in disaster mitigation is closely linked to management success, so that some of the funds available for disaster mitigation should be allocated to improve management effectiveness of protected areas.

Management

12. Once plans have been developed, protected area managers need to ensure that steps needed to maximise disaster reduction potential are included in day-to-day work programmes and priorities including relationship building with local disaster response agencies.

Preface

Not only must we emphasize the importance of nature's capital and the fact that it is being overused, we must also make people understand how nature's capital contributes to world stability and find ways to change the situation.
Klaus Toepfer former Executive Director of the United Nations Environment Programme[2]

This has not been an easy report to write – much of the literature on disasters centres on the terrible consequences of natural disasters on our fellow humans. Thanks to the world-wide web and global media network we can access first-hand accounts of the death and injury wrought by natural disasters and read vivid descriptions of the plight of those left behind in the wake of often overwhelming destruction. Despite the aim of researching and writing a report on environmental issues the stories of the people caught up in these terrible events are compellingly real, and provide what is often an appalling human backdrop to our analysis.

The orphanage in Tegucigalpa, Honduras, was stretched to the limit with children arriving every day after the disaster following Hurricane Mitch in 1998. Over 11,000 people died as a result of the Hurricane.

© WWF-Canon / Nigel Dickinson

But this is not a report about the human suffering which results from natural disasters – although the voices of those affected by disaster can be heard here. Rather it is a discussion about why our environment is becoming less effective in mitigating the effects of natural hazards, and how lack of environmental protection is contributing to the social, economic and environmental costs of disasters.

It is still a depressing story to tell. And the message is hardly new. In many parts of the world the link between environmental management and disaster mitigation has been known and acted upon for centuries. More recently environmental writers have been advising on the need for sound ecological management to mitigate the impacts of a range of natural hazards for 30 years or more[3].

This report repeats many of these calls, but concentrates on one specific conservation strategy, protected areas. Of course, conservation through protection is only one piece in the jigsaw puzzle of responses needed to ensure that when disasters happen the consequences are minimised. There will always be impacts – but if the harrowing accounts of suffering following disasters are to be reduced then every piece in the jigsaw puzzle of disaster management needs to be in place.

As the number of lives lost and the economic and social toll rise, the focus on disasters has sharpened. Report after report, conference after conference and agreement after agreement list the terrifying impacts of natural disasters on our world and call for better disaster management in the short-term and disaster reduction in the long-term. This report looks specifically at the latter issue and as such will contribute to the call from the 2005 World Conference on Disaster Reduction to take a closer look at "*the environmental aspects of disasters, and particularly in the critical roles in disaster reduction of managing and maintaining environmental systems to reduce the impact of disasters*"[4]; and provides input to the UN's Inter-Agency Secretariat of the International Strategy for Disaster Reduction (ISDR) note that "*Although the inherent links between disaster reduction and environmental management are recognized, little research and policy work has been undertaken on the subject. The intriguing concept of using environmental tools for disaster reduction has not yet been widely applied by many practitioners*[5].

Chapter 1: Natural Disasters: A Global Phenomenon

A healthy environment enhances the capacity of societies to reduce the impact of natural and human-induced disasters, a fact largely underestimated.
International Strategy for Disaster Reduction[6]

What is a natural disaster?

To discuss the impacts of disasters and the strategies available to mitigate their impacts it is important first to be clear about what we mean by the term disaster when linked to natural events (see box 1). As the ISDR points out: *"Strictly speaking, there is no such thing as a natural disaster, but there are natural hazards, such as cyclones and earthquakes … A disaster takes place when a community is affected by a hazard … In other words, the impact of the disaster is determined by the extent of a community's vulnerability to the hazard. This vulnerability is not natural. It is the human dimension of disasters, the result of the whole range of economic, social, cultural, institutional, political and even psychological factors that shape people's lives and create the environment that they live in."*[7]

The literature on disaster management has increasingly made the links between disasters and natural systems. Put simply if natural systems are degraded and the effectiveness of ecosystem services reduced then the consequences of natural hazards such as heavy rain, hurricanes, earthquake or drought are likely to be exacerbated and can in some cases lead to a disaster – hence the phrase "natural disaster". It is therefore likely that if natural systems are compromised, either locally through activities such as deforestation or wetland drainage, or globally, due to the impacts of climate change, the impacts of the disaster are likely to increase.

Terminology

Hazard: A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.

Disaster: A serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources.

Disaster risk management: The systematic process of using administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping capacities of the society and communities to lessen the impacts of natural hazards and related environmental and technological disasters. This comprises all forms of activities, including structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) adverse effects of hazards.

Disaster risk reduction (disaster reduction): Conceptual framework of elements which may minimise vulnerability and disaster risks, to either avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of disasters, within the broad context of sustainable development. The framework is composed of a range of actions including:

- ✓ Risk awareness and assessment including hazard analysis and vulnerability/capacity analysis
- ✓ Knowledge development including education, training, research and information
- ✓ Public commitment and institutional frameworks
- ✓ Measures including environmental management, land-use and urban planning, facility protection, application of science and technology, partnership and networking and financial instruments
- ✓ Early warning systems including forecasting, dissemination of warnings, preparedness measures and reaction capacities

Edited from the basic definitions on disaster developed by the UN's ISDR Secretariat[8]

Disaster prone

Results from a global analysis of disaster hotspots by the World Bank estimate that about 3.4 billion people (more than half of the world's population) are exposed to at least one hazard and that 25 million km^2, some 19 per cent of the Earth's surface, is prone to hazard[9]. One of the main reasons for the increasing attention being paid to natural disasters and their consequences is that there seems to be a strong trend towards more numerous hazards becoming disasters leading to greater loss of life and more serious economic impact. Given the amount of the world which faces such risks, the costs, in social, economic and environmental terms, of any increase in hazards and resulting disasters are likely to be great.

Much of the information collated on disasters comes from a few big insurance companies such as Munich Re and Swiss Re. Such information focuses on disasters linked to short-term events (i.e. earthquakes, fire, storms or other extreme weather events) as opposed to long-term events such as the effects of drought, and tends to provide the most detailed information, not surprisingly, on insured losses. But even given these limitations, insurance companies have been one of the first industrial sectors to examine closely the trends in disasters – natural and man-made.

Flooding in East Dongting Lake, Hunan Province, China. Over 20,000 people have died due to flooding in China since 1990 (source EM.DAT)

© WWF-Canon / Yifei Zhang

Over the last 50 years the number of disasters has clearly increased. Although some of this increase may be the result of more accurate reporting, the trends are hard to ignore. About 100 disasters per decade were reported from 1900-1940, this increased to 650 during the 1960s, 2,000 in the 1980s and reached almost 2,800 in the 1990s[10]. In 2001, one author predicted that the "*1990s may go down in history as the International Decade of Disasters, as the world experienced the most costly spate of floods, storms, earthquakes, and fires ever*"[11]. But this trend of increasing natural disasters and the impacts of disasters has continued into the 21st century, and now every decade seems to be the 'International Decade of Disasters'. Table 1 below lists some of the most serious disasters since the new millennium (in general, those disasters with the most victims and those accruing the most costly insurance losses according to Swiss Re in that year). Although by no means a complete list of all disasters the world has seen during this period, the list served as the basis for the choice of case studies in this report (emboldened in the Table). It also provides an overview of the causes of some of the most serious natural disasters between 2000 and 2006.

Extreme weather

Due to the many different types of extreme weather events, there has been a corresponding proliferation of definitions of extreme weather appropriate for different applications at different times and places[12].

The U.S. National Oceanic and Atmospheric Administration (NOAA) uses a definition of extreme weather based on an event's climatologically-expected distribution. An event is called extreme if occurs, for example, only five per cent or less of the time. NOAA notes, however, that the exact choice of cut-off of the climatologically probability value used in the definition is somewhat arbitrary.

A simple example of extreme weather is therefore when the temperature drops to a level which occurs less than five per cent of the time, say below -20 C. Extreme events, by definition, are rare[13].

Table 1: **Natural disasters of the 21st Century**

Cause	Impact	Loss of life	Insured loss: (US$ million)
	2000[14]		
Persistent rain in and around Mozambique (6th February)	**10 million people affected by flooding**	**919**	Not available (n/a)
Monsoon in India and Bangladesh (August)	**Floods**	**1,200**	n/a
Heavy rain in Tokai, Japan (10th September)	Floods	18	990
Storm Oratia in Northern Europe (29th October)	UK's 'hurricane', widespread structural damage	16	747
	2001[15]		
Earthquake in El Salvador, Guatemala (13th January)	Numerous landslides	845	n/a
Earthquake in Gujarat, India (26th January)	Major infrastructure damage. Felt across northern India and much of Pakistan, and in Bangladesh and western Nepal[16].	15,000	110
Hail storm and tornadoes in Kansas City, US (6th April)	Considerable structural damage and floods	0	1,900
Tropical storm Allison in the US (6th June)	Serious flooding in the southern United States, primarily in Texas	33	3,150
Torrential rainfall in Algeria (11th November)	Flooding	886	n/a
	2002[17]		
Earthquake in Afghanistan and Pakistan (25th March)	Houses destroyed and landslides blocked many roads. Felt in northern Afghanistan, the Islamabad-Peshawar area, Pakistan and Tajikistan[18].	2,000	n/a
Spring storm in the US and tornadoes (27th April)	Damage across east coast of US	6	1,675
Heavy rain in the Elbe and Danube catchment (August)	**Flood impacts in Germany, Czech Republic and Austria**	**38**	**2,500**
	2003[19]		
Tornadoes, hail and severe storms in US (2nd May)	Infrastructure damage	45	3,205
Earthquake in Algeria (May)	Infrastructure damage – thousands of homes destroyed	2,266	5,000
Heat wave in Europe (July-August)	**Forest fires (in Portugal costs estimated at US$1.6 billion)**	19	1,600
Heat wave in US (October)	Drought and forest fires particularly in California (housing cost losses estimated at over US$2 billion)	18	2,035
Earthquake in Bam, Iran (26th December)	Almost entire city destroyed and population buried under the rubble	41,000	1,000

Cause	Impact	Loss of life	Insured loss: (US$ million)
2004[20]			
Haiti and Dominican Republic heavy rain (23 May)	Floods and landslides	3,344	n/a
Hurricane Charley (11th August)	Significant infrastructure damage after making landfall in south-west Florida at peak intensity	24	8,000
Hurricane Ivan in the Caribbean and US, (September)	Catastrophic damage in Grenada and heavy damage in Jamaica, Grand Cayman, and western Cuba	124	11,000
Hurricane Jeanne in the Caribbean and US (13th September)	Floods and landslides, with Haiti worse affected	3,034	4,000
Earthquake and tsunami in the Indian Ocean (26th December)	**Major loss of life and infrastructure in South Asia**	**280,000**	**5,000**
2005[21]			
Hurricane Katrina in Gulf of Mexico (24th August)	**Floods and coastal impacts primarily in the US**	**1,326**	**45,000**
Hurricane Rita in Gulf of Mexico (20th September)	Most intense tropical cyclone ever observed in the Gulf of Mexico, significant damage in US	34	10,000
Earthquake in Pakistan (8th October)	**Landslides and floods**	**73,300**	**n/a**
Drought East Africa (failure of rains in later half of year)	11 million people faced with food shortages throughout East Africa and the Horn of Africa[22]	n/a	n/a
2006[23]			
Tornadoes and storms in the US (6th April)	Infrastructure damage	12	1,282
Tornadoes and storms in the US (13th April)	Infrastructure damage	1	1,850
Earthquake in Indonesia (27th May)	Destruction in heavily populated areas of Java	5,778	40
Heat wave in Europe (June)	Heat related deaths recorded in the Netherlands, Belgium and France	At least 1,900	n/a

The social impacts of disasters include loss of lives and livelihoods, injury and displacement, increased risk of disease, interruption of economic activities and loss of, or damage to, infrastructure, communications and important cultural values and heritage[24]. The World Health Organisation's Collaborating Centre for Research on the Epidemiology of Disasters (CRED) has been maintaining an Emergency Events Database (EM-DAT) since 1988. EMDAT contains core data on the occurrence and effects of over 12,800 mass disasters in the world from 1900 to present[25]. From this data the major five natural hazards by number of deaths are (starting with the highest death toll): drought; storms; floods, earthquakes and volcanoes[26].

As Table 1 indicates, the number of people affected by disasters remains staggeringly high; more people are affected by disasters than by war; at any one time it is estimated that 25 million people are displaced from their homes as a result of disasters[27]. The estimated figures for the number of dead provide chilling testimony to the devastating effect of disasters with over a million people being killed between 1970 and 1979; over 800,000 between 1980 and 1989; over 600,000 between 1990 and 1999 and already well over a million during the first six years of the new century[28]. But even using these figures of lives lost to chart the rise in natural disasters seems too simple as it fails to take into account the terrible suffering of all those displaced, widowed or orphaned, of the livelihoods ruined, the home lost and the environmental damage following disasters.

Although few of us could be considered as totally safe from natural disaster, some areas of the world are more disaster prone than others. This vulnerability to disaster increases as populations rise, urbanisation increases and more and more people move to high-risk areas such as floodplains, coastal areas, small islands and steep slopes. As well as living in areas vulnerable to natural hazards, the effect of development on disaster impact is dramatic in terms of social costs: on average, 22.5 people die per reported disaster in highly developed countries, 145 die per disaster in countries with medium human development, and 1,052 people die per disaster in countries with low levels of development[29]. Overall about 75 per cent of natural disasters between 1970 and 1997 occurred in the Asia and the Pacific region, mostly in the poorest of developing countries[30] and more than 95 per cent of all deaths as a result of natural disasters are in least developed nations[31]. The main reasons being that these areas are more susceptible to natural hazards in general, there is less planning control in relation to infrastructure development and countries are less prepared to mitigate the effects of disasters.

Encroachment of housing on the mangrove forest of San Pedro, Ambergris Cay, Belize.

The economic impacts of disasters are experienced through the damage or destruction to assets resulting from the hazard itself, or from the natural disaster that follows many hazard events. The insurance company Munich Re researched the trend of economic losses and insurance costs over the 50 year period at the end of the last century. The analysis of ‘great natural catastrophes’ (a natural catastrophe being defined by Munich Re as ‘great’ if the ability of the region to help itself is distinctly overtaxed, making interregional or international assistance necessary[32]) found that between 1950 and 1959 there were 20 such catastrophes accounting for US$38 billion in economic losses (re-calculated at 1998 values), between 1990 and 1999 there were 82 such events, with economic losses rising to US$535 billion. Disasters had thus multiplied fourfold, whilst economic losses were 14 times greater[33].

Although providing a useful indication of what disasters are costing us, figures relating to insurance losses do little to indicate the actual economic impact of disasters. For instance, in 1999 at least 42.5 per cent of the damage caused by the flooding in Austria, Germany and Switzerland was covered by insurance; in Venezuela during the same year, only four per cent of flood damage was insured. Furthermore, the most expensive disasters in financial or economic terms are often very different from those which are most devastating in human terms. Thus during the 1990s, on average earthquakes accounted for 30 per cent of all damage, but only nine per cent of deaths, whilst famine was responsible for 42 per cent of all recorded deaths, but accounted for four per cent of damage[34].

As with the social costs the impacts of disasters are felt unevenly across countries; and disasters can have very significant effects on already vulnerable economies. Among the least developed countries, 24 of the 49 face high levels of disaster risk[35]. For example, in the US the economic losses of the 1997-1998 El Niño were US$1.96 billion or 0.03 per cent of GDP; whilst the economic losses in Ecuador were US$2.9 billion, which represented 14.6 per cent of country's GDP[36]. Hurricane Mitch caused massive destruction and loss of life in Central America; Honduras was hardest hit with economic losses estimated at US$3.64 billion or about 69 per cent of GDP in 1998. In comparison, Hurricane Andrew resulted in estimated damages of US$30 billion in the US, but this accounted for less than 0.5 per cent of the GDP in 1992[37]. Overall the World Bank estimates that from 1990-2000, natural disasters resulted in damage of between 2 to15 per cent of an affected country's annual GDP[38]. Comparing the economic impacts of the 2000 flood in Mozambique with the 2002 flood in Central Europe (see case studies) illustrates the disparity in how national economies are impacted by natural disasters. According to the World Bank, the Mozambique flood resulted in a 45 per cent drop in GDP in 2000, whereas in Germany, the 2002 flood is estimated to have caused less than a one per cent drop in GDP[39].

The economic costs of disasters are also far reaching and there can be a long period between the actual disaster and the economic impacts. For example, low reservoir levels resulting from long-term drought and siltation linked to deforestation led to reductions in hydropower generation in Kenya in 1999 and 2000. Water and power rationing followed, with the losses from rationing alone being estimated at US$2 million per day, and the cost of unmet electricity demand was estimated at US$400-630 million, equal to between 3.8 and 6.5 per cent of GDP[40].

Dead cattle due to drought in Gujarat, India

Chapter 2: Causes of Disaster

Why does heavy rainfall in one area just result in a rather miserable day for anyone outside, while for others it leads to loss of life and infrastructure and massive environmental damage? There are many natural hazards which can trigger disasters, but these can be classified under two main types as defined by the ISDR Secretariat:

- ✓ *Geological hazard*: Natural earth processes or phenomena that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.
- ✓ *Hydro-meteorological hazard*: Natural processes or phenomena of atmospheric, hydrological or oceanographic nature, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation[41].

Whether these hazards turn into a natural disaster has been summarised by the following simple Pressure and Release (PAR) Model: *Disaster Risk = Hazard + Vulnerability.* The likelihood of hazards leading to disasters is thus primarily dependant on an area or people's level of vulnerability. Many issues can increase vulnerability but these tend to depend upon:

- ✓ root causes: e.g. limited access to resources or poor political or economic systems
- ✓ dynamic pressures: e.g. lack of training, skills, investment, local institutions
- ✓ macro-forces: e.g. rapid population growth or urbanisation, poor planning, deforestation, decline in soil productivity

Together these issues can result in vulnerable conditions (e.g. fragile physical environments or local economies, or lack of preparedness to disaster) which when combined with a hazard can lead to disaster[42]. The level of vulnerability, and thus the likelihood of a hazard developing into a disaster, is therefore in many cases in our control.

In this chapter we look at some of the issues relating primarily to environmental change which are making us more vulnerable to natural disasters, including climate change, forest loss, changing hydrology, coastal developments and overall issues of poverty and governance. In the following chapter we review the impacts that these factors are having.

Changing climes

Evidence of a link between climate change and climate variability is mounting rapidly. According to climate experts, as our climate changes the hydrological cycle will intensify, in particular rainy seasons will become shorter and more intense and droughts will grow longer in duration.

The Intergovernmental Panel on Climate Change (IPCC) states quite clearly that the "*warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level*" [43]. The evidence for change comes from the trends observed over the last century. The IPCC states (all the below have levels of confidence of above 90 per cent) that during the 20th century:

- ✓ Global mean surface temperature increased by 0.6-0.2°C, with land warming more than oceans
- ✓ Surface temperatures in the Northern Hemisphere increased more than in any period during the last 1,000 years
- ✓ Cold days decreased for nearly all land areas
- ✓ Continental precipitation increased by 5-10 per cent in the Northern Hemisphere and decreased in some regions (e.g. north and west Africa and parts of the Mediterranean)
- ✓ In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts increased in recent decades

- ✓ El Niño events (i.e. the major temperature fluctuations of surface waters in the tropical Eastern Pacific Ocean which affect the climate of the whole southern hemisphere) became more frequent, persistent and intense during the last 20 to 30 years compared to the previous 100 years[44].

And we are to blame. As the IPCC state: "*There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities. Detection and attribution studies consistently find evidence for an anthropogenic signal in the climate record of the last 35 to 50 years*"[45]. Anthropogenic climate change, or 'global warming', is caused by increasing concentrations of greenhouse gases which trap the heat in our atmosphere by preventing radiation from escaping into space[46].

The changes we are creating in our climate are having a direct impact on the hazards which can lead to disasters. Although geological hazards tend to lead to the greatest loss of life per event, hydro-meteorological hazards are affecting ever larger numbers of people: an estimated 157 million people in 2005, up by seven million compared to 2004[47]; and according to the World Water Council (WWC) "*Extreme weather records are being broken every year … Economic losses from weather and flood catastrophes have increased ten-fold over the past 50 years, partially the result of rapid climate change*"[48].

In many countries hydro-meteorological hazards are the major cause of natural disasters. In Malaysia, for example, most natural disasters result from heavy rains[49]. And whatever the reason, there is plenty of evidence that climates are fluctuating. A review of global changes in rainfall, for example, found increased variance in precipitation *everywhere*. In particular, there has been increased precipitation in high latitudes (Northern Hemisphere); reductions in precipitation in China, Australia and the Small Island States in the Pacific; and increased variance in equatorial regions[50].

Climate change thus has the potential to increase the severity of all types of hydro-meteorological hazards; for example flooding risks can increase in a number of ways: from the sea (higher sea-levels and storm surges); from glacial lake outburst (a problem in countries such as Nepal); and from rainfall – for instance, heavier rainfall or rainfall that is more prolonged than in the past[51]. The intensity and frequency of extreme rainfall and the projected decline in return period (i.e. an estimate of how long it will be between rainfall events of a given magnitude) of extreme rainfall events are also likely to result in more numerous landslides[52].

Although we are still only beginning to understand the links between our climate and global warming, climate change impacts, whatever the cause, are being felt all over the world. During the 1960s and 1970s, more than 90 per cent of the natural disasters in the United States were the result of weather or climate extremes, in particular due to increased precipitation; and the magnitude, frequency and cost of these extreme hydrological events in some regions of North America are predicted to increase further[53]. In subtropical South America, east of the Andes, annual precipitation has increased in some areas by as much as 40 per cent since the 1960s[54]. In China it was reported in 2005 that: "*disasters like typhoon, rainstorm and flood and low temperature and freeze injury were more severe than normal years*"[55]. Data on the West African drought of the 1970s and 1980s showed that decreased precipitation of 25 per cent lead to a 50 per cent reduction of water flowing into lakes and rivers[56].

Even apparently natural weather patterns seem to be changing. The El Niño events of 1997-1998 were the most intense occurrences of this climatic phenomenon during the 20th century, leading to extensive flooding, extended drought conditions and widespread wildfires[57].

Forest loss

Over the last century there has been a steep decline in global forest cover and a parallel, although less recognised, decline in the quality of much of the forest that remains. Deforestation, mainly conversion of forests to agricultural land, continued at about 13 million hectares per year from 2000 to 2005, a slight lessening of the rate in the previous decade, with most losses in the tropics[58]. Forest cover in temperate regions is increasing, following historical forest clearance, although much of this restored forest is in heavily modified form. Around 3.8 per cent of the global forest is made up of plantations[59]. There is no worldwide survey of forest degradation or commonly accepted definitions, but it is increasingly acknowledged to be a problem. Loss of forest quality can include removal of key species and simplification of composition and structure and fragmentation.

The loss of forest quality and quantity has been linked with increasing vulnerability to a number of hazards, including increased precipitation and storm surges, and can thus be a major contributor to floods, landslides and avalanches.

Forests provide a range of ecosystem services that can directly or indirectly mitigate natural hazards, see Table 2 below.

Table 2: **Hazard mitigation services from forests**

Service	Hazard
Protection of water catchments by forests	Floods
Protection of coasts by mangroves and coastal forests	Storms
	Tsunami
	Sea-level rise
Soil stabilisation	Landslip[60]
	Rapid erosion during floods or storms
	Desertification
Slope stabilisation	Landslip
	Avalanche
	Rock-fall
Water interception by cloud forests[61]	Drought
Shading canals and reservoirs to reduce evaporation	Drought
Windbreaks	Typhoons and storms
	Snowdrift
Firebreaks	Spread of fire
Non timber forest products	Back-up food sources in the event of drought etc

Direct cause and effect linkages are difficult to assess and also vary depending on the particular circumstances and the scale of flooding involved. Many authorities already consciously use forest protection or restoration to help mitigate floods and report positive results. Restoration of forests in the watershed above Malaga, Spain, centuries ago, for example, ended the flooding that had been recorded at regular intervals over 500 years[62].

There is less evidence that forest cover offers protection against major ‘once-in-a-lifetime’ floods[63]. In part this is because impacts of land use on hydrological and landscape processes can only be verified within small areas, and most research to date has been undertaken in small-scale watersheds. At a larger scale, with complex natural processes, it is difficult to detect changes due to specific land use, resource extraction or conservation practices, particularly on a short time scale[64].

Linking deforestation and flood risk

The theoretical connection between deforestation and flood risk has been made as follows:

- ✓ Removal of natural vegetation tends to reduce evapotranspiration losses
- ✓ Exposure of soil surface to the full energy of falling rain causes the break up of soil crumbs, clogging of pores and reduction of infiltration capacity
- ✓ Sun baking the soil leads to cracks that can speed drainage
- ✓ Vegetation thus reduces water loss through transpiration and interception[65].

Thus as the amount of rainfall increases, it is likely that the resilience offered by soil and plant cover diminishes as well[66]. Hurricane Mitch, for example, struck at a time when the soils were already saturated; it is argued therefore that the severe flooding that followed would have been inevitable even if the forest cover had been intact[67]. However, even in this situation models developed and verified in southern Honduras, based on data from the Namasigue watershed and validated in the adjacent El Triunfo watershed, have suggested that sites covered by shrub fallow and forests had relatively low incidence of landslides regardless even of the topographic features[68]. This issue is examined in more detail on page 39.

Destruction caused by the flood-waters of Hurricane Mitch, December 1998

Examples of natural disasters linked with deforestation include:

- ✓ Much of the damage that followed the cyclone that hit India's Orissa coast in October 1999 occurred in the extensively-deforested new settlement areas along the coast. A storm surge devastated a 100-km long stretch of coastline killing thousands of people. According to local reports, illegal immigrants had been encouraged to settle in the area by vote-seeking politicians. The construction of homes led to the destruction of sand dunes, mangrove and casuarina forests, removing the traditional barriers to storm surges and high winds[69].

- ✓ In 2003 the Indonesian Environment Minister likened illegal loggers to terrorists, after devastating floods on the island of Sumatra killed at least 80 people. The North Sumatra governor, Rizal Nurdin, blamed illegal logging for the disaster, and said the central government was not doing enough to tackle the problem[70].

- ✓ In the Philippines, flash floods and landslides in 2004 left over 1,600 people dead or missing. President Gloria Arroyo blamed the disaster on the indiscriminate logging that has left the country with less than six per cent of its original forests[71].

- ✓ In October 2005, Tropical Storm Stan brought record volumes of rainfall to El Salvador; it left 100 people dead and tens of thousands homeless. Resulting landslides in the mountain range of La Cordillera El Bálsamo, which crosses a large part of Salvadoran territory, left many communities without communication, electricity or water. For years, environmental groups, such as Friends of the Earth El Salvador, had warned of increasing vulnerability to flooding due to deforestation and wetland destruction[72].

✓ Changes in the Yangtze River basin in China have been blamed for the increasing severity of floods. Upstream deforestation (85 per cent of the forest cover in the Yangtze basin has been cleared by logging and agriculture[73]), reduction in the area and number of lakes and wetlands, and encroachment on flood plains have all been cited as having a detrimental effect on the river's ability to mitigate the effects of heavy rain. In 1998, severe floods of the Yangtze and Yellow Rivers displaced tens of millions of people, killed thousands, and caused about US$20 billion in damage[74]. Deforestation was believed to have had such a disastrous impact that during the height of flooding China's State Council issued an emergency order calling for immediate action[75]. Logging was banned in forests on the upper Yangtze River, and the middle and upper Yellow River, followed by a moratorium on logging across most of the country's natural forest[76]. Although some disagree on the exact role of deforestation in relation to this particular flood, there is general agreement on the long-term link between deforestation and flooding in the region[77].

Coursing over a distance of 6,380 km, the Yangtze is the longest river in China and the third longest in the world after the Amazon in South America and the Nile in Africa.

Changing flows

Fresh water fulfils our most basic needs – for drinking, washing and watering crops and livestock. Rivers can provide transportation links, power and nutrients. Natural wetlands have many ecosystem values, but these are often the areas we choose first to drain for our agriculture. It is no wonder therefore that so many of our settlements have developed near large bodies of water.

But our relationship has hardly been symbiotic. We've controlled, drained, dammed and diverted our water sources, often with little thought to the holistic function of rivers and wetlands. In Europe, for example, the River Rhine has lost more than 85 per cent of its natural floodplains to buildings and agriculture over the past two centuries[78].

The River Thames, London, UK. Over seven million people depend on the river for water and 124 sewage treatment works carry away the sewage of the 11 million people who live in the Thames Valley.

Analyses of river fragmentation world wide, found 37 per cent of the 227 large river basins reviewed were strongly affected by fragmentation and altered flows (i.e. with less than one quarter of their main channel left without dams) and 23 per cent were moderately affected. Although 40 per cent were found to be unaffected, the only remaining large free-flowing rivers in the world occur in the tundra regions of North America and Russia, and in smaller coastal basins in Africa and Latin America[79].

As figures on global wetland coverage differ widely, there is no precise source for the extent of wetland loss worldwide[80]. In 1996, however, the OECD estimated that the drainage of wetlands for agricultural production, the principal cause of wetland lost, has effected around 60 per cent of available wetland in

Europe and North America; 27 per cent in Asia, six per cent in South America and two per cent in Africa – making a total of 26 per cent wetland loss worldwide[81].

Of course many people argue that our need for productive agricultural land justifies our use of wetlands. But wetlands also have great value to mitigate natural hazards. A global assessment of the value of wetlands estimates that the median economic value of wetland (at year 2000 values) for flood control is US$464 per hectare per annum[82]. The Netherlands, a country famous for its iconic landscapes of agriculture and windmills created by wetland drainage, is turning back the clocks for some of its wetland habitats. With climate change threatening increases in sea-level and extreme river discharge, the economics of maintaining dykes (artificially constructed embankments) are being re-considered. As a result in areas which are not heavily developed, a multi-million Euro programme of river restoration is being carried out including the broadening floodplains, re-creation of water retention areas in natural depressions, and reopening of secondary river channels[83].

The famous windmills of Kinderdijk / Alblasserwaard, Rotterdam, the Netherlands

In general, the drainage of wetlands and marshes contributes directly to changes in the timing of runoff, the amount of natural storage in the basin, and the vulnerability of the channel to erosion[84]. Their loss increases the vulnerability of the watershed to flooding. Thus all over the world our rivers and wetlands can no longer provide their full range of ecosystem services. Without these services our vulnerability to hazard increases. Conversely, even our efforts to control rivers can increase vulnerability, as people often settle in flood-prone areas as they believe risks are lowered by protective structures such as dams, dykes and diversions, or because fertile, but still vulnerable land, is created by flow disruption. Structures that prevent rivers from flooding often provoke extremely damaging floods when water eventually overflows (see Mozambique case study)[85]; and in urban areas paving of surfaces significantly reduces infiltration, natural storage is reduced by improved drainage, and streams are often constricted by development or crossings[86].

Vulnerable coasts

When coastal processes are ignored and natural protection removed, the vulnerability to hazards is increased …[87].

Coasts are dynamic, fluid places which can provide an important defence against hazards. However human modifications of natural landforms and the effects of climate change are putting this mitigation role at risk. Changes in sea-levels are a natural part of a shoreline's evolution. However, climate change has been linked with rises in sea-level far beyond the normal evolutionary processes. Coastal wetlands are already declining by one per cent per year to indirect and direct human activities. If sea levels rise by one metre more half of the world's coastal wetlands could be lost[88]. And according to the IPCC this process is already underway as "*sea-level rise and human development are together contributing to losses of coastal wetlands and mangroves*", which is, as a result, "*increasing damage from coastal flooding in many areas*"[89].

Wide beaches and high dunes act as dissipaters of wave energy and dunes can provide natural protection between the ocean and inland property[90]. Salt marshes, mangroves and other forested estuarine wetlands act as the frontline coastal defence against incoming storms breaking the force of wind and waves[91]. In particular mangroves can have a regulating effect by protecting shores from storm surges and waves and by preventing erosion. But just as can be seen in other forest types, mangroves are losing quality and quantity. An FAO study of mangrove status concluded that the current mangrove area worldwide has fallen below 15 million hectares, down from 19.8 million ha in 1980 and that mangrove deforestation continued, albeit at a slightly lower rate in the 1990s (1.1 percent per annum) than in the 1980s (1.9 percent per annum). This decline in mangrove loss reflects the fact that most countries have banned the conversion of mangroves for aquaculture purposes and requires environmental impact assessments prior to large-scale conversion of mangroves for other uses[92].

There has been some computer modelling of wave force and fluid dynamics which suggests that tree vegetation may shield coastlines from tsunami damage by reducing wave amplitude and energy; and that 30 trees per 100 m^2 in a 100-m wide belt may reduce the maximum tsunami flow pressure by more than 90 per cent[93]. A study in Thailand looking at the correlations between disasters and mangrove loss between 1979 and 1996 across 21 coastal provinces found that a one km^2 decline in mangrove area will increase the expected number of disasters by 0.36 per cent[94]. The same study calculated the resulting economic impacts associated with changes in forest area, for 1979-96 and for 1996-2004. During 1979-1996, the estimated real economic damages per coastal event per year in Thailand averaged around US$189.9 million (at 1996 values). For this period, the marginal effect of a one km^2 loss of mangrove area is an increase in expected storm damages of about US$585,000 per km^2. Over the period between 1996 and 2004 the estimated real economic damage per coastal event per year in Thailand averaged around US$61.0 million (at 1996 values). For this period, the marginal effect of a one -km^2 loss of mangrove area is an increase in expected storm damages of about US$187,898 per km^2[295].

Results from monitoring programmes indicate that about 30 per cent of the world's reefs are seriously damaged. It is possible that there are no pristine reefs left in our oceans at all, and it has been predicted that 60 per cent of all reefs will be lost by 2030[96]. Not only is the loss of reefs having major impacts on biodiversity, but their role in mitigating sea-level rise is also being lost. In the Caribbean, a part of the world particularly vulnerable to storms, more than 15,000 km of shoreline could experience a 10-20 per cent reduction in protection from waves and storms by 2050 as a result of coral reef degradation[97]. Modelling of changes in the Seychelles suggests that wave energy has doubled as a result of sea-level rise, loss of coral reefs due to bleaching, changes in reef make-up and the wave regime. The models predict that, over the next decade, it will double again as a result of further damage to the reefs[98].

Devastated coastal area in Aceh province of Indonesia after the 2004 tsunami

© WWF-Canon / Yoshi Shimizu

Poverty and governance

"*Well-managed ecosystems can mitigate the impact of most natural hazards, such as landslides, hurricanes and cyclones. In addition, productive ecosystems can support sustainable income-generating activities and are important assets for people and communities in the aftermath of a disaster*"[99].

As noted in Chapter 1, the term 'disaster' has been defined as: a serious disruption to the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources. Of course, any natural event has the potential to "*exceed the ability of the affected community or society to cope using its own resources*". But generally the more vulnerable communities or societies are likely to feel the worst impacts. This vulnerability to the impact of hazards is highest in developing countries, where consequently over 90 per cent of natural disasters fatalities occur[100]. The poor suffer more from the impacts of disasters and recover more slowly after the event.

Many of the environmental issues highlighted in this report are directly related to issues of poverty and governance. Around the world, the pressures of poverty, population growth and inequitable land rights are forcing people to live or produce food in the most vulnerable areas, such as steep hillsides and unprotected riverbanks. Research suggests that 80 per cent of the poor live on marginal land in Latin America, with 60 per cent in Asia and 30 per cent in Africa[101]. Much of this marginal land will be relatively more susceptible to a variety of extreme weather events. In Honduras, for example, 90 per cent of the best agricultural land is owned by 10 per cent of the population. As a consequence 82 per cent of the rural population in Honduras and over two thirds of rural populations in Guatemala and Nicaragua live on the fragile hillsides[102]. Furthermore, migration to urban and coastal areas has increased the number of people vulnerable to hazard so that although seismic activity has remained constant over recent years, the effect of earthquakes on the urban population appears to be increasing[103].

Although poorer people are more susceptible to natural disasters, where resource rights are clearly defined, equitable and verifiable, poor and marginalised communities are better equipped to survive disasters and recover after them[104].

Chapter 3: Disaster Impacts

"Many ecosystems have been frayed to the point where they are no longer resilient and able to withstand natural disturbances, setting the stage for 'unnatural disasters' – those made more frequent or more severe due to human actions. By degrading forests, engineering rivers, filling in wetlands, and destabilizing the climate, we are unraveling the strands of a complex ecological safety net."

Janet Abramovitz, WorldWatch Institute [105]

Unnatural disasters?

Our environment should provide us with some defence against natural disaster, but as our activities increasingly undermine the environment, our vulnerability to hazard increases as does the likelihood of disaster striking and the impacts of these disasters being devastating. As UNEP states: "*'Natural' can be a misleading description for disasters such as the droughts, floods and cyclones which afflict much of the developing world. Identifying human-induced root causes, and advocating structural and political changes to combat them, is long overdue*".[106]

This refining of the terminology relating to so-called 'natural' disasters is rooted in some worrying data; while the number of geological disasters has remained reasonably steady, the number of hydro-meteorological disasters has increased. This chapter thus concentrates on a range of hydro-meteorologically linked disasters, including flooding, hurricanes/typhoons, landslides, drought, desertification and fire.

Woman standing in front of her home destroyed by Hurricane Mitch, Los Juanitos village, Choluteca, South Honduras, November 1998

© WWF-Canon / Nigel Dickinson

Hydro-meteorological events

Many of the natural processes linked to hydro-meteorological events are critical to ecosystem health. Floods, for example, perform a range of ecologically valuable functions by distributing large amounts of water and suspended sediment over vast areas, restocking soil nutrients to agricultural lands and replenishing water supplies. But, as the previous chapter discussed, a range of issues are increasingly affecting these natural processes and helping to turn them into the disasters that regularly hit headlines around the world.

In the 1990s more than 90 per cent of those killed by natural disasters lost their lives in hydro-meteorological events[107]. As noted earlier the world's most vulnerable populations – in particular those living on fragile or degraded lands – are most likely to bear the brunt of 'natural' disasters. In 2005 half the international disasters dealt with by OCHA, the UN Office for the Coordination of Humanitarian Affairs, were related to climate; by 2007 nearly all were climate-related[108].

There has been a general upward trend in the number of natural disasters in Asia and the Pacific due to hydro-meteorological events in the region[109]. Other areas, such as Central and South America are also becoming increasing vulnerable:

- ✓ *"[Hurricane] Mitch was not a natural disaster. The disasters have been happening over the years while we have been devastating the forests, burning the soils, and leaving the watersheds unprotected. Mitch was just a response to all those disasters*." Raúl Zelaya, World Neighbours Area Representative, Central America[110]
- ✓ "*We expect the impacts of a changing climate to increase, with a greater area of our country becoming desert, more woods and jungle being lost, torrential rains, hurricanes and greater seasonal instability*." Asociación Mexicana de Transformación Rural y Urbana, Mexico[111]

Flooding

UNEP has characterised five main types of flood:

- ✓ Flash floods: which follow heavy rainfall in a short period over a relatively small area, they are common in arid, hilly and steep areas, mountainous regions and metropolitan areas.
- ✓ River floods: which follow seasonal prolonged heavy rain, melting snow or a combination of both. River floods occur when water flow surpasses the capacities of natural or artificial banks of a river or when dams or dykes break. River floods are often the result of poor planning and design, either in terms of river bank or floodplain management or dam/dyke building and maintenance.
- ✓ Coastal and estuarine floods: caused as a result of sea-level rise beyond normal levels usually due to ocean storm surges and tsunamis.
- ✓ Glacial lake outburst: leading to floods in high mountainous glacial environments; an increase has been attributed to global warming and the resulting snow and ice melt.
- ✓ Ponding: when water accumulates in closed depressions as a result of soil saturation or impermeability, typically on manmade surfaces or soils with slow percolation rates[112].

Flooding is of course a natural, and often beneficial, process. However, floods can also become disasters. Indeed, of all the natural disasters, floods have the greatest potential to cause sudden, catastrophic damage and affect the greatest number of people worldwide. Every year flooding accounts for two thirds of the people affected by natural disasters[113]; between 1971 and 1995 floods affected more than 1.5 billion people worldwide[114]. During the ten-year period from 1986 to 1995, floods caused a global economic loss of about US$195.3 billion[115].

Over 90 per cent of people affected by natural disasters worldwide live in Asia as many of the countries in the region have large populations and are particularly prone to flooding[116].

Flooded areas of the Dongting Lake, Hunan Province, China

© WWF-Canon / Michel Gunther

There is evidence that the number of people affected and economic damages resulting from flooding are rising at an alarming rate[117]. Research released in early 2007 reported that floods increased by 57 per cent in 2006, compared to 2004[118] and the IPCC has predicted potential future increases in flood peaks of approximately 15 per cent in temperate zones due to increased storm activity and overall increases in precipitation[119]. Regional changes in water levels and flooding back up these trends:

- ✓ Since 1998 floods in Europe have caused some 700 deaths, the displacement of about half a million people and at least Euro 25 billion in insured economic losses[120]. The floodwaters of the River Rhine at the French-German border, for example, rose 7m above flood level approximately once every 20 years between 1900 and 1977. Since 1977, that level has been reached on average once every other year[121].

- ✓ In 1993 the Mississippi River in the US submerged 75 towns, killed 48 people and cost US$10–20 billion in damages. Over the previous century modifications have resulted in the loss of up to 85 per cent of the river basin's wetlands, and changes in riparian and in-stream habitat[122]. Following the floods the government bought out some flood-prone residents and moved them to areas outside the 100-year flood plain, thus reducing future claims[123].

Hurricanes and typhoons

When cyclones develop sustained winds of 119 km an hour they become the most destructive storms known on earth: the hurricanes of the Atlantic and northeast Pacific or the typhoons of the western Pacific. Concern about an increase in storm intensity was first raised in 1988[124], based on the theory that in a warmer world, deeper depressions could produce stronger winds, waves and storm surges. The IPCC, for example, states that models indicate that "*it is* likely *that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation*"[125]. Although the debate about the impacts on climate change is far from over, there is already evidence of more severe storm events. In 2005, for example, Latin America and the Caribbean experienced 26 tropical storms including 14 hurricanes – one of the most destructive hurricane seasons in history[126].

We do know that globally our seas are warming; since 1900 the mean surface temperature has risen by approximately 0.4°C. Cyclones are 'fuelled' by warm and humid air above tropical oceans which must be at least 26.5°C and 50 m deep. It would thus follow that the warmer our seas the more areas will reach this critical temperature and more storms will develop[127]. Until recently, only two tropical cyclones had been recorded in the South Atlantic, and no hurricanes. But on 28 March 2004, the southern coast of Brazil saw its first ever hurricane, Hurricane Catarina. Twenty-three cities were struck and 33,000 people were left homeless. Hurricanes do not normally occur in the South Atlantic because sea-surface temperatures are too low to develop intense weather systems; however, researchers from Brazil's National Institute for Space Research believe that Catarina was related to warmer sea temperatures. They warn that some areas rarely or never visited by hurricanes may become vulnerable to more frequent severe storms in the future[128].

At a time when the possibility of damage from storms is increasing, so is our vulnerability. The low elevation coastal zone (the continuous area along the coast that is less than 10 metres above sea-level) represents just two per cent of the world's land area but contains 10 per cent of its total population (i.e. over 600 million people) and 13 per cent of its urban population (representing around 360 million people). Almost two-thirds of the world's large cities, i.e. those with populations of more than five million inhabitants, fall at least partly within this zone. The least-developed nations, on average, have a higher proportion of their total population in this zone than high-income nations, for example, half of Africa's 37 cities with over a million people are either within or have areas that are within the low elevation coastal zone and many of Asia's largest cities/metropolitan areas are in the floodplains of major rivers (e.g. the Ganges–Brahmaputra, the Mekong and the Yangtze) and cyclone prone coastal areas (the Bay of Bengal, the South China Sea, Japan and the Philippines). And immigration is increasing this trend. The coastal provinces of China, for example, experienced a net in-migration of about 17 million people between 1995 and 2000, further pressuring an already crowded area[129].

Climate change scenarios warn of rapid sea-level rises within the next 30–50 years; with estimates of the rise varying between 18 and 59 cm by the end of the century. If this proves to be the case the number of people flooded by storm surges is bound to multiply. One estimate suggests that some 10 million people are currently affected each year by coastal flooding and that this number will increase under all the climate change scenarios[130].

Landslides

Two types of landslide are recognised: *shallow landslides* typically to a depth of one or two metres on steep slopes where debris moves quickly and *deep-seated landslides* which usually extend to the bedrock.

This landslide left 3,000 homeless in West Papua, Indonesia (former Irian Jaya)

It is generally agreed that vegetation cover can prevent the occurrence of shallow landslides[131], whilst large landslides on steep terrain are less influenced by vegetation cover[132]. In the Pacific Northwest of America, where hundreds of landslides now occur annually, one study found that 94 per cent originated from areas with clearcuts and logging roads[133].

Research into landslide hotspots by the World Bank has indicated that countries most susceptible to landslides (Central America, Northwestern South America, Northwestern USA and Canada, Hawaii, Antilles, the Caucasus's, mountain ranges in Iran, Turkey, Ukraine, Himalayan belt, Taiwan, Philippines and Celebes, Indonesia, New Guinea, New Zealand, Italy, Iceland, Japan and Kamtchatka) tend to be those areas with high forest cover; which seems to argue against the theory that deforestation is linked to landslide intensity[134]. However, what these figures probably suggest is that landslides hotspots tend to be in areas with differing altitudes and high rainfall (i.e. hilly and mountainous areas), and are thus ideal areas for tree growth, as opposed, for example, flatter areas of lower rainfall which are characterised by grasslands and steppe type habitats. Also areas with high forest cover tend to be areas with the most logging activity, and thus in some cases increased slope vulnerability.

Natural hazards such as earthquakes or heavy rain are often the precursors to a sudden onset of numerous shallow landslides. For example, the Pakistan earthquake in 2005 (see case study) caused a series of shallow type landslides occurring on steep slopes and road cuts[135].

Many thousands of people are affected by landslides every year (see figure 1). This figure is likely to remain high as vulnerability is increased by soil instability as a result of overexploitation of natural resources and deforestation as well as growing urbanization and uncontrolled land-use. Furthermore, as more marginal land is used for habitation and agriculture and traditionally uninhabited areas such as mountains are increasingly being used for recreational and transportation purposes, people are increasing their vulnerability to potentially hazardous terrains[136].

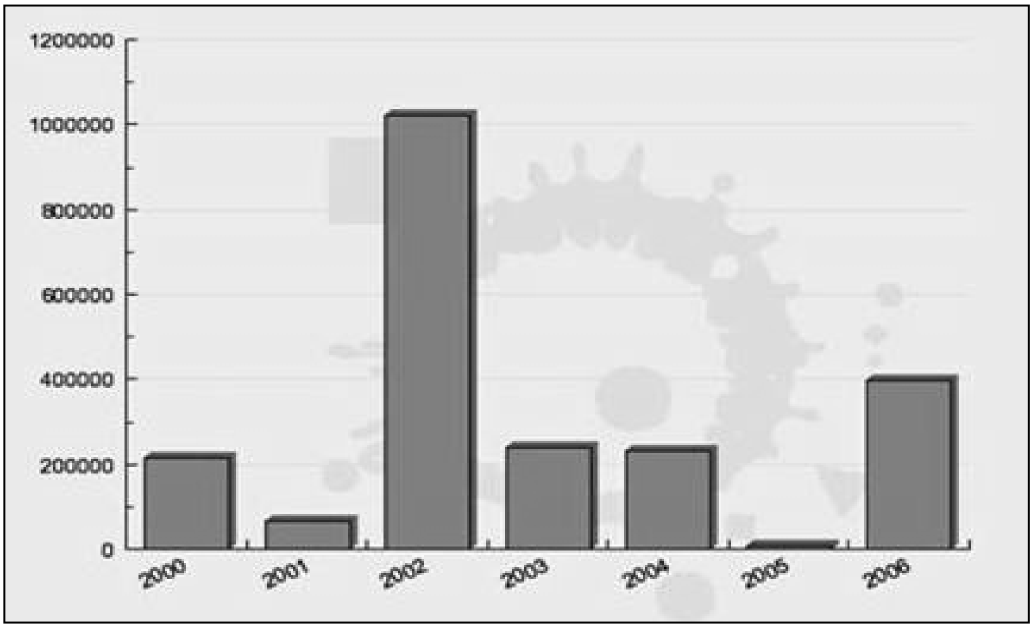


Figure 1: The number of people affected annually by landslides in the 21st Century[1]

Drought and Desertification

Drought is a complex, slow-onset phenomenon; as such it is often left out of the data on sudden catastrophic disasters from sources such as insurance companies. However, drought has perhaps the greatest long-term negative impact on human livelihoods.

Although a range of hazards and vulnerabilities can turn a drought into a disaster, the large number of people affected by drought in the early 21st century is closely related to widespread, severe climate anomalies[137]. For example, global precipitation was below the 1961-1990 average in 2001, as a consequence:

- ✓ drought was experienced across Afghanistan, Pakistan and neighbouring countries
- ✓ many areas in East Africa, much of Central America experienced drought during the middle part of the year, which is traditionally the rainy season, and
- ✓ drought affected much of Western Australia and parts of Queensland[138].

Similar 'peaks' in drought disasters were experienced in previous decades with Africa experiencing some of the worst droughts and famines in terms of number of people affected in 1972-73 and 1984-85. Indeed, 34 per cent of Africa's population lives in arid areas compared to just two per cent of Europe's population. The countries in Africa most regularly affected by drought including Botswana, Burkina Faso, Chad, Ethiopia, Kenya, Mauritania and Mozambique, where the impacts of drought and subsequent famine are exacerbated by inadequate transport facilities to receive and distribute food and medical aid[139]. By 2020, between 75 and 250 million people in Africa are projected to be exposed to an increase of water stress due to climate change[140]. Worldwide, the increase in the range and severity of droughts is predicted to leave almost a third of the planet with extreme water shortages by the end of this century[141].

As well as the impacts of climate change, land use practices are also contributing to vulnerability to drought. The clearing of tropical forests in Central and Western Africa, for example, has been blamed for altering the local climate and rainfall patterns, and thus increasing the risk of drought[142].

[1] Source: EM-DAT: The OFDA/CRED International Disaster Database, www.em-dat.net, Université Catholique de Louvain, Brussels, Belgium. Graph created on 26/02/07

Over millennia, Africa has evolved land-use systems to accommodate natural variations in rainfall and temperature. Climate change, however, is likely to accentuate this variability. Modelling has indicated rapid, major shifts in climatic conditions in space and time[143]. Rapid change will disrupt long-held agricultural practices which will have serious implications for food security and long-term land-use systems and productivity. Studies show that ecosystems are stabilised by the symbiotic relationships between humans, animals, soils, vegetation and climate. In many areas arid environments have reached an equilibrium preserving stability, however disturbances caused by desertification can become self-accelerating, with droughts promoting the process even further[144]. Given the various factors which could contribute to changing climates, it is thus perhaps not surprising that there are some indications that droughts are becoming more prolonged and their impacts more severe. Recent research, for example, suggests that droughts increased by 47 per cent in 2006 compared to 2004[145].

And of course, it is not just Africa which is feeling the effects of these changes in climate. For instance, over the past 100 years rainfall has decreased by more than five per cent over much of the land bordering the Mediterranean. In parts of Asia land degradation, mostly in the form of desertification, is one of the region's most serious environmental problems. Although desertification is clearly linked to land use practices, drought can deepen the effect and extend the area of desertification with decreases in plant cover[146].

Signs of desertification process in the Alentejo region, Portugal.

© WWF-Canon / Claire Doole

Fire

As noted above changes in climate are likely to bring drier conditions; this along with more severe storms will play a role in changing fire patterns. Research into the links between climate and forest change is being intensified with emphasis on the increased risk of fire[147]. In North America, for example, fire severity is predicted to increase in the future due to higher numbers of lightning strikes and the intensity and frequency of windstorms[148]. In 1989, fires in western Canada and the areas east of James Bay were caused by unusual weather conditions including an unprecedented heat wave in the Arctic and in 1995 fires which burned some 6.6 million ha of forest in Canada, were attributed in part due to unusually dry conditions[149]. Indeed, in recent years the area of Canadian boreal forest affected by fire and insects has doubled. With global warming producing greater seasonal contrasts combined with an expected 44 per cent increase in lightning strikes, the area of the Canadian boreal burned is predicted to increase by 78 per cent in the next 50 years[150].

In many natural ecosystems fire is by no means a wholly negative phenomenon and in many dryland habitats it is an essential component of regeneration. Many seeds have evolved to germinate only after fire. The role of fire becomes more complex when human societies get involved. Over-suppression of fire can lead to long-term ecological changes and increase the risk of more infrequent but more severe fires as fuel builds up in forests. Conversely, dense human occupation often leads to an increase in fire frequency due to accidents or arson, which also has damaging impacts. Human-caused forest fires are now a major contributor to global carbon dioxide emissions[151].

The importance of natural fires for ecosystem health began to be recognised in the 1970s and policies automatically suppressing fire were questioned. But allowing 'natural fire' is not without controversy. As with other hazards, many people make their homes in areas at risk from fire and are thus unwilling to let natural processes take place if their homes or livelihoods are affected. In 1988, for example, parts of Yellowstone National Park in the US were allowed to burn naturally after being struck by lightning. The fires spread rapidly because of severe drought and high winds; and thus it was eventually decided to suppress the fires. This, however, turned out to be a huge operation and cost some US$120 million, one of the costliest fire-fighting events in US history[152].

Globally, 95 per cent of all fires are caused by human activities, such as land clearing by farmers, the burning of residues and waste, using fires for hunting or honey collection, as well as deliberate arson (often in relation to contested land use claims or relating to natural resources) or simple carelessness. As ecosystems become more vulnerable to fire because of climate change or land-use practice that encourage the spread of fire, human-induced fire becomes increasingly likely to create natural disasters[153]. Evidence suggests, for example, that forest areas cut for timber are at greatest risk of fire because debris left behind dries out rapidly acting as kindling. In Indonesia during the fires of 1997-1998 and 1982-84, land clearance was the direct cause of most of the fires[154]. Overall, sub-Saharan Africa suffers most from 'unnatural fires'; of the over 170 million ha that burn annually and only some ten per cent of fires are considered necessary for the ecosystem[155].

Chapter 4: Protected areas and disaster mitigation

"*We must, above all, shift from a culture of reaction to a culture of prevention.*
The humanitarian community does a remarkable job in responding to disasters.
But the most important task in the medium and long-term is to strengthen and broaden programmes which reduce the number and cost of disasters in the first place.
Prevention is not only more humane than cure, it is also much cheaper"
Former United Nations Secretary-General Kofi Annan[156]

Introduction: working with nature

The Swiss Alps are a haven for both walkers and biodiversity. Bright yellow signs mark well-maintained footpaths through forests still full of wild boar (*Sus scrofa*) and chamois (*Rupicapra rupicapra*), up steep mountain slopes and onto the wildflower meadows of the high Alps. The forests feel natural and, to the casual eye, ageless, but neither is true. In fact, most of the trees were planted comparatively recently. Around 150 years ago the Swiss government recognised that over-exploitation of trees was leading to serious avalanches, landslides and flooding and introduced a rigorous system of protection and restoration[157]. Stands are managed to help protect against rock fall, landslides and avalanches[158]. Following a serious flooding event in 1987, further steps were taken to use forests as protection against natural hazards, through the *Federal Ordinances on Flood and Forest Protection*[159]. Four main elements of natural hazard management were identified: hazard assessment, definition of protection requirements, planning of measures and emergency planning[160]. Use of forests was recognised as a major component of disaster prevention and today forests in the Alpine region, making up 17 per cent of the total area of Swiss forests, are managed mainly for their protective function. Apart from the important human benefits, these protection forests provide services estimated at between US$2 and 3.5 billion per year[161].

Interest in the use of ecosystems to mitigate natural disasters is growing all the time. Natural systems are in most cases one of the most cost effective components of disaster preparedness strategies. Disaster risk management needs a complicated mixture of activities including measures to avoid (*prevention*) or to limit (*mitigation* and *preparedness*) adverse effects of hazards (see terminology below).

This report concentrates on two of these activities – **prevention** and **mitigation**; and looks at *if* and *how* protected areas might contribute to disaster risk management. We interpret 'prevention' to apply to ways of ensuring that the potential causes of disasters, i.e. hazards such as storms or earthquakes, can take place without resulting in much damage. For example in the case of floods prevention might be because the ecosystem is able to absorb most of the effects of floods. 'Mitigation' refers to actions to offset the effects, such as restoration of floodplains and forests in flood-prone watersheds.

Terminology

Prevention: Activities to provide outright avoidance of the adverse impact of hazards and means to minimize related environmental, technological and biological disasters.

Preparedness: Activities and measures taken in advance to ensure effective response to the impact of hazards, including the issuance of timely and effective early warnings and the temporary evacuation of people and property from threatened locations.

Mitigation: Structural and non-structural measures undertaken in advance to limit the adverse impact of natural hazards, environmental degradation and technological hazards.

Edited from the basic definitions on disaster developed by the UN's ISDR Secretariat[162]

The limitations of artificial barriers to natural hazards

During the heyday of technical optimism in the late nineteenth and twentieth centuries, it was assumed that we could engineer our way out of natural hazards. Some spectacular failures, coupled with a greater understanding of ecology, have led to the recognition that poorly thought through attempts to prevent natural hazards can do more harm than good. Fire suppression, flood controls and landslip barriers can sometimes fail to stop disasters while adding stress to the natural environment, disrupting environmental services and, paradoxically, making people more vulnerable by giving them a false sense of security.

For example, nearly half of the 3,782 km long Mississippi River in the US now flows through artificial channels, introduced in part to control flood surges. But this has simply moved the problem downstream and blocked off natural floodplains that once absorbed excess rainfall. The 1973, 1982 and 1993 floods are thought to have been worse than they would have been before structural flood control began in 1927. After the 1993 flood, a federal task force recommended replacing the policies of structural means for flood control with floodplain restoration and management[163].

Disrupting river flows can have unforeseen side effects besides changing natural flood cycles. The important inland fisheries of Bangladesh rely on annual flooding. Many fish swim upstream to spawn and the monsoon flood connects rivers and static water bodies into a dynamic flood plain system, providing rich feeding grounds for hatchlings and fry for four to five months every year. When floodwaters recede, the expanded fish population starts moving back into the rivers, wetlands, lakes and pools, which are then used for fishing. But flood control embankments often cut across migration routes, which, together with the gradual decline of the dry-season water bodies, have damaged fisheries. According to the Department of Fisheries between 1983 and 1989 fish production declined in Bangladesh by 44,000 tonnes per year partly because of poorly designed flood control[164].

This is not to claim that all artificial barriers, levees, dykes, soil stabilisation schemes and other disaster mitigation strategies based on civil engineering solutions are useless; such initiatives are and will continue to be at the heart of attempts to protect lives and livelihoods. Effective artificial barriers remain above some villages in the Swiss Alps for instance, despite a century of forest management aimed at controlling landslip. But there is now a recognition that some of the engineering solutions have been over-used, or used in the wrong places, or applied without due consideration of their wider ecosystem effects.

Using natural ecosystems and protected areas to counteract hazards

Research shows that the cost of disaster reduction is usually much less than the cost of recovery from disasters[165]. The World Bank and the US Geological Survey estimate that global economic losses from natural disasters in the 1990s could have been reduced by US$280 billion if US$40 billion had been invested in a range of preventive measures[166]. Put simply, the Bank suggests that every dollar invested in effective disaster reduction measures saves seven dollars in terms of reduced losses from natural disasters[167].

Disaster reduction measures include developing response strategies, avoiding settlements and other activities in risk prone areas and increasing the quality of building infrastructure to withstand natural hazards. The question at the heart of this report is whether or not protection of natural ecosystems can provide an effective component of such strategies. Chapter 2 has already argued that the loss of natural ecosystems can exacerbate the impacts of natural disasters, so in theory protection of such systems should provide some level of protection against disaster.

The reality, as is so often the case, is that it depends… The concept of ecosystem resilience is defined as the ability of a system to undergo, absorb and respond to change and disturbance, while maintaining its functions[168]. Many ecosystems are adapted to withstand natural hazards and such extreme events may sometimes be needed to maintain health and vitality[169]. For instance, fire can germinate seeds and provide space for re-growth; floods can bring fertility; and even small landslides and avalanches can open up the forest canopy and stimulate regeneration. However, this is not quite the same as saying natural ecosystems buffer human societies against disaster. The fact that a forest fire is an ecologically sustainable way of maintaining vitality on an ecosystem scale is not necessarily much comfort to people who have had their homes burnt down. Floodplains can often absorb floods but this will not be looked on kindly by people who are living there. The extent to which natural ecosystems can absorb or deflect natural hazards is complex and variable and still surprisingly poorly understood.

It is, for example, popularly assumed that major environmental degradation, particularly deforestation, will increase the impact of natural disasters and this has been widely reported with respect to major floods. Yet there has also been criticism of this assumption; in particular, publications from the Center for International Forestry Research have questioned the links between forest loss and major floods (see page 39 for a more detailed discussion)[170]. It appears that at certain scales of hazard, natural ecosystems are likely to be overwhelmed, so that for example forests can and do help to reduce minor floods but are less effective at mitigating, once in a century floods. In addition, if we want natural ecosystems to mitigate disasters in ways that are convenient for ourselves, then this may require particular management approaches and it therefore follows that disaster relief aspects will need to be reflected in management plans and budgets.

Ecologists, engineers and disaster relief specialists are increasingly looking for the right balance between development, conservation and disaster preparedness, often drawing on traditional approaches used by indigenous peoples or local communities. For example, communities on the coast of Vietnam are very vulnerable to storm damage. Since 1994 local communities have been planting and protecting mangrove forests in northern parts of the country as a way of buffering against storms. An initial investment of US$1.1 million saved an estimated US$7.3 million a year in sea dyke maintenance; and during typhoon Wukong in 2000 the project areas remained relatively unharmed while neighbouring provinces suffered significant losses of life and property[171]. Research in Indonesia calculated the erosion control value of mangroves as being equivalent to US$600 per household per year[172].

The protection or, if necessary restoration, of ecosystem services is increasingly seen to be an important step in disaster preparedness strategies and many governments and intergovernmental organisations are linking disaster mitigation with better management of natural ecosystems. Some key milestones in this process are listed in Appendix 1, including for example:

- ✓ The Millennium Ecosystem Assessment estimated that approximately 60 per cent of the world's ecosystem services (including 70 per cent of regulating and cultural services) are being degraded or used unsustainably, and noted that: "*Changes to ecosystems have contributed to a significant rise in the number of floods and major wild fires on all continents since the 1940s.*" [173].

- ✓ The Intergovernmental Panel on Climate Change has noted that: "*The resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification), and other global change drivers (e.g., land use change, pollution, over-exploitation of resources)*"[174].

However, this process is by no means complete and the ISDR recognises that "*At present, environmental management tools do not systematically integrate trends in hazards occurrence and vulnerability*"[175]. The hypothesis examined here is that protected area management can play a useful role in disaster prevention because intact ecosystems can in some circumstances provide a natural resilience – i.e. the ability to withstand shock – which can in turn help prevent a hazard from becoming a disaster. Below we summarise what is meant by 'protected area' and then go on to look at how protected areas can help prevent or mitigate the impacts of disasters.

What is a protected area?

Although we think of protected areas primarily as instruments for nature conservation, the earliest examples were focused on more immediate human needs, for example either maintaining hunting grounds or grazing pastures, or buffering against extreme climate. We have seen that Switzerland reacted to deforestation by protecting forests in the nineteenth century and similar strategies occur in many European countries. But they are all newcomers compared with Japan, where protection of forests was introduced back in the 15^{th} and 16^{th} centuries[176] to counter landslides caused by deforestation. Today Japan has almost nine million hectares of protection forests; with 17 uses including 13 related to reducing extreme climate events (see Table 3)[177]. In the Middle East, protected areas called *hima* were established over a thousand years ago to prevent grassland from eroding[178]. Many traditionally managed Community Conserved Areas and Sacred Sites can be traced back to the use natural vegetation to protect against extreme weather[179]. There are many more examples, although a complete history of the origins of the protected area concept has yet to be attempted. It was only at the end of the nineteenth century and gathering momentum through the twentieth century that protection of attractive landscapes, nature conservation and most recently conservation of biodiversity became the driving forces behind the huge expansion in national parks, nature reserves and wilderness areas around the world, which now occupy over 10 per cent of the world's land surface and less than 1 per cent of the oceans[180].

Table 3: **Classification of protection forests in Japan related to disaster mitigation**[181]

Type of protection	Details	Area (ha)
Water source conservation	Control of floods and drought	6,070,000
Soil erosion	Control of soil erosion	1,958,000
Landslide prevention	Protecting houses, farms and roads from landslip	46,000
Shifting sand	Preventing sand from shifting	16,000
Windbreak	Reducing wind speed by housing or farms	161,000
Flood control	Reducing damage from river flooding	
Sea damage	Reducing damage from sea salt or tidal waves	
Drought prevention	Protecting irrigation reservoirs from drought	
Snow-break	Protecting roads and railways from snowstorms	
Fog control	Protecting farmland from fog drift	
Avalanche prevention	Blocking avalanches	21,000
Rock-fall prevention	Blocking rock-fall	
Fire prevention	Blocking the spread of fire	400

The term “protected area” covers a very wide range in terms of habitat type, size, condition, management aims and governance. IUCN, the International Union for Conservation of Nature, defines a protected area as “*An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means*”. IUCN distinguishes six categories of protected areas defined by management type[182]:

Category Ia: ***Strict nature reserve/wilderness protection area managed mainly for science or wilderness protection*** – an area possessing some outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring.

Category Ib: ***Wilderness area: protected area managed mainly for wilderness protection*** – large unmodified or slightly modified areas retaining natural characteristics and influence, without permanent or significant habitation, which is protected and managed to preserve its natural condition.

Category II: ***National park: protected area managed mainly for ecosystem protection and recreation*** – natural area designated to (a) protect the ecological integrity of one or more ecosystems, (b) exclude exploitation or occupation inimical to the purposes of designation and (c) provide a foundation for spiritual, scientific, educational, recreational and visitor opportunities.

Category III: ***Natural monument: protected area managed mainly for conservation of specific natural features*** – area containing specific natural or natural/cultural feature(s) of outstanding or unique value because of their inherent rarity, representativeness or aesthetic qualities or cultural significance.

Category IV: ***Habitat/Species Management Area: protected area managed mainly for conservation through management intervention*** – area often subject to active intervention for management, to ensure the maintenance of particular species or habitat types.

Category V: ***Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation or recreation*** – area where the interaction of people and nature over time has produced a distinct character with significant aesthetic, ecological and/or cultural value and high biological diversity.

Category VI: ***Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural resources*** – area containing predominantly unmodified natural systems, managed to ensure long-term protection and maintenance of biological diversity, while also providing a sustainable flow of natural products and services to meet community needs.

IUCN has also identified a typology of different governance approaches within protected areas, each of which has various subsets[183]:

Type A: Government Managed Protected Areas (state governance): a national, sub-national or provincial government body holds the authority and responsibility for managing the protected area,. In some cases, the state may delegate management to a para-statal organisation, NGO, private operator or community.

Type B: Co-Managed Protected Areas (shared governance): complex institutional mechanisms and processes that share management authority and responsibility among many entitled governmental and non-governmental actors. Co-management can range from consultation through to genuine joint decision-making. Co-management is usually needed in transboundary protected areas[184].

Type C: Private Protected Areas (private governance): protected areas under individual, cooperative, corporate for-profit, and corporate not-for-profit ownership. Some forms of accountability may be negotiated with the government in exchange for specific incentives (as in the case of Easements or Land Trusts).

Type D: Community Conserved Areas (community governance): “natural and modified ecosystems including significant biodiversity, ecological services and cultural values voluntarily conserved by indigenous, mobile and local communities through customary laws or other effective means”[185].

Protected areas received an important additional boost in February 2004 when the Convention on Biological Diversity (CBD) agreed a *Programme of Work on Protected Areas*, a wide-ranging and ambitious plan for completing a global network of protected areas[186]. This is the largest and most binding commitment that governments have made to biodiversity conservation through protected areas, with almost a hundred specific, time-limited actions running to 2015[187]. The CBD *Programme of Work* explicitly recognises the role that protected areas play in maintaining ecosystem services, by for example suggesting that ecosystem services are included within gap analyses when identifying potential protected areas, developing relevant markets for ecosystems services and encouraging governments to undertake a full survey of the value of ecosystem services.

Can protected areas help to prevent or mitigate disasters?

Protected areas might play a role in preventing a disaster happening if, for example, they can help to stabilise climate through sequestering carbon (see page 47), but their most immediate role in disaster risk reduction is to ameliorate the effects of a natural hazards once it has taken place. In this regard, protected areas can play three broad roles in preventing or mitigating disasters arising out of natural hazards:

- ✓ Maintaining natural ecosystems, such as coastal mangroves, coral reefs, floodplains, forest, etc, may help buffer against natural hazards
- ✓ Maintaining traditional cultural ecosystems that have an important role in mitigating extreme weather events, such as agroforestry systems, terraced crop-growing and fruit tree forests in arid lands
- ✓ Providing an opportunity for active or passive restoration of such systems where they have been degraded or lost

We describe some examples of where protected areas appear to have prevented or mitigated natural disasters, looking at a range of disasters in turn, including:

- ✓ Flooding
- ✓ Landslides, rock falls and avalanches
- ✓ Tidal waves and coastal erosion
- ✓ Drought and desertification
- ✓ Fire
- ✓ Hurricanes and typhoons
- ✓ Earthquakes

Some of these overlap to a certain extent – impacts of earthquakes often involve landslides for instance – so that we cross reference where necessary. Where there are still debates about the effectiveness of natural ecosystems in mitigating disasters we give both sides of the story. These issues are examined in more detail in the case studies that follow in Chapter 5. But they still add up to a series of snapshots. There has been no quantitative analysis of the role that protected areas could play in disaster prevention, although there are some important calculations of values of natural ecosystems that might be used as the basis of such an analysis. While we have described how the original intent of protecting many areas was to maintain the environmental services that they provided, today these services are rarely described in the literature or in many cases even recognised. Disaster mitigation seldom appears explicitly in management plans and it seems likely that opportunities are being lost in consequence. The following therefore represents a preliminary attempt to start considering these values.

Protected areas' role in mitigating disasters

Flooding

Natural or semi-natural habitats can help to mitigate flooding in two main ways, by:

- ✓ Providing space for floodwaters to go without causing major damage
- ✓ Absorbing the impacts of floods with natural vegetation

Floodplains have evolved as a result of frequent immersion. They contain specialised ecosystems and are often particularly fertile. In places where floods come regularly they are frequently used for agriculture, such as the flood retreat sorghum cultivation along the Omo valley in Ethiopia, or as pasture for livestock. However, the human tendency to alter floodplains accelerated in the twentieth century in ways that have sometimes backfired. As was discussed above rivers have frequently been dammed, canalised or dykes and levees have been built to restrain water and channel it further downstream, destroying natural flooding patterns.

These efforts have often only been partially successful at controlling water flow. Preventing flooding upstream can simply add to the impacts further towards the sea; sometimes in neighbouring states. Wrongly designed drains and culverts can obstruct the flow of water and increase flooded areas[188]. The human impacts of flooding are increased if people settle on floodplains, transforming what were once harmless or beneficial events into major disasters. Problems are exacerbated by climate change and the resulting disruption in rainfall.

There is now increasing recognition that protecting or where necessary restoring natural flows, including flooding, can provide a cost-effective method of addressing flood problems. The science of integrated river basin management (IRBM) – the process of coordinating conservation, management, development and use of water, land and related resources across sectors within a given river basin – seeks to improve the planning within catchments and is also a valuable tool for preventing disastrous floods. Part of this simply involves setting aside flood prone areas for uses other than industry, crops or housing; for example as temporary pasture or as protected areas. In many cases this may also involve restoring traditional flooding patterns and removing dykes and barriers, to provide space for flood waters to escape and reduce downstream impacts[189]. Such approaches are being used on a wide scale.

In Indochina, The Mekong River Commission has been set up to help to work out an integrated management strategy for the whole river system

For example the Wetlands Reserve Program (WRP) is a national voluntary programme throughout the United States aimed at restoring, enhancing and protecting wetlands. By the end of 2006 nearly 750,000 ha of land was included in the programme[190]. In the case of long river systems that cross national boundaries, such considerations also become a matter for political debate (see case study on the Danube). In England, the state conservation body Natural England has argued that the restoration of peat bogs, natural floodplains and lowland marshes should be "*not a replacement for, but a necessary complement to existing flood defences*"[191]. Creating protected areas on floodplains, including through the restoration of natural flooding patterns, can have a dual benefit, by restoring native wildlife and providing space for floodwaters to disperse without causing damage. Protected areas can in these cases either be strictly protected nature reserves or landscape protected areas (e.g. IUCN category V) where traditional cultural management systems such as grazing continue to take place.

In terms of reducing flood risk, establishing a protected area can be a win-win option, by addressing a major gap in global conservation and reducing risks to human populations. Inland waters are currently badly under-protected (e.g. only 1.54 per cent of lake systems are in protected areas[192]) and floodplains have been particularly modified[193]. Floodplains can be exceptionally rich habitats: for example Kaziranga National Park in Assam, India contains the largest population of Asian Rhinoceros remaining on the planet[194].

The UN-ISDR *Guidelines for Reducing Flood Losses*, note that "*The best way to reduce future flood damages is to prevent development from occurring on flood-prone lands…Zoning of flood-prone lands as ecological reserves or protected wetlands can often help to meet broader environmental or biodiversity goals. In addition, such lands often play an important role in sustaining the fishery, and they can also act as temporary storage and infiltration areas*"[195]. And they recommend that "*Alternate use of flood-prone land should be considered where possible. It is better to have the land zoned and used for purposes such as parks, nature areas or ecological reserves than to try and ensure that future development is flood proofed*." And conclude that: "*The land along a river is highly desirable for parks and recreational uses, as well as for ecological reserves*"[196].

Wales, UK: Maintaining natural floodplains
Snowdonia National Park (IUCN Category V), Ynyshir Bird Reserve etc

The Snowdonia National Park cuts across half of the Dyfi Valley in mid Wales, with the river as its southern boundary. Several other more strictly protected areas exist on both banks of the river including two state-owned protected areas and three owned and run by NGOs. The lower valley is a natural floodplain for the Dyfi, a 40 mile river running from the mountains to the east. It floods regularly several times a year across the whole width of the floodplain, not infrequently blocking the road to the town of Machynlleth at its head. Building has been controlled in the area and in all but rare cases the waters stop short of any inhabitation. Some of the area is maintained for summer grazing of cattle and sheep while elsewhere there are bird and salt marsh reserves, some of which have been restored from areas previously used for timber plantations[197].

Flooding across the natural floodplain of the Dyfi River, Wales UK in the Snowdonia National Park

© Nigel Dudley

Europe: From transboundary co-operation to local action
The River Rhine

The River Rhine runs from the Swiss Alps to the coast of the Netherlands, mainly through Germany and France. The European Union has been developing agreements to protect the Rhine since the 1960s, initially focusing on pollution reduction, such as the 1963 Agreement on the International Commission for the Protection of the Rhine against Pollution, and subsequently on improving the river's ecosystem and strengthening cooperation between the European Community and the Rhine riparian States.

The 2000 Convention for the Protection of the Rhine aims to promote the sustainable development of the Rhine ecosystem[198]. Such protection is timely, as the Rhine has lost over 85 per cent of its natural floodplains over the past two centuries and floods are increasing in frequency as a result[199]. In line with an ecosystem approach to river protection countries have been cooperating in the restoration of natural ecosystem functioning as part of flood control and pollution reduction[200]. For example, WWF-Netherlands has been working in Gelderse Poort, located at the top of the Rhine delta, for several years. Flood protection has been a particularly important issue in this region, and has increased in political significance after the floods of 1993 and 1995. Since 2000, the Dutch government has been working on a new flood management programme, 'Ruimte voor de Rivier' (Space for the River), which aims to create a safe and sustainable flood protection programme whilst respecting and enlarging natural and landscape values.

Natural floodplain restoration in a tributary of the River Rhine in the Netherlands

© Nigel Dudley

The opportunity to take a new look at land-use in Gelderse Poort has come about in part because agriculture is becoming less economically viable and alternative livelihood options are being investigated. The whole process is taking place on a voluntary basis, is market driven and is independent of long-term subsidies.

In regard to flood prevention the main aim is to create areas where water can temporarily be retained to minimise flood peaks. The protected area of Millingerwaard, a 600 ha area on the river foreland, has been the pilot area for the overall Gelderse Poort project. Reconstruction of the river forelands to increase the discharge capacity by clay mining and sand mining started around 1990, natural grazing systems (including beavers) for vegetation management were introduced in 1991 and reconstruction of the summer dyke was carried out in 2003[201].

New Zealand: **Protecting diversity and mitigating floods**
Protected Area: **Whangamarino Wetland**, 5,690 ha, Ramsar site

The Whangamarino Ramsar site is the second largest bog and swamp complex in North Island. The wetland has a significant role in flood control (the value of which has been estimated at US$601,037 per annum at 2003 values[202]) and sediment trapping. Values can rise in years when there is flooding and it is estimated that flood prevention in 1998 was worth US$4 million alone. There have been 11 occasions when the wetlands have been needed to absorb floods since 1995[203]. The site is also of considerable biodiversity value and more botanically diverse than any other large low-lying peatland in North Island. This diversity gives it an ability to support a wide range of regionally rare communities. Some 239 wetland plant species have been recorded from the area, of which 60 per cent are indigenous and several are classified as endangered, rare or vulnerable[204].

China: **Protecting freshwater**
Protected Area: **Nansi Hu Nature Reserve**, IUCN V, 129,000 ha[205]

Nansi Lake in the Yellow (Huang) River is part of a chain of permanent, shallow, freshwater lakes and associated marshes. The lakes are an important supplier of water for the local area and are used for flood control, water purification and to support an important fishery[206]. In general the Huang He Plain contains relatively few areas of intact habitat, and protected areas are mainly in the hills[207].

Sri Lanka: **Valuing flood control in wetland protected areas**
Protected area: **Muthurajawella I, 1,029 ha** and **Muthurajawella II**, 257 ha, both IUCN category IV

The two reserves form part of the Muthurajawella Marsh, which covers an area of 3,068 ha near the capital, Colombo. The economic value of these wetlands has been estimated at US$7,532,297 per year (converted to 2003 values), including, for example, US$5,033,800 of flood attenuation[208].

Mangrove forest in Merida, Mexico

© Nigel Dudley

The role of natural vegetation in absorbing the impacts of flooding is more controversial and is still a subject of active debate. Twenty-five years ago, a review of 94 experiments on water balance and flow routing found that deforestation tends to increase runoff and flood peaks. The authors noted that it was hard to develop management best practices or predictions from these studies as each catchment was unique, and much depended on the type of the forest cover, climate and physical characteristics of the area studied[209].

Deforestation has long been anecdotally blamed for increased flooding in tropical or mountainous regions and logging bans in Thailand in 1985 and in China in 1998 were both in direct response to disastrous floods. However, in the early 21st century there was something of a backlash, with researchers casting doubt on claims that forests have an impact on major floods. The public debate over this included a popular booklet from the Center for International Forestry Research (CIFOR) and FAO that argued strongly against linking deforestation to major flooding and against protecting forests for this reason[210]. An accompanying article in the *Washington Post*, began "Deforestation cannot be blamed for widespread flooding"[211]. The results were quoted almost immediately by a Philippine logging company in a full page advertisement in the *Philippine Star* promoting logging within a Philippines national park[212] (which it should be said was not the intention of CIFOR and FAO).

Two years later a counter report came out, consisting of an analysis of flood data from 56 developing countries, which found a significant link between forest loss and increased flood risk. The authors wrote: "*Unabated loss of forests may increase or exacerbate the number of flood-related disasters, negatively impact millions of poor people, and inflict trillions of dollars in damage in disadvantaged economies over the coming decades*"[213]. The paper was the subject of a simulateous article in *Nature* that put it into context by estimating that floods had cost approximately 100,000 lives and US$1 trillion during the 1990s[214]. It also drew an instant response from other researchers who argued instead that the risk of flooding was related more to land use after the forest loss rather than forest loss itself[215]. Overall, the scientific literature seems to confirm that removal of forest cover leads to a decrease in evapotranspiration losses and runoff concentration times[216], the net effect being of greater water surpluses and more rapid runoff thus increasing flood risk[217]. Although there is still no complete consensus on the issue, most researchers appear to agree that forests can in certain circumstances reduce the impact of minor or medium flooding but are unlikely to be able to prevent significantly the impacts of occasional, once in a century catastrophic flooding.

In practice, as in the example in Malaga, Spain quoted earlier, regional authorities are to an increasing extent using forests in an attempt to control flood events with success. This was explicitly recognised by the UN Task Force on Flood Prevention and Detection, who submitted a report to the UN Econonic Commission for Europe stating that: "*Natural wetlands, forested marshlands and retention areas in the river basin should be conserved, and where possible restored or expanded*"[218]. The following example describes a protected area where the role of forestry in flood mitigation has been well studied.

Madagascar: coping with storm flow
Mantadia National Park, IUCN Category II, 15,456 ha[219]
According to one study there is mounting concern, supported by additional evidence from local communities, that increasing rates of deforestation are causing greater flooding in the eastern half of the island of Madagascar where the monsoon rains are particularly severe[220].

Mantadia National Park, established in 1989 as an outcome of Madagascar's National Environmental Action Plan, includes the watershed of the Vohitra River. A productivity analysis measured the economic benefits of the park due to reduced flooding, as a consequence of reduced deforestation, to farmers in the region. Modelling assessed the relationship between land use and storm flow. The results indicated that conversion from primary to secondary forest caused a three-fold increase in storm flow, and conversion from secondary forest to swidden caused up to 1.5-times greater flow. Thus, the scientists concluded that conversion from primary forest to swidden can increase storm flow by as much as 4.5 times. The study quantified the benefits from forest protection within upper watersheds in terms of reduced crop damage from floods in agricultural plots in lower basins and concluded that the net value of watershed protection (in 1997) was US$126,700 (to put this figure into perspective the authors note that in 1991 Madagascar had per capita GNP of US$207). This represented the benefits gained from alleviation of flood damage thanks to the watershed protection function of the Park[221].

Landslides, avalanches and rock falls

Protected areas retain natural vegetation, particularly forests, which can in certain circumstances, prevent and mitigate sudden earth and snow movements by:

- ✓ Stabilising soil and packing snow in a way that stops the slippage starting
- ✓ Slowing the movement and extent of damage once a slip is underway

As mentioned at the beginning of this chapter, the concept that at least a proportion of landslides, avalanches and rock falls[222] can be effectively controlled by maintaining vegetation on steep slopes has been recognised and used as a practical management response for hundreds of years[223]. Conversely, forest clearance can dramatically increase the frequency of, for example, shallow landsliding on steep slopes[224]. Research shows that in Switzerland increased landslide activity can be linked to periods of deforestation over a period of several thousand years[225]. In a review of landslips in Europe for the European Commission, the authors noted that "*The reforestation of hill slopes can help to reduce the occurrence of shallow but still dangerous landslides (mainly mud flows and debris flows)*" and again that "*excessive deforestation has often resulted in a landslide*" [226].

The potential of vegetation is not unlimited and geology, slope and weather patterns are all major and often dominant criteria. Benefits of vegetation are likely to be strongest in the case of small or shallow landslides and mud and snow slips; huge, catastrophic events will not be stopped. Similarly, forests have only limited potential to stop or divert an avalanche or landslide once it is in motion. Research in New Zealand found that deforestation increased the number of landslides but not necessarily the impact of those landslides that do occur[227]. The principal function of an avalanche protection forest appears to be to pin the snowpack to the ground and to prevent the start of an avalanche.

The extent to which protected areas play a role in controlling earth movements, as compared to other forms of protective management, has never been calculated. But given that earth and snow movement are most dangerous when they happen next to settlements, where the incentive to clear vegetation is also often strongest, the survival of natural vegetation usually implies some form of protection, whether or not it is officially a "protected area". Indeed although we found few explicit references to the use of protected areas in avalanche control, there may well be an opportunity in some countries to combine current landslide and avalanche control policies with biodiversity conservation.

China: **Preventing landslides**
Jiuzhaigou Nature Reserve, IUCN Category V, 72,000 ha[228]

The reserve forms the core of the Jiuzhaigou Valley World Heritage site in Sichuan. Some 140 bird species are found, as well as several endangered plant and animal species, including the giant panda (*Ailuropoda melanoleuca*) and the Sichuan takin (*Budorcas taxicolor*)[229]. Government policy has focused on accelerating development through timber extraction and tourism. However, a combination of lack of downstream irrigation water and major flooding led to a ban on commercial logging in 1998 along with the adoption of sustainable forestry policies (although in fact it is doubtful if healthier forests would have prevented this particular flood).

In 1996 a plan was agreed to reduce agricultural land in the buffer zone and plant trees on steep slopes. Initially this was mainly fruit trees, which had limited impacts on soil erosion, but a WWF project helped to develop landscape-scale policies[230]. Most of the 31 mud and rock flows and landslides found in 1984 have been brought under effective control. Residents have received compensation for giving up farmland and many of the remaining thousand Tibetan villagers work as hotel-keepers, craftsmen, guides and entertainers. A tourism boom has brought benefits to communities although there are concerns about impacts of tourism on the natural environment[231].

Nepal: Protecting against floods and landslides
Shivapuri National Park, IUCN Category II, 14,400 ha[232]

Floods and landslides are the most frequent natural hazards in Nepal, claiming an average of 200 lives a year[233]. Shivapuri National Park in the Kathmandu Valley is the main source of water for domestic consumption in Kathmandu and a major recreational site for both local people and visitors.

The area was first protected in 1976, became a Watershed and Wildlife Reserve in 1984 and a National Park in 2002. Over 50 per cent of the watershed is forested, but forest patches are fragmented[234]. The main conservation objectives of the protected area include: "*to protect the natural environment, ensure a reliable and high-quality supply of drinking water for Kathmandu and local people, minimise degradation of land by applying appropriate corrective measures…*". And as part of the protected areas management landslide protection measures have been implemented in 12 localities[235].

Tidal waves and coastal erosion

Protected areas help to retain natural vegetation, reefs and landforms that can help block sudden incursions by seawater, with particular benefits from:

- ✓ Coral reefs
- ✓ Offshore barrier islands
- ✓ Mangrove forests
- ✓ Sand-dunes
- ✓ Coastal marshes

The 2004 Tsunami in the Indian Ocean drew worldwide attention to the potential role of coastal mangrove forests and intact coral reefs in mitigating sudden sea-water surges. A paper published in *Science* drawing on research in India concluded "*that mangroves and Casuarina plantations attenuated tsunami induced waves and protected shorelines against damage*"[236] and these findings were repeated elsewhere in India[237]. However, in common with many other situations where natural vegetation is linked to protection against natural disaster, there is considerable debate with criticisms of the findings[238]. These issues are addressed in greater detail in the case study on page 78.

The role of mangroves in providing coastal defences against surges, rough seas and other abrupt forms of coastal activity is however increasingly being recognised. Since the early 1990s, many countries in

Asia have been attempting to calculate the economic value of their mangrove resources, as in the case of Sarawak, Malaysia[239] and Thailand[240], and introducing restoration programmes in recognition of their coastal protection role as in Bangladesh[241]. Such restoration efforts are being repeated around the world[242]. For example, the value of maintaining intact mangrove swamps for storm protection and flood control in Malaysia has been estimated at US$300,000 per km, which is incidentally the cost of replacing them with rock walls[243] (a barrier that needs to be replaced periodically unlike mangroves).

Similarly, healthy and intact coral reefs are being recognised as providing protection from storm surge and exceptional sea conditions[244], and from more regular erosion[245], while mature sand-dunes and coastal wetland areas also provide valuable buffering capacity. Unfortunately, a large proportion of coral reefs have suffered high levels of damage from over-exploitation, and are also now facing severe threats from bleaching as a result of global warming of the seas. Coral reefs and other shoreline systems are therefore high on the list of habitats requiring protection[246] and marine protected areas are often considered as 'ecological insurance' against acute and chronic disturbances[247]. Offshore barrier islands also offer important protection from storm surges; as the shallow water around the islands slows the surge of water, reducing its strength as it reaches shore.

Honduras: Reducing coastal erosion
Rio Plátano Biosphere Reserve and World Heritage Site, IUCN Category II, 525,000ha[248]

Ibans Lagoon is located within the Río Plátano Man and Biosphere Reserve in the Mosquitia area of Honduras. The reserve is home to three indigenous groups – Miskito, Pech and Tawahka – as well as members of the Garífuna ethnic group and Ladinos from other parts of Honduras. One of the pressing concerns for these communities is the erosion of the narrow coastal strip caused by the waves from both the lagoon and the sea, particularly during bad weather. This erosion has been exacerbated by the removal of shore vegetation, including mangroves, for firewood and house building or to provide easier access to the lagoon for boat landings and washing. Like much of the Caribbean, Honduras can be affected by tropical storms and hurricanes, which increase the risk of erosion and flooding. In 2002, MOPAWI, a Honduran NGO, began working with the communities of the coastal strip to identify the scale of the environmental problems and ways to tackle them. During a series of workshops involving men, women and children from 15 different communities, participants developed a community action plan for the management and protection of the lagoon and its associated ecosystems. Workshop participants gave highest priority to reforesting the lagoon shore with mangrove and other species to reduce erosion and improve fish habitats; and activities related to this have subsequently taken place[249].

Jamaica: **buffering against floods and sustaining local economies**
Black River Lower Morass*,* Ramsar site, 5,700 ha[250]

The Black River Lower Morass is the largest freshwater wetland ecosystem in Jamaica. It occupies the southern portion of St Elizabeth parish and consists of two separate wetlands, the Upper and Lower Morasses. The Morass lies on the coastal floodplain and protects the lower reaches of the Black River, the island's largest river[251]. The marsh acts as a natural buffer, both against flood waters from the rivers and against incursions by the sea[252] and is an important economic resource for some 20,000 people[253].

India: Planning to protect coastlines

The Indian Coastal Regulation Zone (CRZ) Notification is an example of a national attempt to protect sensitive coastal ecosystems legally, formulate guidelines for coastal activities, and demarcate areas for conservation[254]. There are four categories in the coastal regulation zone, which is defined as the boundary from the high tide mark up to 500m inland. The first category (CRZ I) includes areas that are ecologically sensitive and important such as protected areas, wildlife habitats, mangroves, corals/coral reefs, areas close to breeding and spawning grounds of fish and other marine life, area rich in genetic diversity and areas likely to be inundated due to rise in sea-level consequent upon global warming[255]. All activities in the various zones are subject to the conditions set out in the legislative framework[256].

Drought and desertification

Protected areas can provide barriers against the impacts of drought and desertification by:

- ✓ Reducing pressure (particularly grazing pressure) on land and thus reducing desert formation
- ✓ Maintaining populations of drought resistant plants to serve as emergency food during drought or for restoration

Droughts cause immediate problems of their own and also, in combination with factors such as changes in grazing pressure and fire regimes, cause an increased tendency to desertification, even in parts of the world where this has not previously been the case. The disasters associated with drought and desertification are usually slower-moving than the sudden calamities associated with sudden influxes of earth or water but may have an even higher casualty rate.

Desertification in campos grassland in Rio Grande do Sol, Brazil

© Nigel Dudley

The role of protection strategies in providing insurance against drought has been utilised for centuries and, for example, is the basis of the *hima* system that set aside land to protect grazing in the Arabian Peninsula and was formalised under Islam[257]. Today, there is increasing recognition that protection of natural vegetation may be the fastest and most cost-effective way of halting desert formation. The Kingdom of Morocco is basing the establishment of eight national parks on the twin objectives of nature conservation and desertification control. It is developing co-management governance structures so that local stakeholders can be involved in decision-making[258] and the need to protect dunes and other slopes to stop soil erosion is more generally recognised by local people[259]. In Mali, the role of national parks in desertification control is recognised, and protected areas are seen as important reservoir of drought-resistant species[260]. In Djibouti the Day Forest has been made a protected area, with regeneration projects initiated, to prevent further loss of this important forest area and attendant desert formation[261]. Many effective management systems may be traditional community conserved areas rather than formal protected areas. For example, the native people of the Thar desert in India have a tradition of preserving village grazing lands called '*gochars*', and green woodlands called '*orans*' to reduce erosion; *orans* are in additional sacred natural sites[262].

However, protected areas also come with costs in some situations, for example if they deny access to local people of the natural systems that they have traditionally relied on during periods of drought. In addition, protected areas will only be effective if they agree and implement the right management policies. Use of off-road vehicles for example in the Canyonlands National Park in the United States increases soil disturbance thus reducing vascular plants and increasing albedo, which may in turn reduce rainfall[263]; all these factors are likely to increase desertification.

Jordan: restoring vegetation cover through restricting grazing
Dana Nature Reserve: 31,000 ha wildlife reserve, IUCN Category IV and MAB biosphere reserve

Jordan has undergone desertification over centuries and pressures on land are increasing. In Dana, this tendency has been partially reversed, by reaching an agreement with local farmers and herders to reduce stocking densities of goats by 50 per cent and providing alternative livelihood options through ecotourism and craft development[264]. Despite continuation of grazing, the area of the reserve has undergone major natural regeneration, stabilising soil and providing important wildlife habitat.

Fire

Protected areas can protect against fire by:

- ✓ Limiting encroachment into the most fire-prone areas
- ✓ Maintaining traditional cultural management systems that have controlled fire
- ✓ Protecting intact natural systems that are better able to withstand fire

It should be noted however that badly managed protected areas (e.g. those with long-term fire suppression regimes) can almost certainly increase fire risk as compared to some traditional management systems.

Incidence of fire is increasing around the world, caused by a combination of warmer climates and human actions. The role of protected areas is often complex (see case study on Portugal) and depends more than in most other issues discussed here on the particular social and ecological circumstances as well as on management choices and implementation.

In fire-prone areas, where natural fire is an expected and necessary part of ecosystem functioning, protected area management may have to be a trade-off between what would be ideal for nature and what is acceptable for neighbouring human communities. Many protected areas in savannah grasslands and dry tropical forests use prescribed burning to stimulate some of the impacts of wildfire without allowing the hottest and most dangerous fires to develop[265]. In other cases, control of grazing pressure by livestock can help to maintain frequent "cool fires" on grassland, which prevent the build-up of inflammable material, thus reducing the threat of serious fires. Co-management systems can also sometimes enable local communities to be involved in fire management within and around protected areas, thus creating important buffers for settlements and agricultural land.

In fire dominant areas there is often a trade-off between managing for biodiversity elements (which will include leaving forests to attain old-growth characteristics and support deadwood species) and managing to reduce fire risk. In countries like Australia protected area managers often use prescribed fire in protected areas to reduce threats of large-scale fires developing and moving out into surrounding farmland and settlements.

Indonesia: **Protecting against forest fire impacts**
Kutai National Park, 198,629 ha, category II[266]

Although the forest fires of 1982-3 had major impacts on Kutai National Park, studies of the area found that fire killed more trees in secondary forest than in primary forests, and that selectively logged forests suffered comparatively more damage due the opening up of the canopy creating a drier climate and the logging debris providing fuel for fires. In the more mature protected forests fire swept through the undergrowth only affecting larger trees were fire crept up trees covered in lianas[267].

Philippines: Community protection of natural forests
Mount Kitanglad National Park, Mindanao, Philippines

Kitanglad Integrated, a local NGO, worked with the Department of Environment and Natural Resources and other NGO partners to establish the Kitanglad Volunteer Guards, made up of volunteers from different ethnic communities in the area who undertake fire watching duties. Being members of volunteer guard initiatives fits well with traditional ideas of land stewardship and a council of tribe elders endorses their appointment. Training is provided along with transport and a headquarters[268].

Hurricanes and typhoons

Protected areas can help address problems of hurricanes and typhoons through:

- ✓ Their role in mitigating floods and landslides
- ✓ Directly buffering communities and land against the worst impacts of a storm events (e.g. storm surge)

Extreme storm events are an annual hazard in some parts of the world, and are anxiously tracked by citizens in regions such as the Caribbean where they have wreaked increasing destruction over the last few decades. Some of the side effects of hurricanes and typhoons, such as flooding, landslides and coastal damage, are described separately in this chapter.

As with the other disaster-related discussion there has been a debate about whether or not natural vegetation, including forests, can help absorb the main impacts of such storms and thus reduce effects on people, crops and property, in particular in relation to Hurricane Mitch that caused huge damage in 1998 and Hurricane Jeanne in 2004.

Hurricane Jeanne hit several Caribbean islands. Although rainfall was similar across the islands, its impacts were very different. Storms resulted in seven flood-related deaths in Puerto Rico, 24 in the Dominican Republic and over 3,000 in Haiti. Researchers concluded that the main reason for the difference was related to rural-urban migration and the consequent change in forest cover, particularly in mountain regions. Forest cover in Haiti has been reduced through planned and unplanned deforestation to less than three per cent. Seventy years ago, forest cover in Puerto Rico was similarly degraded and severe erosion and floods were common, but today forest cover has increased to almost 40 per cent and a similar process of forest recovery is underway in the Dominican Republic[269]. The percentage of land cover in protected areas is markedly different as well, with Haiti having only 0.3 per cent cover whilst the Dominican Republic has 24.5 per cent[270]. It is possible that the human tragedy that unfolded in the wake of Hurricane Jeanne could have been substantially avoided if forest cover and protection had been in place. Perceptions in the countries involved seem to attest to these theories. Jean-Baptise Anthony Rabel, a resident of Mapou Town, Haiti lost his family and livelihood in the 2004 flooding; his analysis of the causes of the floods is clear: "*We are facing serious environmental problems in our hometown. A lot of trees are cut down to make charcoal and our government is not upholding its responsibilities. We pay the consequences: the place is turning into a desert and there is nothing to keep the water when it rains*"[271]. However, there were dissenting voices. David Kaimowitz, former director of CIFOR, argued strongly against the role of forest loss in Haiti being linked to increased risks[272] and against the mitigating role of forests in Hurricane Mitch[273]. Other researchers differ, pointing to the greatest landsliding associated with deforested slopes[274], a phenomenon that has been recorded in many other areas[275].

In general, opinion is tending towards the argument that intact forest cover, along with other natural ecosystems, can help to ameliorate the impacts of hurricanes and storms, even if such natural defence systems may be overwhelmed by the most intense events. As Salvano Briceno, Director of the ISDR, stressed: "*Environmental degradation has been the main cause of the devastating floods, which occurred last year in Haiti and the Philippines. The entire United Nations system, together with member states, national and regional organizations, have to commit themselves fully to disaster risk reduction policies if we want to avoid a re-emergence of such events there or anywhere else in regions often prone to natural disasters"*[276].

However, maintaining forest cover includes consideration of both the area under trees and the quality of the forest that remains. "Loss" is by no means always absolute and different forms of forest degradation may lead to incremental loss of their ability to mitigate natural hazards[277]. For example in Dominica five factors have been identified as major contributors to vulnerability of forests in the face of hurricanes: forest structure, species composition, reforestation, forest gaps and logging damage. Although maintaining forests in particular situations can have immediate impacts on disaster mitigation, protecting high quality forests overall can help to address both these and the underlying causes of disasters (as highlighted in chapter 2).

Brazil: **Valuing ecosystem protection**
Protected area: **The Pantanal Conservation Complex and World Heritage Site** (which includes the Pantanal Matogrossense National Park (IUCN category II); Dorochê Private Reserve, Acuziral Private Reserve and Penha Private Reserve (all IUCN category Ia)), 187,818 ha

The Pantanal is one of the world's largest wetlands. It is situated mostly within the Brazilian states of Mato Grosso and Mato Grosso do Sul. Its vast alluvial plain covers around 140,000km^2 and includes a variety of important habitats, including river corridors, gallery forests, perennial wetlands and lakes, seasonally inundated grasslands and terrestrial forests[278]. The environmental resources of the Pantanal ecosystem have been valued at over US$15.5 billion per year[279]. More specific annual values have been estimated at: US$120.50 million in terms of climate regulation, US$4,703.61 million for disturbance regulation and US$170.70 million in relation to erosion control[280].

Earthquakes

The main role of protected areas in the case of earthquakes is in:

- ✓ The prevention or mitigation of associated hazards including particularly landslides and rock falls
- ✓ Providing zoning controls to prevent settlement in the most earthquake prone areas

The role in landslides has been discussed above and is the subject of the case study on Pakistan. Protected areas might also have a potential role in maintaining particularly vulnerable areas free of settlement: as discussed earlier the impact of earthquakes depends largely on the number of people living in the region, the strength of built structures and the effectiveness of response strategies. The association between the earthquakes and protected areas has not been carefully studied.

Earthquake destruction in Afghanistan, March 2003.

© WWF-Canon / Biksham Gujja

Protected areas helping mitigate the causes of disasters

Can protected areas help in reducing the underlying causes of disasters as well as providing "first aid" in cases where disasters occur? In Chapter 2 we looked at some of underlying causes of "natural" disasters that were directly relate to loss of natural systems and the ecosystem services the provide. Perhaps the most pervasive of these is climate change.

Climate change plays both ways in protected areas. Extreme climate change could result in the whole philosophy of protection needing to be revised, for example because endangered species can no longer survive in the protected areas originally set up for their conservation. Some protected areas may literally need to be relocated, or will require major changes in management to counteract additional stresses[281]. Physical links between protected areas will become increasingly important if plant and animal species have to migrate quickly to keep up with changing ecological conditions[282]. Many researchers believe that they are already finding impacts of climate change on protected areas[283].

On the other hand, protected areas offer possibilities both for addressing some of the effects of climate change and for mitigating climate change itself by sequestering carbon. Carbon sequestration is one of the most important steps that can be taken in terms of addressing the root causes of disasters. It can be divided into two closely related phenomena:

- ✓ Carbon storage – whereby previously 'captured' carbon is stored over the long-term in plant biomass and the soil
- ✓ Carbon sequestration – whereby 'new' carbon is sequestered from the atmosphere

The early debate about carbon and forests focused on the role of afforestation and forest restoration in capturing carbon from the atmosphere and thus reducing overall carbon dioxide levels. Whilst it is comparatively simple to calculate the amount of carbon that will be stored by a given plant species under a particular set of conditions, it is much more difficult to be certain about how long the carbon remains in storage. Carbon sequestered by plantations of fast growing trees that are then used for paper and pulp may be back in the atmosphere in a few years if the paper materials are burnt or decay. Although carbon sequestration by growing trees remains a significant strategy for addressing climate change it has also attracted vociferous critics.

The role of mature forests in providing carbon storage has also increasingly been investigated, in part because it is recognised that in some circumstances they may continue to sequester carbon[284], but also because the potential of "avoided deforestation" has been recognised and funding is becoming available. Commercial companies and others are paying to store carbon to "offset" carbon dioxide that they emit through energy use, transport etc. The efficacy of offsets is still subject to debate, with critics claiming that it is little more than buying indulgences, with a negligible impact on the rate of climate change. Others see avoided deforestation as an opportunity to bring fresh money into conservation and avoid further deforestation losses. There have been efforts to agree codes of practice to protect local peoples' rights and to maximise conservation benefits[285].

More broadly, an increasing number of protected area authorities have started to see carbon storage as a key function of many of their protected areas, which should be recognised in assessments of their overall worth and political importance. Carbon storage is being promoted as a way of financing protected areas[286] and of persuading governments that avoiding deforestation is a legitimate and important political priority. As part of this process, protected area practitioners are calculating the value of carbon sequestration and storage and some early results are summarised in Table 4 below.

Table 4: **Examples of carbon sequestration by protected areas**

Country[287]	**Amount of carbon sequestered**
Argentina	Sustainable forest management over 70,000 ha including Baritu and Calilegua National Parks, expected to sequester 4.5 million tons of carbon over 30 years
Belize[288]	The Rio Bravo Conservation project aims to protect 61,917 ha, thus mitigating 8.8 million tons of carbon dioxide over 40 years
Bolivia[289]	Over 800,000ha added to Noel Kempf National Park, estimated to sequester 7 million tonnes of carbon over 30 years
Canada[290]	4.43 gigatonnes of carbon in 39 national parks, at a value of US$72-78 billion (although figures range from $11 billion to $2.2 trillion depending on valuation of carbon sequestration)

Country[287]	Amount of carbon sequestered
Czech Republic	Replacement of monocultures with mixtures of indigenous species in the Kroknose and Sumava National Parks, expected to sequester 1.6 million tons over 15 years
Ecuador	Purchase of additional 2,000 ha of the Bilsa Biological Reserve, expected to sequester 1.2 million tonnes over 30 years
Madagascar[291]	A project to reduce forest loss in 350,000 ha of the Makira Forest to the same rate as in nearby national parks is expected to sequester 9.5 million tons of carbon dioxide over the next 30 years
Philippines[292]	Protection and restoration of 12,500 ha in the Sierra Madre Quirino Protected Landscape, to sequester an expected 126,000 tons of carbon dioxide over 25 years
Uganda[293]	Calculation of carbon sequestration in the national park system which is worth US$17.4 million a year
Uganda	Reforestation of 27,000 ha in Mount Elgon and Kibale National Parks: expected to sequester 7.1 million tons
USA[294]	The 16,000 culturally and ecologically significant trees in Washington, D.C. managed by the National Parks Service store 4000 tonnes of carbon and sequester 90 tonnes each year

Overview: how protected areas can mitigate against natural disasters

The preceding sections have discussed the evidence for and against the mitigating role of protected areas in a range of disasters. As a rapid reference tool for protected area managers and others, we summarise the key findings in Table 5 below.

Table 5: **Mitigating role of protected areas against natural disasters**

Disaster	Mitigating role of protected area	Protected area habitat type	Examples	Notes and management implications
Flooding	Providing space for overspill of water / flood attenuation	Marshes, coastal wetlands, peat bogs, natural lakes	▪ Snowdonia National Park, UK ▪ Whangamarino Wetland, New Zealand ▪ Nansi Hu Nature Reserve, China	
	Absorbing and reducing water flow	Riparian and mountain forests	▪ Mantadia National Park, Madagascar ▪ The protected areas being created in the Lower Danube in Europe	Still debate about scale of effect
Landslip, rock fall and avalanche	Stabilising soil, loose rock and snow	Forest on steep slopes	▪ Jiuzhaigou Nature Reserve, China ▪ Shivapuri National Park, Nepal	
	Buffering against earth and snow movement	Forests on and beneath slopes	▪ Protected areas in Switzerland	Less effective than stabilisation

Disaster	Mitigating role of protected area	Protected area habitat type	Examples	Notes and management implications
Tidal waves and storm surges	Creating a physical barrier against ocean incursion	Mangroves, barrier islands, coral reefs, sand dunes	▪ Rio Plátano Biosphere Reserve, Honduras ▪ Coastal protected areas in Sri Lanka such as Yala and Bundala National Parks	Still debate about scale of effect
	Providing overspill space for tidal surges	Coastal marshes	▪ Black River Lower Morass, Jamaica	
Drought and desertification	Reducing grazing and trampling pressure	Particularly grasslands but also dry forest	▪ Dana Nature Reserve, Jordan	Can include managed areas (e.g. category V)
	Maintaining drought-resistant plants	All dryland habitats	▪ Protected areas in Mali	Both as feed and as stock for restoration
Fire	Limiting access to fire-prone areas	Use of strict management (e.g. category Ia)		Through agreed zoning policies
	Maintaining management systems that control fire	Savannah, dry forest, temperate forests, Mediterranean scrub	▪ Mount Kitanglad National Park, Philippines	Often Community Conserved Areas
	Maintaining natural fire resistance	Fire refugia in forests, wetlands	▪ Kutai National Park, Indonesia	
Hurricanes and storms	Buffering against immediate storm damage	Forests, coral reefs, mangroves, barrier islands	▪ The protected areas of the Sundarbans in Pakistan and India	
	Buffering against floods and landslips	See above		
Earthquake	Zoning to control access to high risk areas	Low population earthquake prone areas		Through agreed zoning policies
	Buffering against landslides	See above		

Chapter 5: Could protection have helped?

The previous chapters have highlighted the trends, causes and impacts of natural disasters and we have offered some evidence of how protected areas could form part of disaster prevention and mitigation strategies. But what really happens when disasters strike? Rather than simply develop case studies looking at well known examples of protected areas which provide benefits in terms of stability, the seven case studies presented here take as their starting point some of the most costly disasters seen so far in this new, but already record-breaking century, either in terms of human-lives lost or economic impacts, or in most cases both (as identified in Table 1 on page 10). The case studies discuss the environment-related issues that contributed to making these such terrible disasters and where the advantages in using environmental management and protection in particular could have, or in a few cases did, reduce vulnerability to the impacts of the disaster. Of course, we also recognise that this is only part of the story, and many of the impacts of these disasters were caused by a multitude of other factors such as poverty, poor land-use planning, poorly built or maintained infrastructure and inadequate warning and response systems. The case studies are:

- ✓ The Mozambique floods of 2000 and 2001
- ✓ The 2000 floods in Bangladesh
- ✓ Central and Eastern Europe flooding in the Lower Danube in 2006
- ✓ Heat waves and forest fires in the summer of 2003 in Portugal
- ✓ The Indian Ocean Tsunami in 2004
- ✓ Hurricane Katrina in the USA in 2005
- ✓ The Pakistan Earthquake of 2005

All these events were extraordinary, and many can be described as ‘once in a hundred year’ events. But were they really? Five of the seven case studies are linked to hydro-meteorological hazards – which as we have already discussed are likely to increase as the impacts of global warming take effect. The two disasters linked to geological hazards although extreme highlight vulnerabilities which could turn a range of hazards into disasters in the future. There is clear evidence, as discussed in the previous chapter, that environmental protection through protected areas can help prevent and mitigate the effects of more regular and less dramatic hazards, which could have become disasters; but what role can protected areas play in these ‘once in a lifetime’ events?

All the case studies clearly catalogue a range of issues that have contributed to increased hazard vulnerability; with the lack of effective environmental protection being a major contributing factor in creating such record-breaking disasters. The potential role of conservation through protection could play in future disaster mitigation is thus an urgent theme which runs through these case studies, but which has to date elicited a wide range of responses. The case study on the Danube floods presents perhaps the most optimistic scenario with continent wide agreements, such as the EU Floods Directive, calling for protection and restoration of floodplains and the more specific Lower Danube Green Corridor Agreement bringing four countries together to increase protection and restore degraded habitats across the floodplain. Regional transboundary approaches are also developing in Mozambique. But here the links between conservation proposals made in the Protocol on Shared Water Course Systems under the auspices of the Southern African Development Community and the major transboundary protected area initiatives which are underway in the region are only slowly being made. As the case study reports protection and rehabilitation of the major rivers catchments which flow through Mozambique could play a role in reducing the floods which are now becoming a frequent occurrence in this country which is more usually known for the devastating impacts of droughts. But resources need to be made available to fully study the role protection could have in disaster mitigation.

The case study from Bangladesh also looks at the impact of flooding. Here the great mangrove system known as the Sundarbans has a well documented role in coastal protection. However, although some of the area is protected, the mangrove forests in general continue to be lost and even those which are protected are severely threatened by sea-level rise. Protection and management strategies are thus urgently needed to ensure the effective conservation of this vital ecosystem and its role in disaster prevention and mitigation. The role that mangroves, and coral reefs, play in mitigating disasters is also discussed in the case study on the Indian Ocean Tsunami. Here there does seem to be real evidence emerging of the importance of intact ecosystems, and protected areas in particular, in mitigating tidal surges. But clearly there are far too few such areas protected in the region to provide more than limited protection to areas under threat. A similar conclusion can be drawn from the case study on Hurricane Katrina, which has also resulted in calls for more effective protection and conservation strategies aiming as much at hazard mitigation as at biodiversity conservation.

Whereas all the case studies on flooding include reference to at least policy level, if not always ground-level, recognition that environmental issues had a role to play in the reported disaster, two of the case studies have a less positive story to tell. The impacts of environmental degradation are at the heart of the case study on the earthquake in Pakistan. Although a geological event, much of the devastation was caused by the large number of shallow landslides which were probably exacerbated by major forest loss in the region. At present there is no evidence that the reduction of forest cover is seen as a major issue in relation to disaster mitigation in the country and local rebuilding efforts are probably leading to increased deforestation. And finally the forest fires that struck much of the Mediterranean in the 2003 heat wave are examined in relation to Portugal, one of the areas worse hit by the fires. Here there seem to be no obvious links in terms of disaster mitigation between the protected areas and the rest of the landscape affected by fire. The reason being that protected areas, which are primarily managed as Category V landscape areas, are suffering the same fate as areas without protection, that is to say, major land use change as centuries old land management systems are abandoned. This is leading to increased fuel loads which are susceptible to fire. The lesson here is thus perhaps one of effective management. Protected area management regimes are going to have to take more heed of land use and fire hazards to maintain values and thus contribute to hazard mitigation.

Overall the messages from these case studies could be summarised as:

- Environmental degradation played a major role in making all disasters reviewed here so extreme;
- Although there is evidence that protected areas can help mitigate impacts, in these disaster prone areas protection levels are generally low and often those areas which are protected are not effectively managed with disaster mitigation as a key element;
- There is a need to make more explicit the links between protected area and disaster mitigation strategies, both in terms of designating new protected areas and in the management of existing areas;
- Protected area management needs to consider the effects of climate change and land use patterns in relation to disaster mitigation strategies as well as in relation to biodiversity impacts;
- Transboundary conservation and restoration projects, which include the development of protected areas, offer the potential to be particularly effective in hazard prevention and mitigation .

As we will go on to discuss in the final section of this report there is an increasingly urgent need to both recognise the role that protected areas can play in disaster mitigation and to include disaster mitigation functions into protected area system planning. Only then we will really be able to analyse the role protected areas can and, when disasters strike, do play in mitigating the impacts.

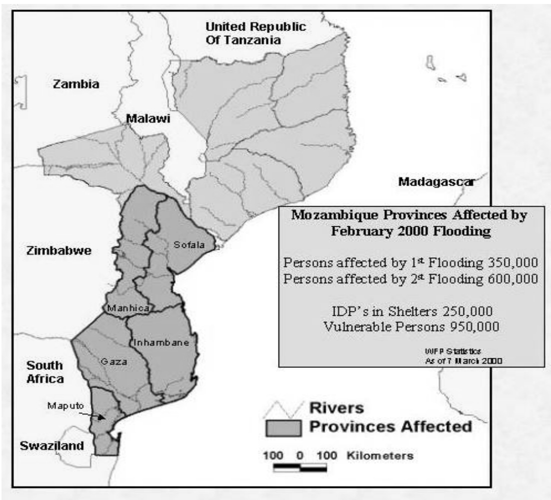
Mozambique Floods: 2000 and 2001

Introduction

Mozambique is vulnerable to a range of natural disasters, in particular floods and droughts, because of its geographical position and tropical climate. Heavy rainfall can be triggered by cyclones and tropical depressions from the Indian Ocean and cold fronts from the south[295]. Between 1965 and 1998, the country experienced twelve major floods, nine droughts and four major storms. But these events were overshadowed by the massive floods which took place in 2000 and 2001[296].

In February 2000, heavy and persistent rain across southern Africa resulted, for the first time on record, in the simultaneous flooding of all of the major river systems that flow into the sea through the southern half of Mozambique[297]. The floods resulted in the loss of some 800 lives, with millions being displaced and infrastructure loss and damage estimated at a value of over US$450 million[298]. As if the devastation of 2000 had not caused enough problems for the country, 2001 saw further floods, this time focussed on the Zambezi River. Over 500,000 people were affected by the floods and damage has been estimated at some US$36 million[299].

Mozambique has a comparatively good history of disaster management; in the 1980s the Department for the Prevention and Combating of National Calamities was established with the objective of promoting early warning and mitigation activities and in the 1990s a variety of mitigation measures were instituted[300]. However, most of the studies and efforts relating to the management of extreme weather events focussed on drought with relatively little attention being paid to floods and other natural disasters. There is, for example, a World Meteorological Organization (WMO) Drought Monitoring Centre in Harare but no centre for monitoring floods in the region[301]. But flooding is a serious risk. The impacts of climate change, land use changes and the disruption of river and wetland systems, primarily through dam construction, are changing the ecosystem's ability to deal with sudden climatic events such as storms and cyclones. As some 20 million people, more than 50 per cent, of the population of the Zambezi basin are concentrated around its wetlands the need to review wetland use and flood management is becoming increasingly urgent[302].



Areas affected by 2000 flooding

The causes of the disaster

"*A wetland is a sponge which soaks up extra water and then releases it slowly into a watershed or river system. When you remove it you remove this safety valve*"
Richard Boon, Wildlife and Environment Society of South Africa

Mozambique shares borders with South Africa, Zimbabwe, Zambia, Malawi and Tanzania. About half of the country is made up of flat coastal plain (there is 2,500km of coastline) and many sizeable rivers flow through Mozambique to the Indian Ocean. More than 50 per cent of Mozambique's land area is part of an international river basin; with nine major rivers passing through the country – the Maputo, Umbelúzi, Incomati, Limpopo, Save, Buzi, Pungoé, Zambezi and Rovuma[303], all with their origins in other countries further upstream (see box). This means that decisions made about river waters and catchments beyond the borders of Mozambique can have a major impact within the country[304].

Shared resources – major rivers and countries:

- ✓ Maputo: formed by the confluence in southwestern Mozambique of the Great Usutu River (flowing from Swaziland) and the Pongola River (flowing from South Africa)
- ✓ Umbelúzi: Swaziland
- ✓ Incomati: South Africa, Swaziland
- ✓ Limpopo: Botswana, South Africa, Zimbabwe
- ✓ Save: Zimbabwe
- ✓ Buzi: Zimbabwe
- ✓ Pungoé: Zimbabwe
- ✓ Zambezi: Angola, Botswana, Malawi, Namibia, Tanzania, Zambia, Zimbabwe[305]
- ✓ Rovuma: Tanzania, Malawi

The majority of the country can be described in terms of four main vegetation types: flooded savannah consisting of open grassland and mixed freshwater swamp forests[306]; coastal mangrove forests[307]; coastal forest[308] and miombo woodland[309]. Although the climate of the region is predominately dry, about 80 per cent of annual precipitation falls between October and March making seasonal flooding a natural part of the country's ecosystems. Major floods have been recorded in all the international river basins shared by Mozambique, with the exception of the Rovuma[310].

<u>2000 floods</u>

The flooding of 2000 was an extreme and disastrous event. The rains far exceeded levels normally expected during the rainy season. For example, the accumulated rainfall over a three-day period in Maputo Province alone was only a little less than the total rainfall experienced between September 1998 and January 1999[311].

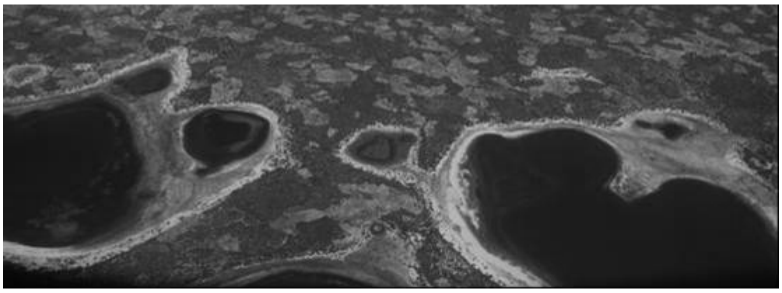
The 2000 event began in late January when torrential rainfall caused some flooding of the Incomati, Umbelúzi and Limpopo rivers in Maputo and Gaza Provinces. This was followed by two periods of heavy rainfall in early and late February 2000 with the rains falling on land that was already soaked and unable to absorb further moisture. A cyclone, Elaine, also hit Inhambane and Sofala Province from 21st to 22nd February[312] and at the same time further heavy rains occurred in Zimbabwe[313]. The combination of these weather systems on already saturated soil resulted in extensive flooding[314]. The volume of water in the Limpopo River increased rapidly. Waves of water, reaching up to three meters high, descended the river, flooding the city of Chokué and the commercial area of Xai-Xai City both in Gaza Province[315]. From 5th to 8th March another cyclone, Gloria, sat off the Mozambican coast bringing strong wind and further heavy rains for the next two weeks. The Buzi River, which had flooded in early February, flooded again on 15th March 2000, in part as a result of water release from the Chicamba dam. Save River, which had also flooded in February, flooded again on 16th March and the Pungue River flooded on 18th March[316].

This was clearly an extraordinary series of events and the accompanying disaster was unfortunately an almost inevitable result – but could this flooding have been made worse by a decline of ecosystem services in the region[317]? To discuss these impacts a combination of factors linked to the interruption of the ecosystem services need to be considered including:

- ✓ wetland destruction
- ✓ overgrazing in the upper watershed
- ✓ forestry operations
- ✓ dam construction
- ✓ land use planning

- ✓ **Wetlands**

Africa's wetlands play a vital role in the ecosystem by holding rainwater and runoff, but analysis of the causes of floods often point to reclamation of the wetlands around lakes and rivers for cultivation, reducing their flood absorption capacity[318]. Wetland degradation has occurred on the Mozambican side of the floodplain-delta area as wetlands are extensively used for agriculture and hence their capacity to hold water has been compromised.



Receding coastal wetlands Mozambique

© WWF-Canon / Meg Gawler

- ✓ **Grazing**

Following the 2000 floods, conservationists in the region stated that the overgrazing of grasslands in the upper watersheds of the Limpopo River in Botswana, Zimbabwe and South Africa had played an important part in disrupting the system's ability to absorb heavy rainfall, and were a contributory cause to the disaster[319]. Grasslands that are overgrazed or damaged by poor burning practices are hardened, this lead to more water flowing over the ground and into rivers instead of seeping into the soil[320]. In the 1990's the first Global Assessment of Soil Degradation (GLASOD) by UNEP reported on land degradation in the Limpopo River Basin. Although human-induced soil degradation was considered low in Mozambique, moderate degradation was reported in northeast Botswana and in adjacent areas of Zimbabwe, as well as in northeast South Africa and the southern tip of the catchment. High degradation was reported in the southwest upper catchment in Botswana and extreme degradation in three areas in Limpopo Province in South Africa, corresponding with densely populated communal areas[321]. Before the flooding, the Rennies Wetlands Project surveyed the upper catchment of the Sand river in Mpumalanga province, South Africa, and found that 80 per cent of the wetlands and grasslands had been tilled for subsistence farming or were overgrazed[322].

- ✓ **Forestry**

Another catchment study of the Sabie River in South Africa suggested that the reduced return period of runoff relative to rainfall is the result of the extensive forestry operations impacting on the upper reaches of the catchment, and may have influenced the severity of localised flooding within the catchment[323]. Although almost half of the Sabie-Sand River Basin falls within the protected areas of the Kruger National Park, the Sabie-Sand Game Reserve and four smaller nature reserves, some 20,000 ha of the upper catchment has been cleared of natural vegetation and replaced with exotic forestry species which is leading to degradation of the river within these conservation areas[324].

- ✓ **Dams**

The rivers that flow into Mozambique have been subjected to considerable alterations in their flow. The negative role played by dams in the 2000 flood is two-fold: immediate effects during the flood crisis and the long-term environmental effects. The release of water from dams during periods of excessive rain is often a major contributing factor in downstream flooding. In 2000, water was released from several dams during the crisis, including: the Pequenos Libombos dam on the Umbelúzi River (which exacerbated floods around Maputo in February); the Macarretane dam released water from the Limpopo River (causing a metre rise in water levels during the night of

26th/27th February), the Chicamba dam (causing the Buzi River to flood); and the Massingir dam on the Elephants River (resulting in higher water in the Limpopo and thus increasing the flooding in the town of Chokwe). Much of the subsequent discussion around the roles that the dams played in the disaster has revolved around issues primarily related to dam management (e.g. emergency planning, timing of water release, dam maintenance and overall water levels)[325]. There are however equally important longer-term effects on the role of dams and flooding in relation to changes in river flow, vegetation and human settlement (see section below on the 2001 floods).

Small dams, for agricultural purposes, can have similar affects. A study of the Kolope-Setonki subcatchment of the Limpopo river, for example, found the area effected by small dams rising rapidly, from two to 50 per cent between 1955 and 1987, leading to reduced water flow, loss of forest quality (for instance the fast growing Ana Tree (*Faidherbia albida*) was suffering considerable die back in the subcatchment) and increased grasslands[326].

- ✓ **Land use planning**
  Since independence in 1975, the Limpopo river basin has been the region in Mozambique most devastated by floods. Although in part this is due to the natural characteristics of the basin and the climate in the region, the Limpopo is the Mozambican basin which has seen most development within its flood plain[327]. This utilisation has been poorly planned and tends to exacerbate the damage caused by the floods. Some areas affected by the disaster in 2000 did have land use plans, however these were not adhered to due to inadequate enforcement. For instance in some areas, roads were built in unsuitable locations leading to soil erosion and landslides. In Maputo durin the flood gully erosion inundated the Matchikitchiki area leaving 800 families homeless[328].

<u>2001 floods</u>

Although analysis in South Africa indicated that the floods experienced during February 2000 were the result of extremely rare weather patterns, the frequency and intensity of cyclones are expected to result in an increase in floods in part due to the impacts of climate change[329,330]. The 2001 flooding of the Zambezi River are thus perhaps a better indicator of the impacts and consequences of the flooding which Mozambique is likely to suffer with increasing frequency in the coming years. In this case the floods were the result of consistent and heavy rain, a far less extreme and rare event in Mozambique than the accumulated weather event which lead to the 2000 floods. This heavy rainfall resulted in water levels beyond the coping capacity of the various dams on the river forcing water to be released which lead to flooding in large areas beneath the dams.

The Zambezi River (2,574 km) is the fourth largest floodplain in Africa and the largest system flowing into the Indian Ocean. Rising in Angola it has a catchment area of over 1.5 million km^2, encompassing the Democratic Republic of Congo, Botswana, Zambia, Zimbabwe, Tanzania, Malawi and Mozambique. The river makes it final journey to the sea in Mozambique through a mosaic of grassland and swamp forest, the Marromeu Complex, some 100 km inland from the ocean and a system of mangrove forests and deltas along nearly 300 km of Mozambique's coast[331].

The Zambezi provides many benefits for the countries it flows through, and in Mozambique in particular its power has been harnessed to provide electricity. However hydro-electric dams can bring problems as well as benefits. Overall, dams tend to reduce small flooding events which are characteristic of rivers in areas of concentrated rainfall, such as those in Southern Africa. Although this reduction in floods may seem beneficial there is evidence that these can exacerbate the damage caused by major floods. Small floods wash away sediment and plant material on banks; without these regulating activities rivers get smaller (flow will already have been reduced though damming), banks become more stable and settlements are constructed in areas which are no longer seen as being threatened by flooding. When major flood events happen there is less space for the water to flow through and more sediment, vegetation and buildings to be washed away, which also cause further problems downstream of the flood.

The construction of Kariba (in Zimbabwe and Zambia) and Cahora Bassa (in Mozambique) dams as well as other large dams in the Zambezi system have profoundly altered the hydrological regime of the Delta. Prior to the construction of Kariba Dam, peak floods spread over the 12,000 km^2 Delta. Floodplain grasslands were inundated for up to nine months of the year, and many areas were saturated throughout the dry season. With the completion of the Kariba Dam in 1959 and Cahora Bassa Dam in 1974, nearly 90 per cent of the Zambezi catchment became regulated and the natural flood cycles of the lower Zambezi River permanently interrupted[332]. Only runoffs from tributaries of the Moravia-Angonia and Manica Plateaus in the Lower Zambezi catchment remain unaffected by river regulation[333].

The ecological effects of the dams are many fold; and environmentalists are concerned that natural disasters, such as the floods in 2001, are being made far worse due to dam construction and management. Detailed survey and research work carried out by the International Crane Foundation concluded that vegetation changes are directional rather than cyclical and are resulting from the hydrological degradation of the delta system. These effects include:

✓ **Changing plant species**
Species of flora characteristic of higher areas on the floodplain and surrounding escarpment are establishing in relatively low-lying areas; thicket species are increasing in frequency and biomass in areas of open woodland; savannah and savannah species are increasing in frequency and biomass in areas of open floodplain; along the coast, species characteristic of saline grassland communities are increasing in frequency and biomass in areas occupied by freshwater grassland species; and mangrove species are decreasing at the inland margin of the coastal mangrove associations.

✓ **Open floodplain decreasing**
The composition of large expanses of floodplain is changing from species characteristic of long-duration, deep-flooding conditions to short-duration, shallow flooding conditions.

✓ **Increasing fire**
As much as 95 per cent of the delta burns during the dry season which is almost certainly due to the drying of floodplain[334].

✓ **Declining wildlife numbers and carrying capacity**
Drying conditions have facilitated access to the floodplain for commercial hunting of large mammal populations, e.g. African buffalo (*Syncerus caffer*) and waterbuck (*Kobus ellipsiprymnus*), and other species, e.g. Vulnerable Wattled Cranes (*Grus carunculatus*), are affected by reduced carrying capacity related to changes in the timing, duration and extent of floodplain inundation[335].

✓ **Land use change**
The social changes bought about by the altered environment of the Zambezi delta are also profound. Newly formed islands and stabilised areas of the lower river are being inhabited[336] as the fertile soil found in floodplains makes these areas particularly desirable places for human settlement. Although the creation of agricultural land may seem a bonus for countries with important agricultural economies and high levels of poverty such as Mozambique, these changing patterns of settlement constrain the options available for managing floods in the lower Zambezi when disasters strike.

Historically, the annual spread of floodwaters in the Zambezi restricted settlements to terraces above the active channel. After peak flooding, farmers moved on to the floodplain to cultivate the fertile soils. Over the past forty years, however, floodplain farmers have adjusted to the reduced threat of flooding by encroaching onto historically flood-prone areas along the Zambezi River, including sandbars[337].

Thus following weeks of heavy rain in the early part of 2001 flooding in the Zambezi River began to reach critical levels and many people were put at risk. By early March the Mozambique Institute for Disaster Management was estimating that at least 77 people had been killed by the floods, about 89,000 had been displaced and overall up to 490,000 were affected. The Cahora Bassa Dam was pouring out water, releasing an average of 8.4 million litres of water per second, while the Kariba Dam was discharging at about half that rate[338]. By late March the floods had claimed 81 lives and affected 635,000 people, of whom more than 200,000 were displaced[339].

Impacts on human well-being

Mozambique is one of the poorest countries in the world following years of political instability. Until the 2000/2001 floods however the country was making major economic progress, with GDP increasing and inflation rates falling from 705 per cent in 1994 to just 6 per cent in 1997. The floods were however a major set back to this development[340]. As well as the loss of life and shelter there were major losses to agricultural production and natural vegetation cover. Environmental degradation included soil erosion, water pollution and deforestation[341].

In Mozambique 80 per cent of the population is reliant on subsistence agriculture and on the erratic and unpredictable rainfall. The repetitive cycle of floods and droughts can thus have serious consequences for well-being[342]. Following the floods in 2000, for example, over 10 per cent of productive land was lost as were about 40,000 head of cattle, some five million people were directly or indirectly affected by the disaster, nearly two million were put in severe economic difficulties, one million were in urgent need of nutritional and/or medical assistance and 350,000 were displaced and left homeless[343]. But of course floods are also ecological important and can aid productivity. Thus, for example, the 2001 Zambezi floods bought some important benefits, e.g. fisheries were significantly improved for the next years; the deposition of sediments on the floodplain improved agricultural productivity (especially considering that sediment is usually trapped in Cahora Bassa Dam) and, although data is not available, it is likely that the floods were also beneficial to the prawn industry on the Sofala Bank[344].

The future – what role can protected areas play in hazard mitigation?

The land-use changes bought about by dam construction and changes in water flow were clearly a contributing factor in the floods of 2000 and 2001. A key recommendation to lessen the impacts of floods in the future would therefore be to restore environmental flows on the Zambezi and other rivers affected by large dams thus redistributing flood flows to the early wet season and reducing the impact of large floods caused by reaching reservoir maximum storage level as occurred in 2001[345].

In response to these disasters a process of intense regional cooperation has begun, focusing mainly on improved technical collaboration including anticipating, mitigating and responding to sudden-onset natural hazards, such as cyclone-triggered trans-boundary floods, and allocating more resources to risk reduction. For a long time, the water sector has focused on the development of cooperative agreements on shared river basins and water resource, but the floods of the 21st century have underlined the need to pay greater attention to regional flood risk, in addition to recurrent drought[346].

In 2000, the Mozambique government requested the United Nations Environment Programme (UNEP) and United Nations Centre for Human Settlements (UNCHS Habitat), to assess the impact of the floods on the environment and human settlements and to formulate recommendations for environmental restoration and vulnerability reduction.

Recommendations relevant to the focus of this report include:

- ✓ Assess the land use practices, which affect floods and assist in capacity building. An assessment of the land use practices in the river basin (including Zimbabwe, South Africa and Botswana where applicable) should be carried out. This should focus on the practices, which affect floods such as draining of wetland, deforestation and recommend measures for mitigation (Recommendation 10).

- ✓ Habitats such as wetlands, mangroves, coral reefs, and marine should be assessed. The possibilities and implications of the destruction and poor management of ecosystems which act as flood sinks (wetlands, woodlands, forests, grasslands etc) in the region should be investigated. An interdisciplinary team should carry out the assessment. The effects of floods on forestry should be assessed taking into account the needs of the new settlements, accommodation centers and the host communities and prepare a plans for mitigation. These might include adopting policy for the management of forests and reforestation (Recommendation 11)[347].

Since the affected areas are transboundary river basins, UNEP and UNCHS also suggested that recommendations could be adapted within the framework of the Southern African Development Community (SADC). Indeed article 2.3 of the Protocol on Shared Water Course Systems states that: "Member States lying within the basin of a shared watercourse system shall maintain a proper balance between resource development for a higher standard of living for their peoples and conservation and enhancement of the environment to promote sustainable development"[348].

This transboundary theme is also being taken up in conservation management and could provide an important impetus for helping protect the watersheds which so greatly impact Mozambique ability to deal with extreme weather conditions. The 35,000 km^2 transboundary area known as the Great Limpopo Transfrontier Park (GLTP) was agreed between Mozambique, South Africa and Zimbabwe in 2000, and confirmed by an Establishment Treaty in 2003. GLTP includes Kruger National Park in South Africa, Limpopo National Park in Mozambique and Gonarezhou National Park in Zimbabwe as well as the Sengwe communal land. These areas will make up the core area of a much larger, nearly 100,000 km^2, Greater Limpopo Transfrontier Conservation Area (GLTFCA) to include the Banhine and Zinave National Parks in Mozambique as well as a number of private nature reserves and conservancies in South Africa and Zimbabwe[349]. In addition, it is proposed that through a Biosphere approach the area could be extended east to the coast between Xai Xai and Inhambane, and south towards Coromane Dam, cross the Komati, and follow the Lebombo Mountains to Swaziland, Mlawula Game Reserve and the Pequenos Lebombos to link with the Maputo Transfontier Conservation Area and the Lebombo Spatial Development Initiative in South Africa[350].

Transboundary initiatives are thus developing both in river management and conservation strategies, and together these issues are being considered in a UNEP/GEF medium sized project on: sustainable land use planning for integrated land and water management for disaster preparedness and vulnerability reduction in the Lower Limpopo Basin. Being implemented in Mozambique, South Africa and Zimbabwe the project aims to develop an integrated flood management programme in the three lower Limpopo Basin countries that stresses disaster preparedness and mitigation techniques and includes sustainable land use planning[351].

Monsoon in Bangladesh 2000: A discussion on climate change

"Bangladesh is one of the countries most likely to suffer adverse impacts from anthropogenic climate change"
Saleemul Huq, Chairman, Bangladesh Centre for Advanced Studies, Dhaka[352]

Introduction

Bangladesh, China and India are the most flood-prone countries in Asia due to their geography and climate[353]. One of the disasters highlighted in Table 1 at the beginning of this report was the monsoon flooding which affected India and Bangladesh in 2000. Drought followed by extensive floods killed thousands, displaced millions (over 30 million people were affected by the floods in north and north eastern India alone), destroyed crops leading to food shortages and damaged infrastructure[354].

This disaster was unfortunately not an unprecedented event. Bangladesh, in particular, is a country vulnerable to a number of hazards including cyclones, droughts and earthquakes as well as floods. Indeed, Bangladesh has the dubious honour of topping the list of countries facing the highest mortality rate from multiple hazards identified by the World Bank[355]; whilst in contrast ranking low on just about all measures of economic development[356].

Unlike the other case studies presented in this report, this study takes it lead from the flooding disaster of 2000 to discuss in more depth the implications of climate change in Bangladesh. Because Bangladesh as well as being vulnerable to a range of natural hazards, is, due to its geographical location, low and flat topography and high population density, one of the most vulnerable countries in the world to the effects of climate change and sea-level rise[357]. The most recent projections of impacts in Bangladesh include sea-level rise, increased monsoon rains and an increase in air temperature in the Bay of Bengal[358]. The relationships between these projections, natural hazards and potential disasters, as well possible mitigating factors, are discussed in this case study.

Bangladesh's 700 km coastline is home to 35 million people – over a quarter of the national population – and this is projected to reach 40-50 million by 2050[359]. Overall the country has one of the highest population densities on earth, some 1,000 people per km^2 in most areas and even higher along the coasts. It is one of the wettest countries in the world, and most of the land area is low-lying comprising mainly of the delta of the Ganges-Brahmaputra-Meghna rivers which converge at the Bengal Basin/Bay of Bengal; 80 per cent of the country is classified as floodplains[360]. Normal flooding (*barsha*) affects about 30 per cent of Bangladesh each year, land use (i.e. cropping patterns and varieties) and settlement are well adapted to these floods which provide major benefits in terms of soil fertilisation and the provision of breeding grounds for fish. Abnormal flooding (*bonya*) can submerge more than 50 per cent of the total land area, and can be very destructive[361].

Three main flooding hazards stand out:

- ✓ *Coastal and estuarine floods*: The Bay of Bengal suffers significant and frequent landfall of tropical cyclones and the extensive coastal lowland areas exacerbate the impacts of the storm surges associated with cyclones[362].
- ✓ *Flash floods*: More than 80 per cent of the country's annual precipitation occurs during the annual monsoon period, between June and September, which can lead to floods mostly in the Northeast and Eastern Hills regions[363].

- ✓ *River Floods*: The combined discharge of the three main rivers which cross Bangladesh to reach the ocean is among the highest in the world. Some 1,105,612 km³ of water crosses the borders of Bangladesh every year, 85 per cent of it between June and October. Nearly 93 per cent of the surface water resources originate outside Bangladesh's borders making it is difficult to predict and control floods[364].

The most disastrous floods, in terms of lives and livelihoods lost, occur in the coastal areas when high tides coincide with the major cyclones[365]. Although the flooding in 2000 was serious in Bangladesh, previous flooding events (as highlighted in Table 6 below) have unfortunately been worse. In 1998, for example, the worst flooding in living memory lasted over a 10 week period, affected more than 17 million people and 68 per cent of the country. During the 2004 monsoon season, Bangladesh again experienced severe flooding across 33 districts that affected approximately 36 million people and killed nearly 800 people[366].

Table 6**: Top 10 recent natural disasters in Bangladesh in terms of numbers of people affected**

Disaster type	Date	Number Affected
Flood	August 1988	73,000,000
Flood	July 1974	38,000,000
Flood	20th June 2004	36,000,000
Flood	May 1984	30,000,000
Flood	22nd July 1987	29,700,000
Drought	July 1983	20,000,000
Flood	July 1968	15,889,616
Wind Storm	11th May 1965	15,600,000
Wind Storm	29th April 1991	15,438,849
Flood	5th July1998	15,000,050

Source: EM-DAT: The OFDA/CRED International Disaster Database, www.em-dat.net, Université Catholique de Louvain, Brussels, Belgium

The causes of the disaster

Bangladesh is one of those poor countries which may face the irony of being forced to adapt to and mitigate the consequences of man-made global warming and climate change, which are largely not of their own making; while they have little human, societal, technological, or financial capability for such adaptation and mitigation[367].

Bangladesh's climate is influenced primarily by monsoon and the mean annual rainfall is about 2300 mm; although there is a wide spatial and temporal distribution with annual rainfall ranging from 1200mm in the extreme west to over 5000mm in the east and north-east. Its low lying costal zone is placed between the extensive drainage network of the Ganges-Brahmaputra-Meghna river system on one side, and tidal and cyclonic activity from the Bay of Bengal on the other[368].

Predictions for the country's future climate were studied by the OECD in early 2000. The results found that all climate models estimated a steady increase in temperatures, with little inter-model variance, and that most models estimate an increase in rainfall during the summer monsoon, because the air over the land will warm more than air over the oceans in the summer[369]. More specific climate change predictions and impacts relating to flooding include:

- ✓ **Increased flooding**
  The IPCC projects that by the middle of this century the annual average river runoff and water availability will increase by 10-40 per cent in high latitudes and in some wet tropical areas[370]. Analysis of global climate models suggest a five-fold increase in rainfall during the Asian monsoon over the next 100 years, with major implications for flooding in Bangladesh[371].

- ✓ **Reduced natural drainage**
  The combined effect of sea-level rise, subsidence, siltation of estuaries, higher riverbed levels and reduced sedimentation in flood-protected areas, along with infrastructure developments will impede drainage and increase water-logging, impacting agriculture and increasing the potential for water borne disease[372].

- ✓ **Increased cyclones**
  As noted above Bangladesh is very vulnerable to cyclones – between 1797 and 1991 it was hit by 60 severe cyclones[373]. Although the IPCC has noted that climate models are not particularly effective in predicting the influence of climate change on cyclones, their Third Assessment concluded: "*.. there is some evidence that regional frequencies of tropical cyclones may change but none that their locations will change. There is also evidence that the peak intensity may increase by 5% to 10% and precipitation rates may increase by 20% to 30%"*[374].

- ✓ **Increased storm surges**
  Storm surges are temporary extreme sea levels cause by unusual meteorological conditions and often result in coastal flooding. Cyclones originate in the Indian Ocean and track through the Bay of Bengal where the shallow waters contribute to tidal surges when cyclones make landfall. These surges are likely to be exacerbated by the effects of climate change, as induced sea-level rise will raise the mean water level, and are likely to cause floods of greater depths and increased penetration inland[375]. In terms of fatalities, Bangladesh is already the dominant storm surge hotspot globally[376].

- ✓ **Reduced mitigation functions of coastal wetlands**
  Wetlands are not impacted by short-term fluctuations in sea-level such as tides and surges, but they are susceptible to long-term sea-level rise. Evidence shows that coastal areas with a small tidal range are more susceptible than similar areas with a large tidal range[377].

- ✓ **Changes in river flow**
  Temperature changes may affect the timing and rate of snow melt in the upper Himalayan reaches, thus altering the flow regimes of rivers that rise in the Himalayas and flow through Bangladesh's river network[378].

- ✓ **Loss of land**
  According to the IPCC, the rise in sea-level could be in the range of 15 cm to 95 cm by 2100. Even a cautious projection of a 10 cm sea-level rise, which would most likely happen well before 2030, would inundate 2,500 km^2 or two per cent of the countries total land area[379]. A one m rise in sea-level would inundate 18 per cent of the total land, directly threatening 11 per cent of the country's population and affect some 60 per cent of the country's population[380]. This may result in the total loss of up to 16 per cent of the land area and one estimate suggests a resultant 13 per cent reduction in GDP[381]. Any such loss of land would increase population densities in coastal areas as more people were forced to live in ever smaller land areas, and would have profound effects on coastlines (see discussion below in relation to the Sunderban forest).

- ✓ **Increased drought**
  Although Bangladesh is a predominantly wet country, drought is a recurring problem: with 19 droughts occurring between 1960 and 1991. Climate models tend to show small decreases in rainfall in the winter months of December to February. Although winter precipitation accounts for only a little over one per cent of annual precipitation, this combined with higher temperatures and increasing evapotranspiration may increase drought[382]. Land compacted by drought can also increase the impacts of flood.

This is clearly a worryingly long list of hazards. And when combined together these hazards are likely to increase the possibility of disaster. Indeed, the 1998 floods mentioned in the introduction to this case study, were in part so bad and so prolonged because they were the result of a combination of multiple factors: 1) heavy rainfall and snowmelt in India and Nepal, 2) increased rainfall, between 20 and 50 per cent depending on area, in Bangladesh and 3) elevated tides in the Bay of Bengal from the monsoon[383].

The potential of hazards to become disasters has been further affected by human actions through flood control measures and coastal development impacting the ability of ecosystems to adapt to climate change. During the later half of the twentieth century a series of coastal embankments were constructed to protect low lying lands from tidal inundation and salinity penetration. The land created behind the embankments has been converted to highly valuable agricultural land. The embankments however block the drainage of freshwater from the land on the other side of the barriers after excess rainfall and /or riverine flooding. If sea levels rise as predicted higher storm surges could also result in over-topping of saline water behind the embankments. As the OECD concludes, "*climate change could be a double whammy for coastal flooding, particularly in areas that are currently protected by embankments*" [384]. The causes of natural disasters also have international dimension. The 57 rivers flowing through Bangladesh are all trans-boundary. Upstream deforestation, melting glaciers, soil erosion and water withdrawal (i.e. the Farakka barrage across the Ganges in India) all contribute to the quantity and quality of the water reaching the country, sometimes exacerbating either flood or drought[385].

Mitigating the Impacts

"*We have three adaptation* [to climate change] *options: retreat, accommodation and protection. In view of high population density and shortage of land, retreat is not possible. We should pursue the two other options. Some of the adaptation options are: raising of forest all along the coast, protection of mangrove forests, changing cropping pattern and variety in the coastal area, construction of embankments where feasible, construction of 'safe shelters' for emergency situations like extreme events, etc*"[386]. Anwar Ali, Bangladesh Space Research and Remote Sensing Organization

Natural forest covers an area of about 10 per cent of the total land area in Bangladesh, but only 6-8 per cent of this has good canopy cover. About half of the country's forests have been lost in just the last 20 years, affecting topsoil and causing land erosion[387]; the loss of mangrove forest has been particularly rapid – as discussed below 50 per cent of the mangrove forests of the Sundarbans has been lost in the last fifty years. To mitigate the scarcity of forest resources and their fast deforestation, the government has decided to raise forest area to 20 per cent of national area, and to increase extent of protected area network from 5 per cent of total forest area to 10 per cent[388].

In the 1960's Bangladesh experienced severe cyclones and tidal bores. To protect lives and property from future disasters, the Forest Department began an afforestation programme to mitigate future storm impacts. The Coastal Embankment Rehabilitation Project, for example, reforested embankments to facilitate land stabilization and coastal mangroves over an 85,000 ha stretch along the south-eastern coast. It has been estimated that the results of the project could reduce mortality from cyclonic surges by 50 per cent within a 10 year period[389]. In total over 142,000 ha coastal has been reforested[390];

however, it is reported that about 39 per cent of plantations have not survived due to erosion mainly from to sea-level rise[391].

Mangrove forests are considered to be of importance in the protection to life and property against cyclones and storm surges[392]. The Sundarbans are the largest mangrove forest in the world[393], and represent about 43 per cent of the total natural forest in Bangladesh[394]. They provide a subsistence living to 3.5 million people and offer protection from cyclones in southwest Bangladesh[395]. The Sundarbans are formed from sediment deposited at the confluence of the Ganges-Brahmaputra-Meghna Rivers. They are not a single place, but a constantly changing land and seascape, of estuaries, tidal rivers and creeks, low-lying alluvial islands, mudbanks, sandy beaches and dunes[396]. The Sundarbans extend across southern Bangladesh and India’s West Bengal state; the inter-tidal area is approximately 26,000 km^2 of which some 40 per cent is in India and the rest in Bangladesh[397].

The Sundarbans are named after the large number of Sundari trees (*Heritiera fomes*) that grow in the brackish coastal waters. The trees’ extensive root systems and the mineral-rich waters they grow in support a large variety of species and are critical to the survival of local fisheries. These root systems also help stabilise wet land and coastlines[398] and contribute to the Sundarbans role of buffering inland areas from the cyclones[399]. The mangroves in the Sundarbans break up storm waves that exceed four metres in height[400], and result in the area suffering less from wind and wave surges than those areas with less or no mangroves[401].

The role of the Sundarbans as a vast natural protective belt against storms is however under threat, at the very time when storm damage is predicted to increase. Due to deforestation, the width of the mangrove belt is being rapidly diminished[402]. These changes began some two hundred years ago as a result of forest tracts on low-lying islands being cleared and gradually claimed for cultivation; the reclamation of the broad transitional belt of habitat for agriculture; and an increase in salinity resulting partly from the large-scale irrigation schemes in the upper reaches of the Ganges[403]. Fuelwood and other natural resources extraction[404], unplanned construction, unsustainable use of coastal embankments and increase of coastal shrimp aquaculture have all contributed further this decline[405]. As a result some 50 per cent of the forests has been lost over the last fifty years[406].

Mangrove forest on an island in the Sundarbans Tiger Reserve, Ganges Delta

Although some efforts are underway to protect and conserve the Sundarbans (e.g. the Ganges Water Sharing Treaty signed with India in 1996 which aims to increase dry season fresh water flows and decrease salinity in the Sundarbans), there are predictions that one of the most dramatic impacts of climate change in Bangladesh and India could be the loss of the Sundarbans ecosystem. The possible impacts of climate change are, however, not easy to assess. There is a difficult balancing act between predicting the effects of sea-level rise on the one hand, and thus increasing levels of salinity inland, and increasing rainfall and river flow on the other, which could push the ‘saline front’ further towards the sea[407]. Taken on its own a 25 cm sea-level rise could result in a 40 per cent mangrove loss[408], a 45 cm sea-level rise would inundate 75 per cent of the Sundarbans, whilst a 67 cm sea-level rise could inundate the entire ecosystem. The natural regeneration of vegetation and forest succession however depends on the salinity regime. The freshwater Sundari mangroves are already experiencing a decline probably due to increases in salinity, and some predict further decline or complete loss under climate change with the forests being replaced by inferior quality trees or shrub species[409]. Such changes in forest quality could have a major impact on disaster mitigation as the forest attributes which contribute to mitigation of natural hazards are lost.

The future – what role can protected areas play in hazard mitigation?

Many millions more people are projected to be flooded every year due to sea-level rise by the 2080s. Those densely-populated and low-lying areas where adaptive capacity is relatively low, and which already face other challenges such as tropical storms or local coastal subsidence, are especially at risk...", Intergovernmental Panel on Climate Change, Fourth Assessment Report[410]

Bangladesh is clearly a country facing major challenges in terms of disaster management, as well as the increased impacts of disasters due to climate change. The reduction of vulnerability to extreme weather hazards, good disaster management and adaptation therefore needs to be part of any long-term sustainable development planning[411]. And such a shift has indeed been taking place. The emphasis has moved from only dealing with the aftermath of disasters to planning for managing hazards and disasters. Thus the 2003 Comprehensive Disaster Management Programme (CDMP) advocates a policy and management shift from relief and recovery operations to a more holistic approach of forecasting and community preparedness[412].

In relation specifically to flooding, after decades of flood control measures based solely around large scale structural interventions[413], the 1999 National Water Policy emphasises the need to 'live with floods' rather than controlling them. Flood planning in the policy is therefore based on flood-proofing, developing agriculture based on flood-adapted varieties, minimal disruptions to the drainage networks and fish migration patterns, and improved flood warning and preparedness. The new policy is based around the use of existing resources with public participation and has an emphasis on management and knowledge[414].

One obvious outcome of this change in emphasis should be a renewed effort to conserve the natural disaster defences already available. Given the importance of the Sundarbans for livelihoods, as well as disaster mitigation, the need for conservation, protection and restoration of the ecosystem has been recognised. Protected areas include, in India, the Sundarbans National Park (IUCN Category 1a, 133,010 ha) which includes the core area of Sundarbans Tiger Reserve (258,500 ha), plus the Sajnakhali Wildlife Sanctuary (36,234 ha) which lies within the buffer zone, to the north of Netidhopani and Chandkhali forest blocks, Halliday Island (583 ha) and Lothian Island (3,885 ha) wildlife sanctuaries in the west; and the wildlife sanctuaries of Sundarbans East (5,439 ha), Sundarbans West (9,069 ha) and Sundarbans South (17,878 ha) in Bangladesh[415]. Both the Indian and Bangladesh Sundarbans have been declared World Heritage sites by UNESCO. The three sanctuaries in Bangladesh conserve three main habitat types (high mangrove forests, low mangrove forests, and grassland and banks) and contain a high floral diversity (some 74 plant species of more than 53 genera have been identified to date) [416]. However, these areas only represent 15 per cent of the Sundarbans ecoregion only Sajnakhali is large enough to adequately protect ecosystem functions and many of the protected areas lack trained and dedicated personnel and infrastructure to adequately manage them[417].

The challenge to adequately protect the Sundarbans ecosystem is complicated further by the need to address the impacts of climate change. As yet, however, there is no national policy in place to address climate change risks comprehensively; and although Bangladesh receives something like one billion dollars of aid a year, donor country strategies and project documents generally lack explicit attention to climate change[418].

Mangrove ecosystems can adapt to the impacts of climate change, but much will depend on local conditions. For instance, mangroves should be able to naturally expand their range despite sea-level rise if the rate of sediment accretion is sufficient to keep up with sea-level rise, however this will depend on existing infrastructure and topography, and thus planning should take this into account[419]. Advice in relation to the management of mangrove in the face of climate change is available (as an example see box the below) and should be considered in all future strategies to help mitigate the impacts of flooding in Bangladesh.

Management of mangrove in the face of climate change

IUCN suggests ten strategies that managers could apply to promote the resilience of mangroves against sea-level rise[420]:

- ✓ Apply risk-spreading strategies to address the uncertainties of climate change.
- ✓ Identify and protect critical areas that are naturally positioned to survive climate change.
- ✓ Manage human stresses on mangroves.
- ✓ Establish greenbelts and buffer zones to allow for mangrove migration in response to sea-level rise, and to reduce impacts from adjacent land-use practices.
- ✓ Restore degraded areas that have demonstrated resistance or resilience to climate change.
- ✓ Understand and preserve connectivity between mangroves and sources of freshwater and sediment, and between mangroves and their associated habitats like coral reefs and seagrasses.
- ✓ Establish baseline data and monitor the response of mangroves to climate change.
- ✓ Implement adaptive strategies to compensate for changes in species ranges and environmental conditions
- ✓ Develop alternative livelihoods for mangrove dependent communities as a means to reduce mangrove destruction.
- ✓ Build partnerships with a variety of stakeholders to generate the necessary finances and support to respond to the impacts of climate change.

Central and Eastern Europe: Flooding in the Lower Danube[2]

"Restoration and preservation of floodplains must be a key component of the EU flood risk management directive"
Dr. Christine Bratrich, WWF International Danube-Carpathian Programme[421]

Introduction

Flooding in Europe, as in the rest of the world, is becoming an increasingly costly issue. Lives are lost, people made homeless, livelihoods disrupted and infrastructure damaged. Some of the most devastating European floods in the 21st Century have taken place in the lower reaches of the vast Danube River and watershed, an area of relatively high population density (103 people per km^2) and significant modification[422].

The Danube is a truly European river. The continent's second-longest river originates in the forests of Germany and then flows eastwards for a distance of some 2,800 km before emptying into the Black Sea via the Danube Delta in Romania. The river flows through, or forms a part of the border of, ten countries: Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Bulgaria, Romania, Moldova and Ukraine; in addition, the drainage basin includes parts of ten more countries: Italy, Poland, Switzerland, Czech Republic, Slovenia, Bosnia and Herzegovina, Montenegro, Republic of Macedonia, Moldova and Albania. The Danube's tributary rivers reach even more countries[423].

The Danube's watershed covers more than 800,000 km^2, of which only about seven per cent is protected[424]. A comparison of former natural floodplains (i.e. the floodplains as they were about 300 years ago) and the recent floodplains (i.e. the area remaining between flood protection dykes and/or natural terraces) of the Danube and some of its tributaries indicates a dramatic loss of water retention areas, which is contributing to the increased flood occurrence. Overall the middle and lower Danube has lost about 70 per cent of its former floodplains, and its tributary rivers the Tisza and Sava have lost nearly 90 per and 70 per cent of floodplains respectively[425]. Agriculture and foresty dominate the watershed (67 per cent and 20 per cent respectively) and over 10 per cent of the watershed is developed. Wetlands represent only one per cent of the watershed[426].

This case study concentrates primarily on the lower Danube area which covers approximately 600,000 ha in Serbia, Romania, Bulgaria, Moldova and Ukraine. Flooding has become an unfortunately regular event in the region this century. The first serious flooding event this century was in the summer of 2002, following a period of unusually low pressure across much of Europe. The Danube, along with many other rivers in Central Europe, flooded and over 100 people lost their lives. The estimated economic costs were huge, some Euro10 billion in Germany, three billion in Austria and two billion in the Czech Republic[427]. In 2005, heavy rainfalls affected the upper Alpine catchment of the river, and the main flood wave which reached the middle Danube was only as a negligible 3-5 year event, failing to reach the lower Danube at all. Nevertheless, flash floods in Bulgaria and parts of Romania that year affected Balkan and Carpathian foothill valleys and destroyed many villages. In 2006 flooding along the lower Danube nearly reached the level of a once in a 100-year event. In the entire Danube basin at least 10 people lost their lives and up to 30,000 people were displaced, with overall damage estimated at more than half a billion Euros. The floods were limited to the middle and lower Danube and, mostly driven by snowmelt[428].

[2] This case study is an edited version of WWF Danube Carpathian Programme working paper: *Floods in the Danube River Basin: Flood risk mitigation for people living along the Danube and The potential for floodplain protection and restoration* written by Ulrich Schwarz, Christine Bratrich, Orieta Hulea, Sergey Moroz, Neringa Pumputyte, Georg Rast, Mari Roald Bern and Viktoria Siposs

The causes of the disaster

"*We are in a situation where we are paying the price of the works made against nature*"
Calin Popescu-Tariceanu, Romania's Prime Minister[429]

Since the 1970s the lower Danube has been largely disconnected from its large floodplains and many side channels have been closed, in particular on the Romanian side. This has considerably reduced the discharge capacity of the river system forcing floodwaters to overflow and break the dykes as during the spring 2006 flood event[430].

'Iron Gate' hydro electric power station in Romania/Serbia. The construction of this dam caused a 35 m rise in the water level of the river near the dam.

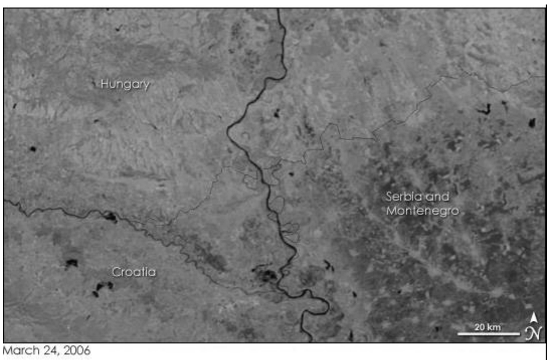
During the last 150 years more than 80 per cent of the former natural floodplain area in the Danube river basin has been lost due to intensive high water regulation works and construction of flood protection dykes. The percentage of loss along the Danube and its main tributaries varies between 28 per cent (i.e. the Danube delta, much of which is protected and designated as a biosphere reserve) to over 95 per cent near settlements. Overall only a few areas in the middle and lower Danube still contain large natural floodplain complexes that are capable of mitigating flood risk. These areas include the Drava-Danube confluence (Kopacki Rit), the Lonjsko Polje or Obedska Bara areas along the Sava, the small Braila Island along the Danube and the Danube Delta.

The winter of 2006 was long and snow-rich and was characterised by an extended period of lower than average temperatures in the Alps and the Western Carpathians. The eventual increase in temperatures led to intensive snowmelt, accompanied by heavy rainfall at the end of March. These factors caused long-lasting high discharges into the Danube and its two most important tributaries, the Tisza and the Sava. These high discharges led to floods affecting the Danube starting in Bratislava and around Belgrade, and subsequently affecting the whole lower Danube in Romania, Bulgaria, Moldova and Ukraine. In some places the river level reached the highest levels in 100 years. The floods started at the end of March in the upper catchment and lasted until June 2006, when several areas were flooded along the lower Danube in Romania[431]. The flooding led to states of emergency being declared in Hungary on 3rd April, Bulgaria on 12th April and by the Serbian Government on 13th and 14th April in those areas affected.

Satellite images and GIS-measurements show that the floods were restricted to the rivers former floodplains[432]. Although the immediate cause was rapid snow melt and heavy rain, the disaster was really the result of years of ill conceived planning and investment which placed property, agriculture and industrial development in the path of the flood waters. The Romanian Prime Minister, Calin Popescu-Tariceanu, publicly blamed the flooding on the country's system of dykes, built in the 1960s and 70s under communism in order to reclaim land for agriculture[433]. The cutting off of side-channels, riverbank enforcement and constructions of dykes and drainage of wetlands for agricultural purposes has altered the dynamics of the floodplain and wetlands. Consequently, their ecological value and ability to mitigate natural hazards decreased dramatically[434].

Impacts on human well-being

The areas most heavily impacted by the 2006 floods were mostly in the agricultural polders (i.e. low-lying land enclosed by dykes) in Romania; e.g. the Baltas of Bistret, Potelu, Calarasi and the island Calarasi-Raul. Overall thousands of hectares were flooded and some 10,000 people lost their livelihoods. Along the Romanian Danube, a total of 650 houses were totally destroyed. In just one area, the Balta Bistret (villages of Bistret and Rast), over 8,000 people had to be evacuated during the flood[435]. Regionally, agricultural land was flooded and crops lost. In Hungary 138,000 ha of fields were submerged, 64,000 ha of which were grain fields; some 225,000 ha, five per cent of Serbia's 4.5 million ha of arable land, were submerged by floods with damage estimated at Euro 35.7 millions; in Romania wheat crops were lost on 10,000 ha, 0.3 per cent of the total wheat acreage[436].



Images from NASA's Terra/MODIS satellite of the border region between Hungary, Croatia and Serbia and Montenegro: the image on the left was taken on 3rd April 2006, the image on the right was acquired ten days earlier and shows the river under normal conditions
© visibleearth.nasa.gov/view_rec.php?id=20573

Mitigating the Impacts

"Lower Danube Green Corridor aims to make the Lower Danube a living river again, connected to its natural flooding areas and wetlands, reducing the risk of major flooding in areas with human settlements and offering benefits both for local economies - fisheries, tourism - and for protected areas along the river."

Orieta Hulea, WWF Lower Danube Green Corridor Programme[437]

Flooding in the Danube and it tributaries may be linked to factors associated with climatic change. Recent studies show that the frequency and intensity of flood events will increase in the future[438]. This will be closely related to changes in the patterns of precipitation and river discharge, and thereby also to other long-term changes in the climate. Though uncertainties are high in many of the projections, scientific confidence in the ability of the climate models to estimate future conditions is increasing. Over the twentieth century, river discharge decreased considerably in many southern European basins, while large increases occurred in Eastern Europe. It is very likely that these changes were due largely to precipitation changes, although discharge is also affected by various other factors such as land-use change or the straightening of rivers. The combined effects of projected changes in temperature and precipitation will in most cases amplify the changes in annual river discharge. By 2070, river discharge is estimated to increase by up to 50 per cent or more in many parts of northern or northeastern Europe. Clearly issues of human-induced climate change need to be addressed, but more immediately the restoration of floodplains could have a dramatic effect on the regions ability to mitigate the worst impacts of flooding. WWF has therefore been stressing in a number of fora's that mitigation of flood damages and the protection and ecological restoration of floodplains must go hand in hand. However, to date this has not been the common practice[439].

WWF analysed in detail the impacts of the 2006 floods in four of the most effected areas in Romania (the Baltas of Bistret, Potelu, Calarasi and the island Calarasi-Raul), which together comprise at least 75 per cent of the area flooded in the lower Danube during April/May 2006. If restoration activities were carried out in these areas and a related area of 500 million m³ and the capacity of the river increased through reconnected side channels and widening of the riverbed, it is predicated that the flood level would have been lowered by up to 40cm during the flood. For the Danube as a whole it is estimated that a reduction of about 10-40 cm is realistic if about two billion m³ along the lower Danube could be restored. With higher values (up to 40cm) for areas close to restoration sites where the dykes need to be opened and lower values (10-20cm) for areas between potential restoration sites without dyke removal. In addition, the flood risk could be mitigated by reconnecting side channel systems and widening of the floodplains upstream of settlements[440].

The short-term devastating impacts on infrastructure and livelihoods of floods can sometimes divert attention from the range of other values that are also lost as the consequence of river fragmentation and alteration. Floodplain ecosystems provide a broad range of services such as the provision of fish, reeds, wood, drinking water, nutrient reduction/storage and, of course, flood risk mitigation among others. In the lower Danube WWF has estimated the added value of a restored floodplain using a range of parameters for economical values (i.e. fish, reed, pasture/cattle) and ecological values (i.e. water storage, nutrient removal, sediment retention, habitat for birds and fishes, aesthetic value). The benefits of restored floodplains were calculated as having an overall value of about Euro 40 per ha per year[441].

The future – what role can protected areas play in hazard mitigation?

Clearly the impacts of floods already seen in the first few years of the 21st century can be greatly mitigated if the existing floodplains are used as retention areas, and main and side-channels can provide additional capacity. However, the restoration of floodplains along the Danube and its tributaries will only effectively reduce the risks of future flooding if it is accompanied by wetland restoration and improvements in the disconnected parts of the system[442]. The river in 2006 reclaimed its former floodplain during the flooding, so logically the restoration of this floodplain will help lead to sustainable and sufficient solutions to flooding in the future.

Wetland along the Danube River, Portile de Fier Nature Park, Romania

Proposals for increased restoration of degraded habitats and protection of floodplains are already underway. Foremost among these is the Lower Danube Green Corridor Agreement facilitated by WWF and signed by Bulgaria, Moldova, Romania and Ukraine in 2000. The signing parties pledged to establish a Lower Danube Green Corridor (LDGC) composed of a minimum commitment of 773,166 ha of existing protected areas, 160,626 ha of proposed new protected areas and 223,608 ha to be restored to natural floodplain; with management ranging from:

- ✓ Areas with strict protection
- ✓ Buffer zones with differentiated protection, in which human activities can be permitted and degraded areas restored
- ✓ Areas where sustainable economic activities could be developed[443].

One major outcome is the development of a network of protected areas (including Natura 2000 sites), representing 70 per cent of the total LDGC area in the four countries[444]. The mosaic of protected areas includes Ramsar sites, Biosphere Reserves, a World Heritage Site (Srebarna Lake) and National/Nature Parks (e.g. Balta Mica a Brailei). However, so far only 6 per cent of the restoration commitment has been accomplished, and the largest wetland areas that have been converted to agricultural polders are still waiting to be reconnected to the river, including those at Potelu, Belene, Seaca-Suhaia-Zimnicea, Gostinu-Prundu-Greaca, Kalimok-Tutrakan, Pardina and Sireasa[445].

The area suggested for restoration in the lower Danube area includes relatively few settlements and very little infrastructure. Since the Danube serves as the border between Bulgaria and Romania, large areas in the 'Baltas' are still publicly owned, which should facilitate their restoration and further use for flood mitigation purposes. Both the ecological and socio-economic analyses of the sites most affected in 2006 show clear advantages for restoration over polder management. The involvement and support of local people is particularly important when launching restoration activities. The combination of sustainable land use, river protection and restoration, and flood protection must be considered right from the beginning of the planning processes. This is crucial to generate both economic values and ecological benefits[446].

Restoration projects, however, will only take place if relevant and effective national and international policies and national legislation are in place. Of particular importance therefore is the EU Water Framework Directive (WFD) which provides an important mechanism for managing the Danube river basin as a whole. The EU Floods Directive requires that Member States take a long-term planning approach to reducing flood risks in three stages. Firstly Member States need to undertake a preliminary flood risk assessment of their river basins and associated coastal zones; secondly, where real risks of flood damage exist, they must develop flood hazard maps and flood risk maps; and finally, flood risk management plans must be drawn up for these zones. The plans required by the Floods Directive are to include measures to reduce the probability of flooding and its potential consequences. They will address all phases of the flood risk management cycle but focus particularly on prevention (i.e. preventing damage caused by floods by avoiding construction of houses and industries in present and future flood-prone areas or by adapting future developments to the risk of flooding), protection (by taking measures to reduce the likelihood of floods and/or the impact of floods in a specific location such as restoring flood plains and wetlands) and preparedness (e.g. providing instructions to the public on what to do in the event of flooding).

The overall purpose of the WFD is to establish a framework to protect all waters (inland, transitional, coastal and groundwater), with the aim of achieving 'good status' in all European waters by 2015. It is an innovative legislation, which brings a holistic approach to water management across the EU through Integrated River Basin Management (IRBM) on a river basin scale. IRBM is based on the natural functioning of freshwater ecosystems, including wetlands and groundwater. It considers the joint assessment of the needs and expectations of all water stakeholders at a basin-wide level and is oriented towards the proper and long-term functioning of ecosystems and maintenance of the associated socio-economic benefits for people. Under the provisions of the Directive, a Danube River Basin Management Plan should be prepared by 2009 addressing key water management issues including hydro-morphological alterations, flood risk management and floodplain/wetland restoration among others[447]. If the lessons learned from the flood events this century and pioneering work being carried out as part of the LDGC are properly acted upon the Danube River may once again provide a vast array of benefits, including flood mitigation, for millions of people in Europe.

Heat waves and forest fires: Summer 2003 in Portugal[3]

"*We are facing an exceptional situation. It's been brought about by absolutely exceptional weather conditions, so we have to respond with exceptional measures*"
Portuguese Prime Minister, Jose Durao Barroso [448]

Introduction: Heat wave hazard

Extreme temperatures are part of nearly every climate on Earth, representing one of the most common natural hazards facing human societies. Portugal's geographic location and climate makes it especially vulnerable to extremely high summer temperatures, when circulation from the Sahara becomes dominant. Indeed, Southwest Iberia has recorded the highest temperatures in Europe (47.3ºC was recorded on August 1st 2003 in Amareleja, the second highest temperature ever registered by National Meteorological Authorities across Europe[4]).

Forest ecosystems cover about one third of Portugal and provide a wide range of goods and services. This high economic importance is paralleled by the importance of forests for biological diversity in a diverse landscape mosaic.

Increasing awareness of health-related impacts and the complex relations with drought, desertification and forest fires, as well as increasing public concern with climate change and environmental issues, have strengthened the need to manage the risks and mitigate the impacts of heat waves. In 2001, the World Meteorological Organisation (WMO) started to use a Heat Wave Duration Index (HWDI), which defines a heat wave as occurring when maximum daily temperature exceeds by 5ºC or more the average daily maximum of the reference period during a period of at least six consecutive days. This definition is based on the heat wave duration rather than its intensity, suggesting that the use of the HDWI should be complemented with an analysis of temperature anomaly.

Although heat waves in Portugal's mainland may occur anytime throughout the year, their impacts are strongest during summer, the period of highest temperatures, because absolute extreme values may be attained. An analysis conducted by the National Meteorological Authority (IM) reveals that June is the month with the highest frequency of heat waves in Portugal[449]. It also states that although several heat waves can be identified in records throughout the 20th century, overall heat wave frequency has increased since the 1980s. Due to their intensity, duration and spatial extent, as well as their social and economic impacts, three major events are highlighted: June 1981, July 1991 and July/August 2003.

The 2003 heat wave was the longest recorded since 1941, reaching 17 days in some inland parts of the country, 14 days in the districts of Beja, Évora, Portalegre, Castelo Branco, Vila Real and Bragança, and more than 10 days in over two thirds of the country (fig. 1). Still, its spatial extent was smaller than in 1981 (fig. 2). Furthermore, the summer of 2003 was preceded by a wet winter and a very dry May, which favoured vegetation growth and increased the available fire load. Such climatic conditions added

[3] **This case study has been written by L N Silva, M Bugalho and A Do Ó from Portugal**
[4] After 47.8ºC recorded in July 1976 in Murcia, SE Spain; but all other highest values (above 45ºC) in the Peninsula, as well as in Europe, were registered in the Guadiana and Guadalquivir basins lowlands (Alcoutim, Beja, Mértola, Sevilla, Cordoba), in SW Iberia.

to the role played by the heat wave in July-August and the associated meteorological surface conditions in the propagation of large forest fires[450].

Risk of heat waves is expected to grow, according to climate change scenarios which point to an increase in the frequency and intensity of heat waves, especially across Mediterranean Europe[451,452].

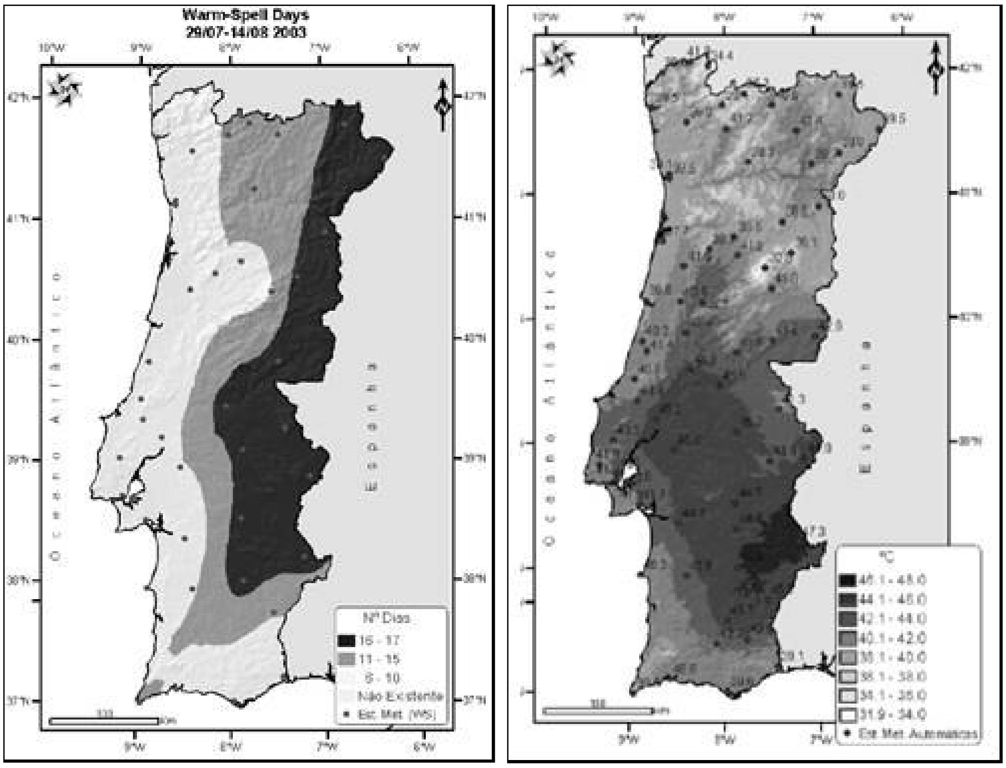


Figure 2: **2003 heat wave in Portugal: length in number of days (left) and highest maximum temperatures (right). The darker colours represent the greatest number of days/highest temperature[453]**

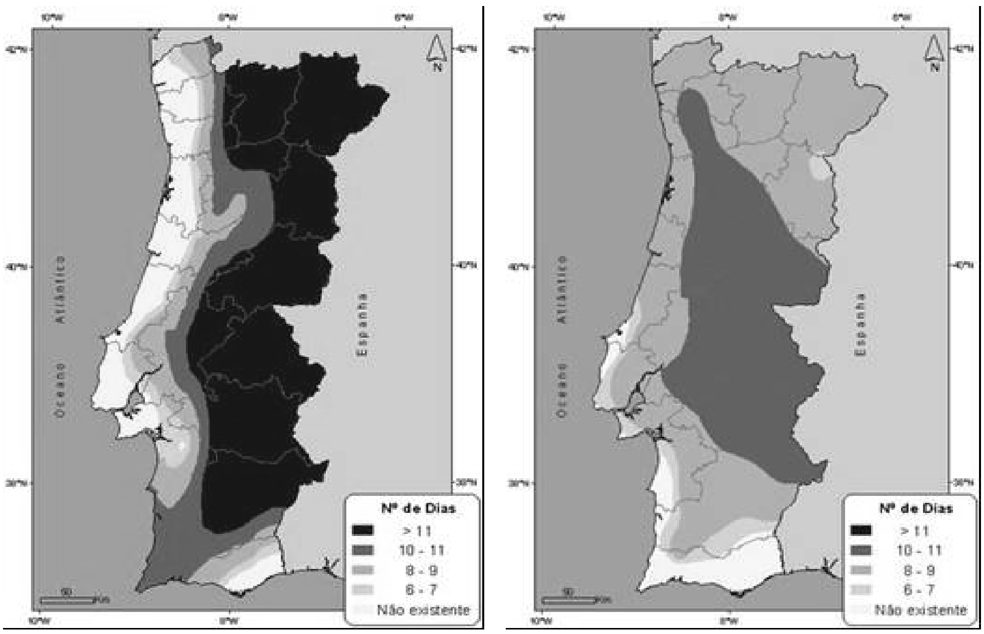


Figure 3: **Comparative length (number of days) and spatial extent of heat waves in 2003 (left) and 1981 (right) in Portugal[454]**

The causes of the disaster: Heat waves and forest fires

Although fire is an important ecological disturbance and regenerative process in Mediterranean ecosystems, the fire regime has been altered over the last few decades and a naturally occurring 25-35 year cycle of fire recurrence in Mediterranean ecosystems has been reduced[455]. This change in the fire regime has meant that fires have increased in intensity and extension, lost their beneficial ecological role and are becoming catastrophic events[456].

The relation between heat waves and forest fires in Mediterranean climates has long been studied[457,458,459, 460], and there is little doubt about the important role of heat waves in creating optimal conditions for the propagation of forest fires. Recent data comparing the meteorological Fire Weather Index (FWI, used for monitoring fire risk in Portugal) and total burnt area in Portugal's mainland is quite clear on this relation[461], showing how most of the total burnt area is concentrated over a few peaks of high index values.

There are thousands of fires every year throughout the country, mainly due to human causes (usually negligence, but also arson). During average weather conditions such fires can be controlled, but during heat waves they easily become out of control and may turn into big wildfires.

The importance of severe heat waves in forest fires is quite evident from the analysis of figure 4, depicting the number of days within the official fire season (May 15 – October 15) under each Daily Severity Rating (DSR) class and the corresponding total burnt area for six recent years. A report published in 2006 by the national forest authority (DGRF)[462] concludes that the relation between DSR and ignitions is quite linear, while the relation of DSR with total burnt area is exponential, with a few high value days causing most of the overall burnt area.

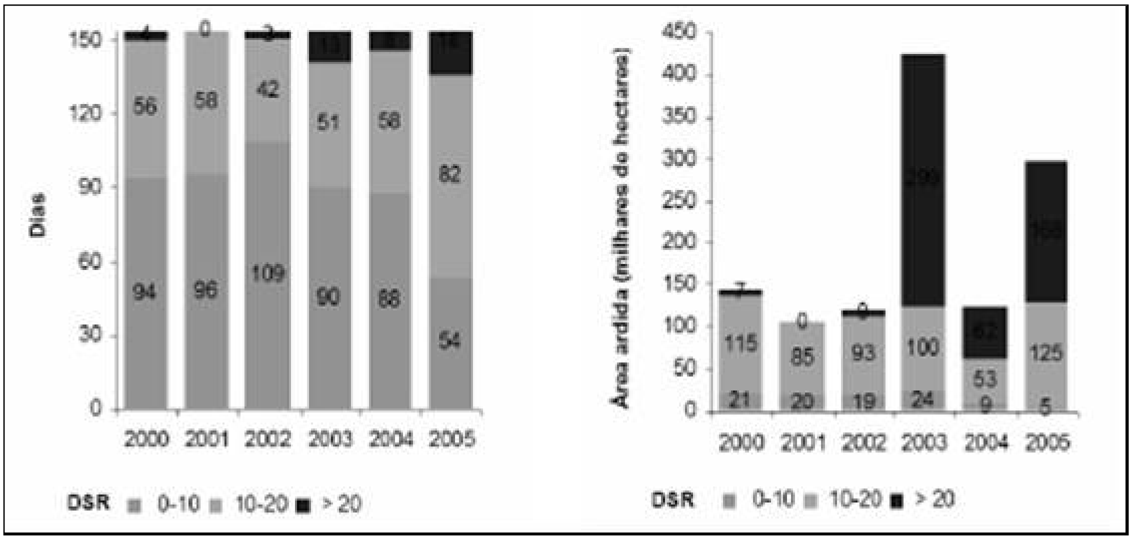


Figure 4: **Number of days (left) and total burnt area (right) under three DSR classes for the 2000-2005 respective fire seasons**

2003 was so exceptional that forest fires, usually concentrated in the northern and central regions, also occurred in the south with great intensity. Of the seven districts with over 10,000ha of total burnt area, all except Faro were fully exposed to heat wave conditions. In the remaining 11 districts, which had less than 10,000ha of total burnt area, only three had 100 per cent of their territory under heat wave conditions[463]. The impacts of this catastrophe were massive: 20 people were killed in fire-related accidents (including four firemen), and damages amounted to almost 2 billion euros[464]. There were also impacts reported on air quality across Western Europe[465].

Although previous heat waves, such as in 1991, have also caused large forest fires and high values of total burnt area, they can not explain the abrupt increase in the latter, as heat waves themselves have not registered such an exponential trend. Therefore, the cause of such increasing devastation has to be sought in relation to either ignition or combustion conditions, which are mostly dependent on land use.

Pereira *et al*[466] have shown that in future scenarios of climate change in Portugal (namely those resulting from doubling of CO_2 concentration in atmosphere) the frequency of hot and dry summer days will increase and consequently the number of days of high risk of fire will also increase (fig. 5). In its turn, a higher number of days with a high risk of fire is positively related to total burnt area (fig. 4).

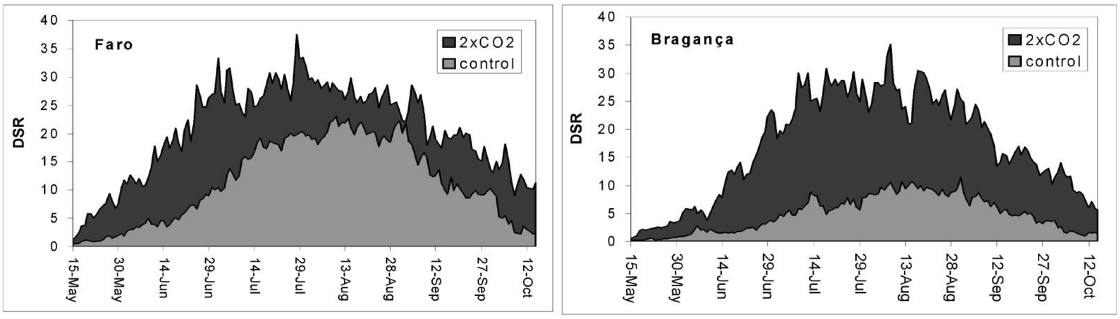


Figure 5: **CO_2 doubling scenario and increase in the number of days with high fire risk (DSR index) in Portugal. Changes seem to be larger inland (e.g. Bragança) than in coastland (e.g. Faro) areas. Adapted from Pereira et al[467]**

Primarily as a result of the European Union Common Agricultural Policy (CAP), several European regions have undergone land abandonment and a subsequent increase in shrublands and/or forested areas. In Portugal, as in other Mediterranean countries, this has been accentuated by migration from rural areas to cities. In Mediterranean ecosystems the diminishing of agricultural activities usually leads to rapid shrub encroachment and invasion of open areas such as grasslands by shrubs. Thus, a reduction of land under agriculture has generally led to dramatic increases of vegetation fuel loads and consequently to larger and more severe fires. Socio-economic factors and related dominant land-uses are thus of crucial importance in partially explaining the increasing fire problem in Mediterranean areas and Portugal in particular[468].

Fires and Protected Areas

Most protected areas in Portugal are managed as IUCN Protected Area Management Category V, i.e., areas in which the interaction of people and nature has created significant ecological, cultural and biodiversity values. In addition to the existing protected areas network, Portugal participates in the European Union Natura2000 network (which includes habitat protected under the EU Habitat Directive, and areas of special protection for birds). The Natura2000 network covers 21 per cent of the Portuguese territory and partially overlaps with the protected area network.

The Iberian lynx

In Portugal different high conservation value landscapes have been maintained due to agro-silvo-pastoral activities. Most of southern Portugal, for instance, is included in the WWF Mediterranean Ecoregion and is considered a significant biodiversity hotspot particularly due to the presence of evergreen oak savannas, i.e. silvopastoral systems of cork and holm oak. Such systems have considerable within and inter-habitat diversity maintained through centuries of human use. Species such as Iberian Lynx (*Lynx pardinus*), the most endangered felid in the world, or the Imperial Eagle (*Aquila adalberti*) depend on such habitats for survival.

Protected areas in Portugal are generally following the trend described above, i.e. land abandonment is leading to an increase of shrubland areas and of fuel loads. Fire management is considered in some protected areas through Landscape Management Plans, which describe actions at the fire prevention level such as environmental education, creation of fire breaks, monitoring and restoration of recently burned areas[469]. However, at present the landscape level changes which are occurring, possibly together with the lack of implementation of Landscape Management Plans, means that the number of fire ignitions in protected areas, as well as of total burnt area, has increased since 1992 (see Table 7)[470], with an average area of approximately 10,500 ha/year burnt, peaking in 2003 (approximately a quarter of the total burnt area between 1992 and 2005).

Table 7: **Comparing burnt area in protected areas and total land area in 1991, 2003 and 2005**[471]

Area type	Total area (ha)	Burnt Area (ha) per year					
		1991[1]		2003		2005	
		ha	%	ha	%	ha	%
Protected areas (PA) [2]	1,819,286	31,480	1.7	110,151	6.1	49,409	2.7
Total land area	8,896,882	182,484	2.1	441,378	5.0	269,716	3.0
Total area excluding PA's	7,077,596	151,005	2.1	331,227	4.7	220,307	3.1

[1] Data for 1991 includes some areas classified in later years
[2] Includes the whole protected area network and Natura2000 sites

Land use is thus of crucial importance for understanding wildfires. In 2005 for instance, another 'heat wave year', shrublands were the main vegetation cover affected by wildfire in Portuguese protected areas with 11,439 ha (60 per cent of total burnt area) affected. Other land uses affected in 2005 were: forest mixed stands (3,472 ha or 18 per cent of total burnt area), Maritime Pine (*Pinus pinaster*) stands (2,790 ha or 14 per cent of total burnt area) and eucalyptus stands (559 ha or 3 per cent of total burnt area). For the Natura2000 areas, approximately 58,000 ha (some 3 per cent of Natura2000 areas) also burned in 2005.

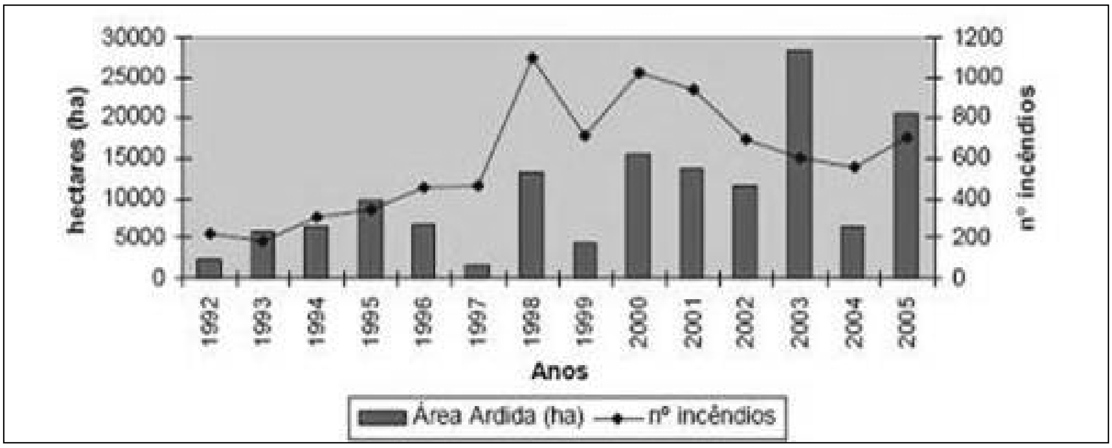


Figure 6: **Number of fires and total burnt area in protected areas network between 1992 and 2005**

Whilst the number of wildfires in protected areas, after an increasing trend, stabilise after 1998, total burnt area shows a different trend with two peaks during the heat waves of 2003 and 2005 (Figure 6). There are apparently no significant differences between the burnt area within and outside borders of protected areas. Land-use changes and heat wave factors seem to be interacting in Portuguese protected areas in the same way as in the rest of the country. To date, protected area fire prevention plans have not made a significant difference to fire frequency however, awareness of the fire problem increased following the fires of 2003 and possibly will result in proper implementation of plans.

Conclusions – what role can protected areas play in hazard mitigation?

Wildfires, particularly those induced by the heat waves of 2003 and 2005, affected Portuguese protected areas mainly through total burnt areas. Main cover affected was shrubland, a land-use resulting from land abandonment, which points to the socio-economic root of the wildfire problem.

At present, existence of a protected area has not significantly affected the likelihood of fires, either in terms of increasing or decreasing the risks. This suggests that protection as such is not a fire prevention measure. However, the landscape-scale planning inherent in Category V protected areas should allow implementation of more effective fire prevention measures, including fire breaks, encouragement of old-growth (with its attendant fire load) in fire refugia and effective public education campaigns. Such preventive measures can enhance the landscape mosaic and contribute to reducing fuel loads and thus contribute to mitigating wildfires and promoting nature conservation.

This may be achieved, for example, through favouring agri-environment schemes in classified areas, aiming to promote economically viable but responsible and conservation-friendly activities**.** If this is not possible, than management of protected areas should simulate human disturbance, through processes such as grazing or prescribed fire that may contribute to maintaining low fuel loads and benefit habitat heterogeneity and conservation aims.

Otherwise, the interaction between predicted increasing heat wave frequency through climatic changes and land use changes leading to higher fuel loads on the field will continue to aggravate the fire problem in Portugal.

Indian Ocean Tsunami: 2004

"The Indian Ocean tsunami of 26 December 2004 and its tragic and devastating consequences were a wake-up call for the global community, dramatically drawing attention to the vulnerability of tropical coastal ecosystems and the dangers of undermining the services they provide to humankind"
UNEP-WCMC report "In the front line"[472]

Introduction

Tsunami is the name given to a wave caused by seismic disturbances; tsunamis can potentially be the largest and most powerful waves on earth. On 26 December 2004 an earthquake deep in the Indian Ocean began a 'chain reaction' of events leading to one of the worst natural disasters of recent history.

The initial earthquake off Sumatra ruptured the fault line in the Indian and Eurasian tectonic plates, which runs through the Andaman and Nicobar Islands, resulting in a series of secondary earthquakes. These earthquakes displaced approximately 30 cubic km of sea water directly above the fault resulting in the generation of waves which were then reflected off land masses and continental shelves to form a complex pattern of tsunamis that lasted for many hours[473]. The first area to be hit, just forty-five minutes after the initial earthquake, was the coast of Aceh Province in Sumatra, Indonesia. In the following hours the tsunami (or in fact many separate tsunamis) wreaked havoc on the coastal areas of 12 countries in the Indian Ocean region (Indonesia, Sri Lanka, India, Thailand, Myanmar, Bangladesh, the Maldives, the Seychelles, Yemen, Somalia, Kenya and Tanzania).

The tsunamis caused immense social, economic and environmental devastation in areas that were already poor. It killed more than 280,000 people and left over a million homeless. It destroyed the livelihoods of an estimated one million people in Indonesia and Sri Lanka alone[474] and there was over a billion US$ worth of damage[475]. As a result the Asian Development Bank calculated that the disaster threatened to result in a further two million people being put into poverty in the region as a whole[476].

The disaster galvanised communities across the world to lend support, aid and sympathy in a rare out-pouring of shared global concern and action; with the aid pledged to affected countries topping US$11 billion[477].

The causes of the disaster

"*Whenever I made noise that there were insufficient mangrove trees in the area, I was accused of being orang tua bodoh (a silly old man)*"
Saidin Hussein, Malaysia[478].

The initial earthquake off Sumatra was the world's largest seismic event in the last 40 years[479]. Its effects were always going to be great. But did the fact that the tsunamis it generated hit coastlines with a long history of degradation magnify these effects?

As discussed earlier in this report, coral reefs and mangroves are two of the world's most endangered ecosystems. Their loss is likely to increase the vulnerability of coastlines, as they play an important role in shore protection, both under normal sea conditions and also during hurricanes and tropical storms (see pages 41). In Asia, 36 per cent of mangrove area has been deforested, at the rate of 1.52 per cent per year[480]. Although many factors are behind this loss a major cause is aquaculture expansion in coastal areas, especially the establishment of shrimp farms[481].

It is clear that in many places the tsunamis effects were made worse because of poor land-use planning and environmental destruction. In the Maldives the tsunami worsened chronic shoreline erosion caused by sand mining and poorly designed coastal buildings; for instance, the tsunami accelerated long-term erosion, probably as a result of reef flat dredging operations from a nearby resort, at the north end of the island of K. Guraidhoo undermining several coastal structures[482]. A larger question relates to whether the levels of protection afforded by intact ecosystems provided any measurable amount of protection in the face of a disaster of the magnitude of the December tsunami.

Resulting environmental effects

The total energy released by the earthquakes that triggered the tsunamis was more than 1,500 times that of the largest nuclear bomb ever detonated[483]. But the devastation seen in terms of human impacts were not matched by impacts on the natural environment. A review of coral reef impacts found that: "*In all of the Indian Ocean countries, the tsunamis have caused less damage to coral reefs than the cumulative direct anthropogenic stresses such as over-fishing, destructive fishing, sediment and nutrient pollution, and unsustainable development on or near them*" [484].

Generally, the environmental impacts affected human well-being more than they caused long-term damage to natural ecosystems. Contamination was found in Sri Lanka, possibly due to the disturbance of sea beds containing arsenic leached from geological formations rich in arsenic in Bangladesh, West Bengal and Nepal, and salt affected hundreds of hectares of paddy fields and other agricultural land, and contaminated wells across the region. Massive amounts of debris caused immediate health hazards and interfered with drainage, causing water-logging and increasing disease risks[485]. And reconstruction efforts led to concerns of further environmental damage due to uncontrolled resource extraction to fulfil the need for material, such as timber and coral, for rebuilding lost homes and business.

Impacts on human well-being

The disaster affected poor communities where people mainly lived off the sea and marginal land, and destroyed or badly damaged a number of towns. Fishing fleets were particularly badly affected. In Sri Lanka about two-thirds of the country's fleet was destroyed or damaged[486].

In the Maldives, one of the worst affected countries (see box below) total asset losses were estimated to be US$472 million, equalling 62 per sent of the country's GDP[487]. In Sri Lanka, output losses resulting from the damage to assets and the disruption in economic activity in the affected areas were estimated at US$331 million during 2005 and 2006, or around 1.5 per cent of GDP[488].

Before the tsunami, more than a third of the population of Aceh and Nias Provinces in Indonesia lived in poverty. Now, almost half live below the poverty line or are dependent on food aid and it is expected that full recovery will take years[489]. In Sri Lanka, a large number of home-based production and income generating activities were destroyed, affecting women in particular, and reducing family incomes, which it is estimated could drive around 250,000 people below the poverty line[490].

On a per capita basis, Maldives was one of the worst affected countries. The tsunami's impact was national in scope. Sixty-nine of the country's 199 low-lying inhabited islands were damaged, 53 of them severely. Twenty were largely devastated, and 14 had to be evacuated. According to the Government, 29,577 residents were displaced by the tsunami. Approximately 12,000 remain homeless, living in temporary shelter or with friends and relatives on their own or other islands. In all, nearly a third of the country's 290,000 residents suffered from loss or damage of homes, livelihoods and local infrastructure.
From UNEP's *Post-Tsunami Environmental Assessment*[491]

Mitigating the Impacts

"*When the first tidal wave came in the middle of the day on December 26, the fishermen were returning from sea. When they realised how strong the waves were, they clung tight to the mangrove trees and were spared from the waves. Even their property on land was saved because the mangroves served as a buffer*,"
P. Balan, Penang Inshore Fishermen Welfare Association adviser, Malaysia[492].

There has been much debate, and a flurry of scientific articles, discussing the role of effectively functioning ecosystems, such as coral reefs and mangroves, in mitigating disasters following the tsunami. And it has truly been a *debate* because although it would seem to be common sense that mangroves and perhaps reefs form natural barriers along the coast (in the Southern Indian district of Chidambaran a sacred grove is known as *Alaithi Kadukal*, which means 'the forest that controls the waves') before the Indian Ocean Tsunami there was relatively little scientific data to back this up[493]. Some computer modelling suggests the importance of vegetation in dissipating the power of tsunamis (see page 21)[494]. Research into the buffering effects of coral reefs has demonstrated that a sufficiently wide barrier reef within a metre or two of the surface reduces by up to 50 per cent the distance inland a wave travels depending on the nature of the tsunami, geometry and health of the reef and the offshore distance of the reef[495]. However field evidence for this is limited, mainly because although many storms reach shore every year, tsunamis, especially those as powerful as the one in 2004, are thankfully rare (fewer than 100 tsunamis were recorded over the last 300 years in the Indian Ocean[496]). There has therefore been much less opportunity to study their impacts and any effective mitigating factors. Studies carried in Japan are the one exception; using historical records studies have noted the role of forests in limiting the effects of tsunami damage and have made recommendations as to forest area required to both mitigate and reduce tsunami impacts[497].

Given the wide area affected by the 2004 tsunami the impacts were varied across the region, as are the causal links between damage and ecosystem mitigation. The examples below review the evidence of where natural systems seemed to offer some protection and where they did not:

Protection:

- ✓ Detailed studies in Hikkaduwa, **Sri Lanka**, where the reefs are protected in a marine park, noted that the tsunami damage reached only 50 metres inland and waves were only 2-3 metres high. At Peraliya, just 3 km to the north, where reefs have been extensively affected by coral mining, the waves were 10 metres high, and damage and flooding occurred up to 1.5 km inland[498].

- ✓ A survey of 24 lagoons and estuaries, also along the coasts of **Sri Lanka**, which suffered the greatest damage in the country showed that where good quality mangrove communities occurred there was little destruction, and the mangroves themselves were not badly affected. However, forests that had been degraded in the past and were no longer dominated by genera such as *Sonneratia* or *Rhizophora* were damaged (as noted below the root structures of some species seem to provide more protection than others)[499].

- ✓ A study of about 250 km (19 locations) on the southern coast of **Sri Lanka** and about 200 km (29 locations) on the Andaman coast of southern **Thailand** found that mangrove species *Rhizophora apiculata* and *R. mucronata* and *Pandanus odoratissimus*, a representative tree that grows in beach sand, were found to be especially effective in providing protection from tsunami damage due to their complex aerial root structure[500]. A further study by the Department of Marine and Coastal Resources in **Thailand** conducted in three provinces of the Andaman coast found that the impact of the tsunami caused significant changes in mangrove forest structure and composition as well as sediment deposition and land erosion. It was found that in mangroves 50 to 70 metres from the coastline the damage was total, there was moderate damage to mangroves 70 to 100 metres from the coast and no damage at 110 to 150 metres. It was therefore recommended that if mangrove forest are to act as natural barrier, or a so-called bio-shield, to protect against tsunami destruction, the thickness of the forest should not be less than 150 metres from the coastline[501].

- ✓ A detailed study of Odu lagoon and Nasiva village (Valachenai), in Batticaloa district, **Sri Lanka** reports that although the tsunami was about six metres high when it reached shore and penetrated up to 1 km inland, the mixed landscape, comprising beach, mangrove-fringed lagoon, coconut plantation, scrub forest, home gardens and the village, seems to have absorbed and dissipated much of the tsunami's energy. By the time the wave reached the village it was less than 40 cm high and caused no loss of life. The mangroves are comprised of a band of trees 5-6 metres deep, of which the first 2-3 m metres (mainly *R. apiculata* and *Ceriops tagal*) were severely damaged by the tsunami. The inner 3-4 metres of mangrove vegetation, however, was much less damaged. The study concluded that mangrove restoration, particularly in the first 300 metres on both sides of the lagoon, should be a high priority due to their importance, both from a biodiversity and environmental security point of view [502].

The devastation around Kalutara, Sri Lanka, about an hour after the first in the series of waves hit

© Digital Globe. Image from Visible Earth, NASA (visibleearth.nasa.gov/view_rec.php?id=17046)

- ✓ Also in **Sri Lanka**, it is reported that at Yala and Bundala National Parks, the vegetated coastal sand dunes completely stopped the tsunami, which was only able to enter where the dune line was broken by river outlets[503] or where the dune had been levelled to allow a view to the ocean from a hotel resulting in extensive damage to the hotel by the tsunami[504].

- ✓ Remote sensing analysis identified pre-disaster mangrove change and post-disaster structural damage and landscape changes in mangrove forests on the Andaman coast of **Thailand**. Field data from five sites (20 villages) which faced similar tsunami exposure suggests that the presence of healthy mangroves afforded substantial protection[505].

- ✓ In the **Maldive Islands**, the coastal vegetation provided important protection to the residents of the islands[506]. Much of the tsunami's force was dissipated in areas where the coast was fronted by a dense hedge of native shrubs such as *magoo* (the bushy evergreen shrub *Scaevola sericea* also commonly know as beach naupaka and sea lettuce) and *kuredhi (Pemphis acidula).* The impact survey carried out by UNEP concluded that: "*In general, natural shorelines and land surfaces fared better during the tsunami than did developed features. Tsunami impacts were greatest where villages or cultivated fields directly abutted the sea with little or no coastal protection. Wherever a fringe of natural coastal forest or mangroves had been left untouched there was a marked reduction in erosion and destruction of buildings*"[507].

- ✓ The conclusions of a major report on the status of coral reefs throughout the tsunami-effected area found that: "*coral reefs absorbed some of the tsunami energy, thereby possibly providing some protection to the adjacent land, however, mangroves and coastal forests afforded the most protection to infrastructure on the land and probably reduced the loss of life in these areas*"[508].

- ✓ In some areas of Kanyakumari and Tirunelveli districts in Tamil Nadu State, **India**, coastal vegetation was found to have served as an initial line of defence in controlling the inundation, conversely those areas where inundation was greatest were river mouths and estuaries[509]. A study of satellite imagery and ground truthing in Cuddalore District, Tamil Nadu also found areas with mangroves and tree shelterbelts were significantly less damaged than other areas[510].

No-Protection

- ✓ An analysis for the UNEP Asian Tsunami Disaster Task Force of more than 50 sites affected by the tsunami, using pre- and post-satellite imagery, indicated that there was greater coastal flooding behind coral reefs, perhaps because channels through the reef accelerated the flow[511]. The research also did not show any clear correlations between the presence of mangroves and reduced shoreline damage[512]; but in later publications this finding was qualified by the fact that the mangrove forests identified in the study were all located in sheltered areas, thus preventing the possibility of addressing the potential protecting role of mangroves forests[513].

- ✓ UNEP-WCMC found that in many cases the locations where mangroves have been reported to have helped protect the shoreline were in areas with small to moderately sized tsunami waves, or were adjacent to deeper water, and thus less susceptible to serious damage[514].

- ✓ UNEP-WCMC concluded that research at the time showed that reefs and mangroves were not the main factor influencing the extent of damage on the coastline. Shores adjacent to deep water tended to be less affected than those next to shallow sloping shelves, regardless of the presence or absence of reefs or mangroves. The shape of the coastline is also influential, with headlands often providing protection while bays and inlets act as funnels, restricting and focusing the force of a wave[515].

So what conclusions can we draw from these findings? It would seem that intact coral reefs may play a small role in dissipating tsunami waves, as in Hikkaduwa, Sri Lanka, but in some places they may accelerate the flow perhaps due to water being pushed through the channels in the reef[516]. There seems to be better evidence on the role mangroves can play in helping to mitigate impacts of storms and even in some case tsunami waves, but forest quality (i.e. species and area of forest cover) may play an important role in the protection afforded – i.e. we need to distinguish between intact and degraded mangroves.

But the debate continues. In December 2006, in an editorial in the *New York Times*, Andrew Baird of the Center for Coral Reef Biodiversity at James Cook University, Australia, criticised former US President Bill Clinton, in his role as special envoy for UN tsunami recovery, for endorsing a US$62 million programme for preserving mangroves and coastal reefs as 'natural barriers' to future tsunamis in Indian Ocean countries[517]. A robust defence of mangroves role in mitigating disasters and a critique of the *New York Times* editorial was provided by Edward B. Barbier of the University of Wyoming, USA, who cites evidence in the literature that healthy mangrove forests can attenuate waves and buffer wind storms. He notes that: "*over the past two decades the rise in the number and frequency of coastal natural disasters in Thailand and the simultaneous rapid decline in coastal mangrove systems over the same period is likely to be more than a coincidence*"[518].

Critiques and differences in opinions are bound to continue, but the debate is less about whether or not natural vegetation provides protection than about whether the protection is sufficient to mitigate truly enormous waves. It is clear that ecosystem services can provide protection from at least some types of storm waves, and from a perspective of broadscale management, both mangroves and coral reefs have far wider benefits than just storm protection – ranging from attracting tourism to increasing fish stocks.

Protection and restoration following the tsunami, could provide the opportunity to restore both people's livelihoods and security and the ecosystem services on which many rely.

The future – what role can protected areas play in hazard mitigation?

"Apart from the actual direct environmental damage observed, it also became clear that urgent action needed to be taken to integrate environmental considerations in the national recovery and reconstruction process, to avoid further environmental deterioration and meet the already well-established pressures on natural resources."
A. H. M. Fowzie, MP, Minister of Environment and Natural Resources, Government of Sri Lanka[519]

Evidence for the benefits of coral reefs and mangroves for shore protection is currently less for tsunamis than it is for storms. But clearly in some cases there is evidence of mitigation offered through ecosystems services. Unfortunately, some of this potential may soon be lost. As reported above, coral and mangrove communities are declining fast, and globally protection is lower than for most other ecosystems. In consequence, coastlines are changing. In Sri Lanka, for example, coral reefs are under threat; even in protected areas they are vulnerable because management capacity has been too weak to prevent destructive fishing techniques from being used[520]; and at least partly as a result of reef damage, erosion on the south and west coasts is estimated at 40cm a year. The cost of replacing the coastal protection provided by these reefs has been calculated as being somewhere between US$246,000 and US$836,000 per km[521], a figure far higher than that needed adequately to manage a protected area. Although many of the countries of the Indian Ocean have designated marine protected areas (MPAs) to conserve coral reefs; few have effective management plans and enforcement of legislation, with the result that the resources continue to decline[522].

Currently, only some nine per cent of the total area of mangrove in the world is protected and there are no accurate figures of coral reef protection[523]. The most logical approach to ensure coastal protection through natural ecosystem services would seem to be the effective protection of remaining natural habitats where these are under threat, followed, where appropriate, by restoration of degraded areas. Of the damage to natural systems caused by the tsunami it is predicted that most coral reefs will recover naturally in 5 to 10 years, provided that other stress factors are removed, and mangrove forests that have only been slightly damaged will re-seed themselves and recover[524]. Mangroves more severely damaged will need more active restoration and many of the countries affected by the 2004 tsunami are already actively restoring mangroves. In Indonesia, for example, 150,000 ha of mangroves are being planted along the coast of Aceh where 300,000 ha of mangroves were destroyed[525].

Of course, as in all of the other case studies in this report, disaster mitigation through ecosystem services is only one of many strategies for disaster preparedness and mitigation. As such it should not be forgotten that knowledge on tsunami identification and immediate responses and appropriate warning systems are of utmost importance. As Andrew Baird rightly points out, we should not use the presence of natural ecosystems as an excuse for under-investing in other disaster preparations. Thousands of lives could have been saved had a tsunami early warning system been established in the Indian Ocean[526].

The range of responses to the Indian Ocean tsunami was discussed in February 2005, at a meeting organised by UNEP in Cairo, Egypt, on coastal zone rehabilitation and management. The meeting adopted the 'Cairo Principles' for post-tsunami rehabilitation and reconstruction[527], the overarching principle of which (principle number 1) is to reduce the vulnerability of coastal communities to natural hazards by establishing a regional early warning system and applying construction setbacks, greenbelts and other no-build areas in each nation, founded on a science-based mapping processes. Principle 3 (see box) is of particular relevance to this report, and provides a suitable overview of 'next steps' which may help mitigate the threat from future tsunamis. This endorsement for the role of these so-called bioshield's was reiterated by the FAO, following an expert workshop on coastal protection in the aftermath of the Indian Ocean tsunami in 2006, with the experts calling for urgent action to be taken to protect existing coastal forests, rehabilitate degraded ones and plant new forests and trees in sites where they are suitable and have the potential to provide protection[528].

The proportion of such areas of natural vegetation or coral that will be incorporated fully into the national protected area system will vary between countries and regions. The role of the less strictly protected categories, such as V and VI, may be especially valuable through allowing sustainable uses such as managed fishing whilst ensuring the survival of natural ecosystems.

Principle 3*: Enhance the ability of the natural system to act as a bioshield to protect people and their livelihoods by conserving, managing and restoring wetlands, mangroves, spawning areas, seagrass beds and coral reefs; and by seeking alternative sustainable sources of building materials, with the aim of keeping coastal sand, coral, mangroves and rock in place.*

Natural barriers to flooding and coastal erosion, such as coral reefs, near-shore rock outcrops, sandbars, and sand dunes should be protected from construction activity and uses that compromise their structural integrity. They reduce, absorb and redirect waves and floodwaters. Wetlands, lagoons, river estuaries, and reefs are essential to sustaining fisheries, public health and the many livelihoods that support coastal populations. They contribute to a healthy and aesthetically pleasing environment for a seaside holiday. A portion of the funds for rehabilitation should therefore be assigned to protect and restore these habitats. Reconstruction will require thousands of cubic meters of sand for cement and for fill, and building materials of every description. Traditionally, many of these materials have been taken from the coast itself. When sand is mined from beaches, dunes and coastal rivers, mangroves are cut for timber, and wetlands filled as building sites coastal settlements become more vulnerable to hazards of every description.

- ✓ Conduct rapid assessments that involve local people in the identification of natural areas important to fisheries production, the recycling of wastes, shoreline stabilization and scenic quality, including coastal wetlands and mangroves, seagrass beds, and coral reefs. The aerial photographs and maps used for establishing setback lines can be used in this process of identifying critical areas.
- ✓ Incorporate these natural features and habitats into a designated coastal bio-shield that maximizes the protection from coastal hazards and the associated benefits provided by these natural features. Adopt measures to protect bio-shields from activities that compromise their natural qualities. Protect them from future disturbance and, where feasible, restore them.
- ✓ Where feasible, plant trees seaward of the setback line to form a greenbelt that buffers the shore from waves, floods and erosion[5].
- ✓ Prohibit the mining of sand, coral and stone from coastal waters within the 20-meter depth contour.
- ✓ Regulate sand mining from rivers.
- ✓ Declare wetlands and mangroves as off limits for harvest of wood.
- ✓ Prohibit the filling of wetlands and estuaries[529].

[5] It should be noted here that feasibility needs to cover a range of issues, to ensure that planting is appropriate, for instance the need to avoid planting of trees in marine turtle nesting sites

USA: Hurricane Katrina

"The levees have made New Orleans habitable since the French arrived, and those same levees through their recent failures have rendered the city uninhabitable by obliterating the buffering landmass that traditionally made New Orleans a safe place to live. When the French arrived in Southern Louisiana, there were vast and dense hardwood forests, followed by vast stretches of freshwater marshes and swamps, followed by endless saltwater marshes, and finally a formidable network of barrier islands. Now, it's all almost completely gone"
Mike Tidwell, author of Bayou Farewell[530]

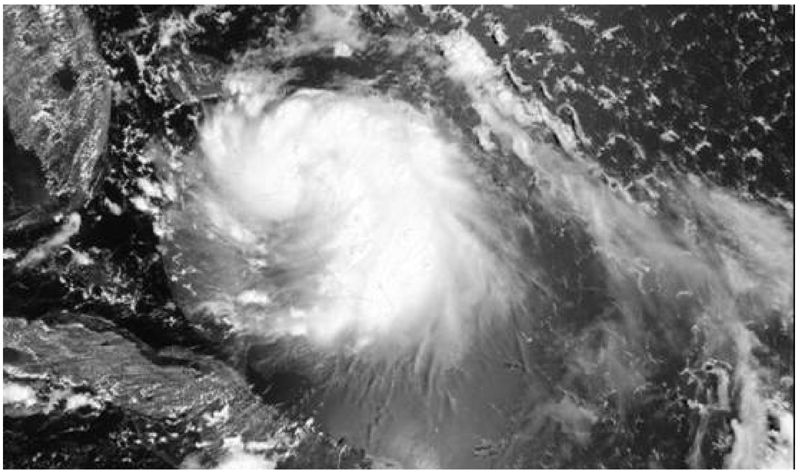
Introduction

The story of Hurricane Katrina, the massive hurricane that devastated America's Louisiana's Gulf Coast, begins not on August 29, 2005 when the hurricane made landfall, but decades earlier in the 1930s[531]. It was during this first half of the twentieth century that the construction of levees for flood control began fundamentally to alter coastal prairies and marshes in Louisiana.

The levees were originally built to protect coastal communities from the periodic flooding of the Mississippi River and other waterways. Over time, however, these levees, in combination with oil and gas development and dredge and fill activities, disrupted the natural hydrological regime of the Louisiana Gulf Coast. Without a natural hydrological regime to deliver freshwater and sediment to replenish coastal wetlands and barrier islands (the long narrow islands of sand that are separated from the mainland by a lagoon or bay), the coastline lost its ability to mitigate the impact of tropical storms effectively. The coastline was no longer an effective natural buffer. Levees that were meant to protect human life and encourage livelihood development actually made people *more* vulnerable to disaster.

This was tragically demonstrated when Hurricane Katrina brought massive rainfall in excess of 2.5 centimetres per minute, storm surge above 9 metres in places, and flash floods that devastated coastal communities along the U.S. Gulf Coast including New Orleans and Biloxi, Mississippi[532]. Had more concerted efforts been made to protect coastal prairies and marshes over the past 75 years, the severe impact of Hurricane Katrina and other tropical storms would likely have been reduced[533, 534].

This case study provides an overview of the U.S. Gulf Coast, investigates the loss of coastal barriers, describes the impacts of Hurricane Katrina, and discusses the role of protected areas in mitigating the negative impacts of hurricanes off the Gulf Coast.



Tropical Storm Katrina approaching Florida

Louisiana and the U.S. Gulf coast

The Gulf Coast of the United States includes the states that border the Gulf of Mexico (i.e. Texas, Louisiana, Mississippi, Alabama and Florida) and represents an ecologically, economically and culturally rich geographical area. Classified as the Gulf Coast Prairies and Marshes Ecoregion, this area contains one of the largest contiguous wetlands systems in the U.S., exclusive of Alaska and Hawaii[535]. Within Louisiana, the Coast Prairies and Marshes Ecoregion extend about 27,700 km^2.

The ecoregion supports numerous natural communities, such as coastal prairies, as well as a diverse range of wetland communities, including salt, brackish, intermediate and freshwater marshes. Cheniers, or ridges of deposited sand and shell dominated by live oaks, also occur within the ecoregion, though less frequently. Commonly found vegetation includes cordgrasses (*Spartina* spp.), common reed (*Phragmites austalis*) and Bulltongue (*Sagittaria lancifolia*) along with associated wildlife such as seaside sparrow (*Ammodramus maritimus*), clapper rail (*Rallus longirostrus scottii*), American alligator (*Alligator mississippiensis*), wading birds, migratory waterfowl, and an abundant variety of fish and shellfish. Due to its diversity of habitat types, it also supports a number of rare and endangered species. These include the globally rare giant blue iris (*Iris giganticaerulea*), Piping Plover (*Charadrius melodus*), Kemp's Ridley Sea Turtle (*Lepidochelys kempii*) and Louisiana Black Bear (*Ursus americanus luteolus*).

Alligator mississippiensis

© WWF-Canon / Martin Harvey

In addition to its rich biodiversity, Louisiana and the U.S. Gulf Coast as a whole, are also of international economic importance. The Port of South Louisiana, for example, is the largest tonnage port district in the Western Hemisphere and the fourth largest port in the world, handling over 248 million tons of cargo a year and accounting for 15 per cent of total U.S. exports[536]. Louisiana is also the United States' largest oil producer and its second largest natural gas producer with much of the oil facilities located along the coastline and offshore. In terms of fisheries, Louisiana has one of the highest commercial marine fish landings in the U.S. accounting for about US$250 million annually. More than 75 per cent of the U.S. shrimp catch comes from Louisiana's coastal waters[537].

The presence of navigable waterways, incredibly productive fishing grounds, and deposits of oil and gas has attracted many people to the Gulf Coast region with more than two million residing in coastal Louisiana alone with an associated capital investment approximating US$100 billion.

Causes of the disaster

"In nature, everything is connected to everything. And if you fundamentally alter a significant component of a natural system you fundamentally alter all of its major components."
Mike Tidwell, Author of Bayou Farewell[538]

In spite of their crucial role in protecting people, commerce and ecosystems, coastal wetlands and barrier islands have been disappearing at an unprecedented rate in the U.S. Gulf Coast due to both human-caused and natural factors. Much of the Louisiana coastal land mass has been literally sinking.

As coastal wetlands and barrier islands disappear, they are replaced by vast expanses of open saltwater encroaching from the Gulf of Mexico. More than 485,830 ha of wetlands have disappeared since the 1930s. The land loss of barrier islands varies but can average as high as 20.3 ha per year[539].

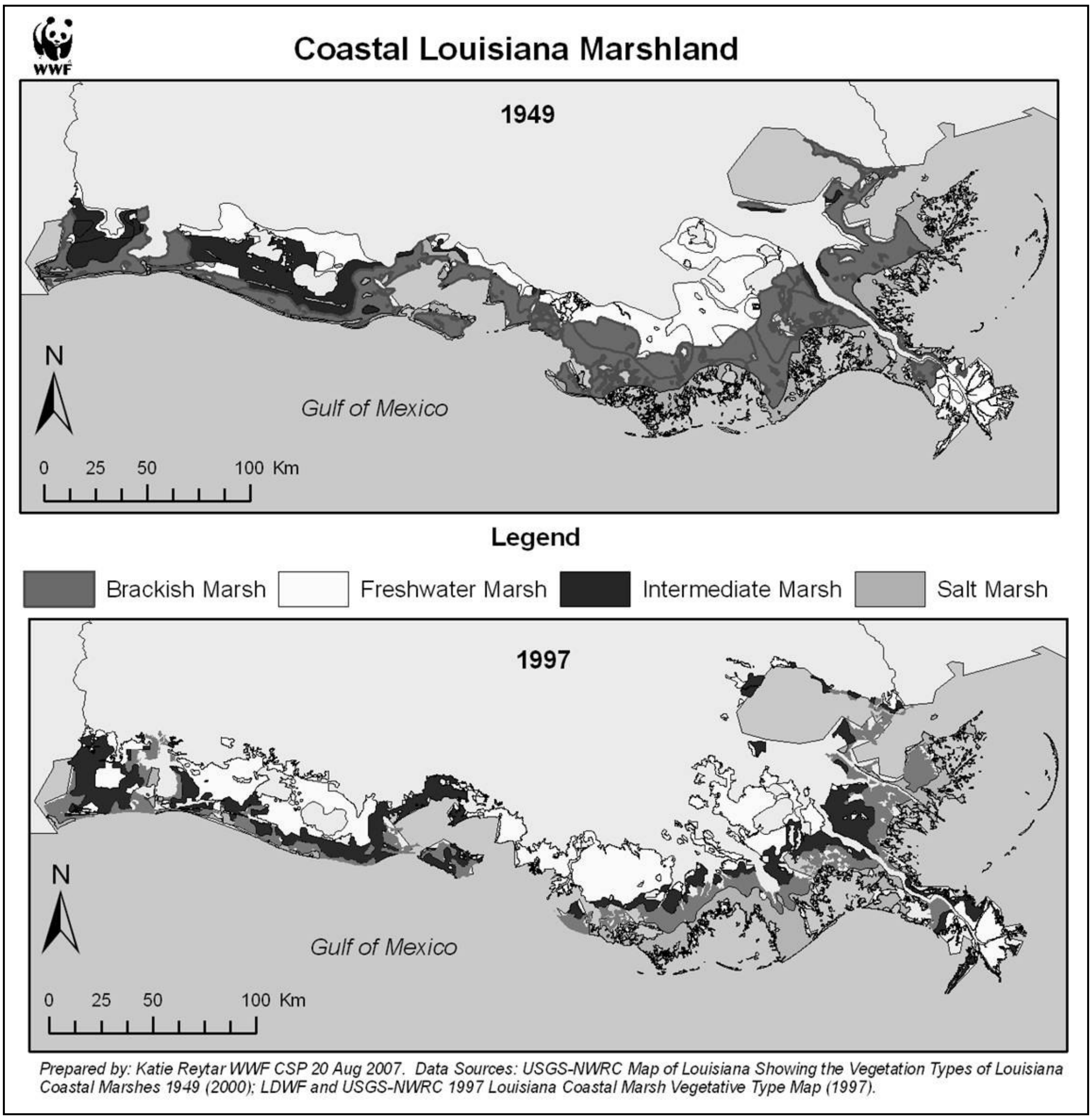


Figure 7. **Coastal Louisiana marshland coverage including brackish, freshwater, intermediate, and salt marshes, in 1949 and 1997**[6]

With the loss of wetlands and barrier islands also goes the many biological, economic and disaster risk reduction functions they perform. Nursery and breeding grounds for fish are destroyed. Essential habitat for resident and migratory birds disappears. Even land that had been used for human settlement, such as barrier islands, is lost. Any beneficial storm surge protection for adjacent populated areas is also affected. The wetlands and barrier islands that make up the Louisiana coastal plain play vital roles in protecting populated areas that lie further inland. A recent study found that "*the extensive loss of coastal marshes and bald cypress forests has increased the threat of storm-surge flooding for the 94,000 people residing in the southern part of New Orleans*.[540]"

[6] Sources: United States Geological Survey – National Wetlands Research Center (USGS-NWRC) (2000); Louisiana Department of Wildlife and Fisheries (LDWF) and USGS-NWRC (1997). Map created on 20/08/07.

✓ **Flood Control Structures**

A major contributing factor to the loss of wetlands has been the construction of a vast network of levees and other flood control structures that were built to contain the Mississippi River and to protect low-lying agricultural and urban areas from flooding. Land subsidence is a naturally occurring process whereby factors such as geological faulting, compaction of muddy and organic sediment, river floods, global sea-level change, wave erosion and tropical storm events have eroded and shaped the coastal Louisiana landscape for thousands of years. Over time, the loss of land has been counter-balanced by the deposition of nutrient-rich sediment from the Mississippi River delta which replenishes land forms. The presence of levees, dykes, concrete channels and other flood control devices has prevented the naturally-occurring sediment replenishment process and resulted in a net loss of wetlands[541].

✓ **Navigation Channels**

In addition to the presence of flood control devices, the establishment and maintenance of major navigation channels, both deep draft and shallow draft, have served as conduits for saltwater intrusion in some areas and barriers to the distribution of freshwater, sediment and nutrients to wetland habitats in other areas. Navigation channels can also subject inland areas to more dramatic tidal influences and wave action which in turn aggravate erosion. Extensive modification of the upper Mississippi and Missouri River watersheds, particularly through the construction of dams and navigation channels, has led to a reduction in overall sediment loading by 67 per cent. Sediment delivery supports the build up of deltas, lagoons, sand banks and coastal wetlands. Periodic changes in freshwater inundation and sediment accumulation also creates the enabling conditions for dynamic ecosystems that typically support high levels of biodiversity[542].

Offshore oil and gas development in the Gulf of Mexico

✓ **Oil and Gas Exploitation**

To make matters worse, coastal Louisiana has been exploited for oil and gas deposits since the early 1920s as evidenced by a network of canals, pipelines and production facilities that were created to service the industry. At present, 50,000 oil and gas production facilities dot the Louisiana coast connected through 14,973 km of oil and gas pipelines. The dredging process that is involved in the establishment of production facilities leads to dredged material banks that are higher than the natural marsh surface. This, combined with the establishment of exploration canals, has exposed land to open water, and fundamentally changed the hydrological regime of the coast's wetlands.

✓ **Land-use change**

The establishment of upstream reservoirs, changes in agricultural practices and land uses, and bank stabilisation measures has led to the reduction of vegetative cover which in turn has lessened the amount of organic matter that is available for wetland soil formation.

✓ **Climate Change**

The sea-level rise associated with climate change is expected to increase two- to four-fold during the next century, increasing storm surge and shoreline retreat along low-lying, unconsolidated coastal margins[543]. The rapid deterioration of coastal barriers combined with relatively high rates of land subsidence has made coastal Louisiana particularly vulnerable to erosion and inundation. The rate of land loss during the next 100 years from both climate change and subsidence is expected to lower New Orleans from 1.5 to 3 metres below mean sea-level to 2.5 to 4.0 metres below mean sea-level by 2100.

✓ **Tropical Storm Events**

The loss of wetlands and barrier islands is greatly accelerated by hurricanes and other tropical storm events. After Hurricanes Katrina and Rita hit in 2005, about 560 km^2 of Louisiana's coastal lands were transformed to water. Over time, some of the land may recover; however, the indications are that some of the change will be permanent with some new areas of open water becoming lakes. As discussed above, according to the U.N. Intergovernmental Panel on Climate Change, global warming will increase the frequency and intensity of tropical storms, which in turn will worsen the situation.

Impacts of Hurricane Katrina

The loss of wetlands and barrier islands as a result of flood control structures, navigation channels, oil and gas exploration, climate change and tropical storm events weakened Louisiana's natural coast protection, making it particularly susceptible to the devastating affects of Hurricane Katrina. When the hurricane made landfall on August 29, 2005, it was one of the strongest storms to impact the United States during the last 100 years. With sustained winds of 225 km per hour and rainfall in excess of 2.5 centimetres per minute, Katrina caused massive destruction in the heavily populated city of New Orleans, as well as the coastal areas of Louisiana, Alabama and Mississippi in the American south. Hurricane Katrina is the costliest natural disaster ever to hit the United States, both in terms of the number of people killed and economic losses[544]. The number of verified deaths has reached more than 1,300. Economic losses are expected to be more than US$200 billion[545], with more than US$23 billion in flood insurance claims expected from the Gulf Coast[546].

The loss of life and property damage was greatly aggravated by breaches in engineered levees and flood walls that were constructed to protect New Orleans from the surrounding waterways, most notably Lake Pontchartrain. Given its location in the floodplain with an average elevation 0.3 to 0.6 metres below sea-level, New Orleans was and remains highly vulnerable to flooding. As a result of the levee breaks, more than 80 per cent of New Orleans was under water with flood levels above 6 metres in some parts of the city[547]. Seventy-one per cent of homes damaged or destroyed belonged to low-income households[548].

Wetlands, coastal barriers and protected areas

Barrier islands act as storm buffers and limit erosion by reducing wave energies at the margins of coastal wetlands[549]. In addition, barrier islands limit storm surge heights and retard saltwater intrusion.

The vast expanses of coastal wetlands that line the Louisiana coastal plain also serve an important function in mitigating the affect of tropical storm events and the erosive forces of waves and currents they bring with them. Over the last several thousand years, the land building processes from the Mississippi River created over 1.6 million ha of coastal wetlands. The coastal wetlands provide a substrate for vegetation which stabilises the soil and increases resistance against tropical storm events. In addition, an extensive skeleton of higher natural levee ridges along the past and present Mississippi River channels and bayous, and along coastal beach ridges were created. The coastal plain effect not only created an extremely productive ecosystem, but also serves an essential role in storm protection.

Over the past several decades, the U.S. Fish and Wildlife Service and Louisiana Department of Wildlife and Fisheries have made significant financial investments in setting up protected areas and improving coastal zone management. Within the Gulf Coast and Prairies Ecoregion, nine wildlife management areas and six national wildlife refuges have been established accounting for protection of over 300,000 ha[550]. In addition to the state and federal preserves, several non-governmental organisations and private individuals have invested in wetlands protection, such as the Paul J. Rainey

Preserve, a 9,000 ha area managed by the National Audubon Society[551]. The total land managed for protection in the Gulf Coast and Prairies Ecoregion is estimated at about 400,000 ha[552].

As a result of the high winds and storm surge from Hurricane Katrina, it has been estimated that more than 70 km^2 of marshland have been transformed to open water or approximately 20 to 26 per cent of the 344 km^2 total area[553]. Some reduction of flood waters and marsh recovery is expected over time, however, it is estimated that much of the marsh loss will be permanent. The marsh loss from Hurricane Katrina also impacted protected areas, such as The Nature Conservancy's White Kitchen Preserve[554]. Hurricane Katrina passed directly over the preserve; large segments of marshland were uprooted and displaced and the area was infiltrated by open water. Domestic debris, large boats, and other objects were also scattered over the marshland. In response to the hurricane, The Nature Conservancy is practicing site remediation through periodic fire management and the control of non-native and off-site species. Downed trees and debris are being cleared from fire-breaks and access roads, and visitor facilities are being rehabilitated.

Although a number of protected areas have been established in the Gulf Coast Prairies and Marshes Ecoregion, they still represent only 14 per cent of the total land area that is almost entirely comprised of ecologically sensitive marshes and wetlands[555]. The presence of protected areas is not enough, however, to provide adequate disaster management function for populated areas along the Gulf Coast. The significant regional impact of flood control structures on the Mississippi River and other waterways so fundamentally altered the hydrological regime of the entire ecoregion that restoring the disaster management function of barrier islands and coastal wetlands will require addressing the flood control structures in addition to setting aside land and improving management of protected areas.

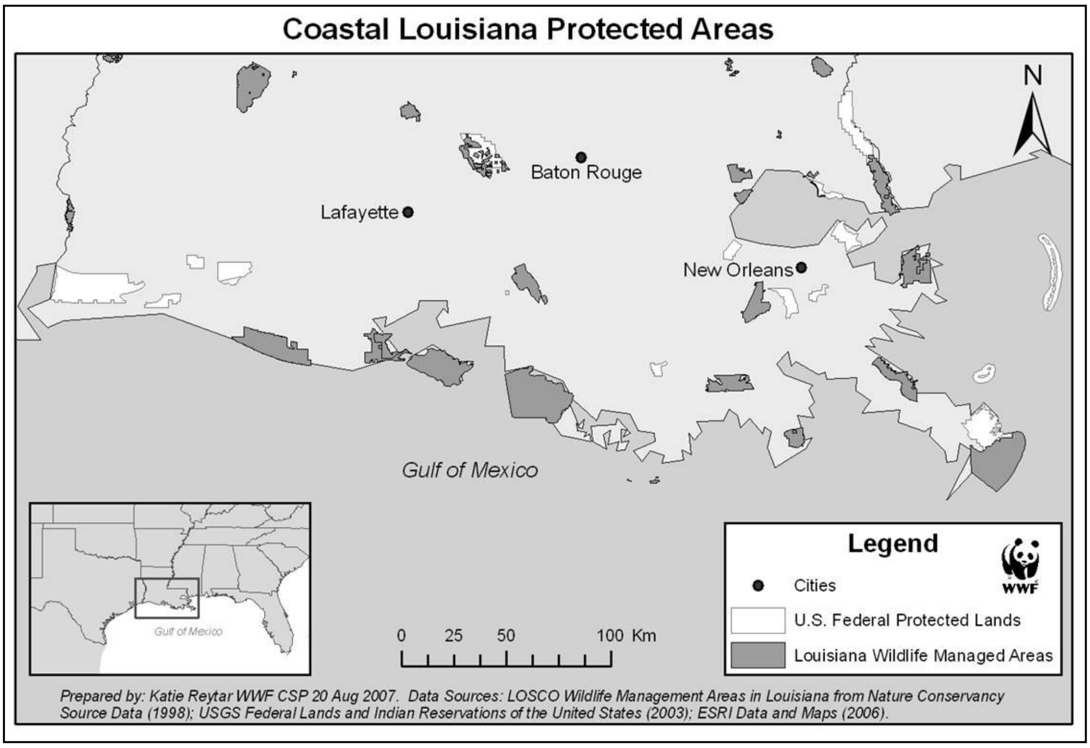


Figure 8: **Protected areas in coastal Louisiana including U.S. federal protected lands and state-owned and privately-owned wildlife managed areas**[7]

[7] Sources: USGS Federal Lands and Indian Reservations of the United States (2003); Louisiana Oil Spill Coordinator's Office (LOSCO) Wildlife Management Areas from Nature Conservancy Data (1998). Map created on 20/08/07.

The future – what role can protected areas play in hazard mitigation?

"Indeed, we have the technology and ability to engineer our way out of this and put in something that's more natural and sustainable."
General Robert Flowers, Chief of U.S. Army Corps of Engineers from 2000 to 2004[556]

For the past 30 years, several the U.S. government agencies and the State of Louisiana have been involved in efforts to stem the loss of wetlands and barrier islands along the coast. A report in 1972, the *Environmental Atlas and Multi-use Management Plan for South-Central Louisiana* first raised awareness of the problem and helped to inform Louisiana's coastal zone management plan[557]. Several laws at the state and national level have also been promulgated in order to address the issue and provide funds for restoration and management, including the Louisiana Wetlands Conservation, Restoration, and Management Act in 1989 and the Federal Coastal Wetlands Planning, Protection and Restoration Act in 1990. More recently, a coalition of local governments, Federal and state agencies, non-governmental organisations, private citizens and academia participated in the 'Coast 2050 Plan', in order to address the issue at a regional, comprehensive and systemic level. In addition to the broad planning efforts, a number of *ad hoc* activities by various stakeholders have taken place to restore coastal wetlands, including vegetation plantings and the use of dredged materials to replace subsided land. In spite of these efforts, however, the marsh loss has steadily continued over time and was only made worse by Hurricane Katrina.

In the wake of Hurricane Katrina, local communities are demanding that existing levees be reconstructed and upgraded to afford increased protection against future hurricanes. At the same time, communities are requesting that the local, state and Federal governments take steps to stem the loss of marshes and wetlands that provide disaster management, economic, ecological and recreational benefits. Unfortunately, these are conflicting aims as the presence of levees, and other human activities such as oil and gas exploration, have so greatly altered the hydrological regime. A fundamental U.S. political issue is that one agency, the U.S. Army Corps of Engineers, is charged with both regulating wetland development and installing and managing flood protection infrastructure. This leads to competing interests where politically and economically attractive infrastructure projects are often chosen over environmentally beneficial restoration projects.

The establishment of protected areas within the Gulf Coast Prairies and Marshes ecoregion has helped to stem the loss of wetlands and is a crucial component of restoring a more natural hydrologic regime. The significant human investment in the Gulf Coast means that the long-term issue of flood control must be addressed. A clear lesson from the past is that the use of 'hard' solutions to solve the problem of natural flooding, such as flood control structures, is not sustainable, and that more natural solutions need to be found. In order for wetlands and barrier islands to achieve their full potential in buffering the impacts from future hurricanes, innovative, long-term solutions are required that combine land conservation with the systemic re-establishment of the regional hydrological regime.

Pakistan: Earthquake and landslides

"*The trees are nails which have gripped the mountains and kept them stable*"
Younis Malik, Forestry Official Pakistan[558]

Introduction

Pakistan's geographical position makes it subject to a number of natural hazards, of which flooding, earthquakes, cyclones and drought/heat waves are the most significant. The earthquake hazard in the Himalaya Mountains is particularly high, due to tectonic movement which is, in effect, pushing India under Tibet. This continental shift builds pressure over time; which is eventually relieved through earthquakes.

Scientists have been predicting a major earthquake in the region for several years[559]; a prediction which came tragically true on 8th October 2005 when Pakistan experienced one of the greatest natural disasters to affect the region in recorded history. The epicentre, which measured 7.6 on the Richter scale, was in the district of Muzaffarabad, in Azad Jammu Kashmir (AJK), but its effects were felt over an area of approximately 30,000 km^2 of AJK and the North Western Frontier Province (NWFP).

It is difficult to imagine the impact of the earthquake on the local people of the area; but to some extent the figures speak for themselves:

- ✓ The death toll reached over 73,000[560]
- ✓ 128,000 people were injured[561]
- ✓ Over 10,000 children are estimated to have lost either one or both parents[562]
- ✓ Some 3.5 million people lost their homes, with 88 per cent of affected homes being in rural areas
- ✓ It is estimated that some 2.3 million people were made food insecure by the earthquake[563]
- ✓ 1.13 million people lost their source of livelihood[564]
- ✓ More than 70 per cent of cities and villages in the six northern provinces of Pakistan were destroyed by the earthquake and its aftershocks[565]

In addition to the direct destruction wrought by the earthquake and the repeated aftershocks (reaching more than 1,000 in the first few weeks – with magnitudes of up to 6 on the Richter scale[566]), landslides bought on by the earth movements added considerably to the impact of the disaster.

The causes of the disaster

"*The forests were once very thick, but the generations pass so people have to build houses and collect firewood and the trees disappear*,"
60-year-old Haday Tullah from Jabla[567]

The October earthquake, being natural in origin, was unavoidable. However, the extent of damage that was caused to human life and property could be attributed to socio-ecological reasons, having its roots in policies and actions related to human use of the mountains and their natural resources. Despite the known likelihood of major earthquakes hitting the region, there has been little thought given to mitigating impacts and the vulnerability of Pakistan to disaster has been exacerbated by unchecked urban development and extensive deforestation. Large parts of the area affected by the earthquake, for example, have lost considerable forest cover over the last few decades as a result of encroachment, illegal logging and agriculture – increasing the likelihood of landslides[568].

Forest Cover in Pakistan

Pakistan has one of the highest deforestation rates in the world. Country-wide, natural and modified forests cover less than 3.5 million ha or four per cent of the total land area. If scrub forests are excluded, the area falls to just 2.4 million ha (or 2.7 per cent of area), of which four-fifths (2 million ha) could be described as being 'sparse', i.e. with less than 50 per cent cover. Good quality (greater than 50 per cent cover) forest in Pakistan thus covers less than 400,000 ha. And forests are still disappearing; with the government's own estimates suggesting that Pakistan's woody biomass is declining at a rate of 4-6 per cent per year[569].

The area affected by the earthquake can be described ecologically as being within the Himalayan moist temperate and Himalayan dry temperate zones[570]. Even in these areas where forests would once have been dominant, the decline in forest cover has been dramatic. Today, forests cover about 11 per cent of AJK compared with nearly 30 per cent in 1947; and in NWFP, a study in the Hazara Division found a 52 per cent decline in forest resources between 1967 and 1992[571]. AJK is particularly known for its high quality cedar wood, which had been generating income from timber for decades until a government decision to ban felling in 1997. However the extraction of 'dead, decayed or diseased' trees allowed deforestation to continue, and with fines for illegal felling at less than US$10 a tree, and many villagers continue to use wood for building and fuel[572].

The commitment of the government of Pakistan to increase the country's area of natural forests has been stated in several policy documents such as the National Environmental Policy 2005 and the Pakistan Poverty Reduction Strategy Paper (PRSP-2003), however activities on the ground do not always seem to be in line with this policy (i.e. a proposed development project within the only remaining in-tact area of the Blue Pine ecosystem in one of the best remaining Himalayan temperate forest areas in Punjab)[573].

That forest clearing accelerates erosion, and thus causes landslides in mountainous terrain has been discussed for more than a century[574]. As noted earlier in this report there are two types of landslide *shallow* and *deep-seated*. Each type is influenced by vegetation cover, but shallow slides are most likely to be caused by reduced forest cover[575].

Almost all the landslides which followed the Pakistan earthquake were the shallow type, occurring on steep slopes and road cuts. A high number of landslide occurred although these were relatively small-scale[576]. These shallow landslides significantly contributed to the damage caused by the earthquake, particularly on the lower slopes inhabited by large human populations. The largest landslide triggered by the earthquake was 32 km southeast of Muzafarrabad, it buried the village of Dandbeh and resulted in around 1,000 fatalities, according to local residents[577].

The geology of a particular site determines if the landscape is resilient to infrastructure development. Natural cover forest can determine the level of stability of the landscape and potential security against floods and landslides to people living downstream**.** The rapid deforestation, coupled with overgrazing, increased the risks of soil erosion and thus the potential for landslides in the region of the October earthquake[578]. Indeed, early reports following the earthquake noted that landslides were particularly severe on slopes that had been stripped of their cover of pines and Himalayan hardwood trees, while many forested slopes remained intact[579]. Furthermore, survey work undertaken shortly after the earthquake reports that these shallow landslides were not associated with specific geological formations; but that they were as deep as the root zone of the vegetative cover, anywhere from several decimetres to a metre deep, and consisted of dry, highly disaggregated and fractured material that cascaded down slopes to flatter areas[580].

Resulting environmental effects

"*In this once-remote region, loss of green cover from commercial logging, local cutting and overgrazing has made the land less compact and less able to retain water, which now rushes easily down mountainsides to set off slides that some call 'ecological land mines'*".
Nithin Sethi, of the Delhi-based Centre for Science and Technology[581]

Several surveys of the earthquake area have been carried out, including a Preliminary Environmental Assessment (PEA) carried out by IUCN immediately following the earthquake. It has however been estimated that it will take at least two years to ascertain the damage to natural resources in Muzaffarabad, the area worst hit[582].

According to the IUCN assessment, the damage to the biophysical environment included:

- ✓ destruction caused by the land and mudslides
- ✓ siltation of rivers and streams
- ✓ damage to both natural and man-made water channels rendering them unusable for irrigation purposes
- ✓ damage to the forest resources, essentially due to landslides and rock-falls
- ✓ damage to agricultural land, especially on the slopes, roads, water mills and fish farms
- ✓ large amounts of debris – which will need to be disposed of[583].

Continuing environmental effects included:

- ✓ further landslides
- ✓ flooding, due to debris damming rivers and streams
- ✓ pressure on dwindling natural resources, especially forests for fuel and shelter needs[584]

The remaining forest is under threat from a predicted 2-300 per cent increase in timber demands for reconstruction. Damage to existing forest cover has not been fully assessed. However, it has been reported that some stripping of forest cover by landslides is visible from satellite imagery, although it does not seem to be extensive, and generally large expanses of forest cover seem relatively undisturbed by the earthquake. However trees may suffer damage to their roots during major earthquakes which will not be visible for sometime[585].

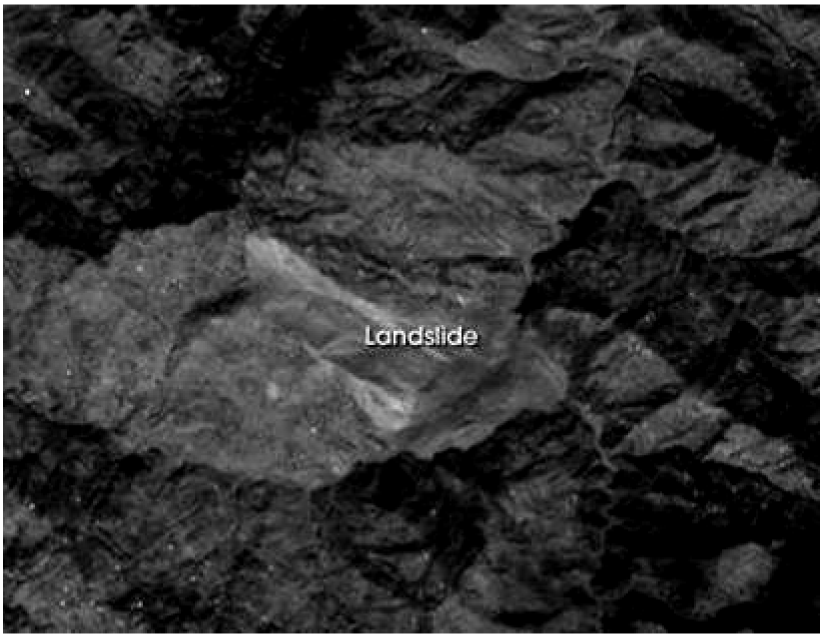
There are three existing and one potential protected area affected by the earthquake. The damage caused on the ecosystems and wildlife of these parks has not as yet been fully assessed[586].

Impacts on human well-being

"*I had farming land but the landslides have destroyed that. It's covered with boulders now. Nothing was spared and it took only a minute for everything to be destroyed*."
Ejaz-Ur-Rehman Khan from the Kaghan Valley[587]

Overall some 5.7 million people live in NWFP and AJK, generally in close-knit families. The districts affected by the earthquake share basic socio-economic characteristics. Apart from a few pockets of high population around 88 per cent of the people live in scattered settlements, ranging from two to 300 households. Agriculture, in particular livestock rearing, is the primary source of employment in rural areas, with agriculture accounting for 60 to 70 per cent of total household income and 37 per cent of total rural employment. In urban areas, development has generally occurred with little or no environmental controls and a high proportion of the population lives in neighbourhoods with virtually no basic services[588].

The devastating impacts of this earthquake will mean that it will take years, even decades, for the regions most affected to recover. On the first anniversary of the disaster, it was estimated that around 66,000 families were still without permanent shelter and the after effects of the earthquake were still being felt through further landslides and flooding[589].



The lighter patch in the middle of this satellite image shows a landslide two km long and over a km wide along the side of the mountain southeast of the earthquake's epicentre between Muzaffarabad, Pakistan, and Uri, India, in the Pir Punjal range of Kashmir

© NASA image created by Jesse Allen, Earth Observatory, using data provided courtesy of Eric Fielding (NASA/JPL, the NASA/GSFC/METI/ERS DAC/JAROS, and U.S./Japan ASTER Science Team

Mitigating the Impacts

"*If there had been more trees, we would not have lost as much. The impact would not have been as great. It is our mistake*"
Qayoon Shah, teacher at the Jabla village school[590]

As noted above the earthquake hit an area of extreme environmental vulnerability within Pakistan. Certainly this vulnerability is in large part due to Pakistan's geographical position, but the resulting impacts of events such as major earthquakes have surely been exacerbated by the degradation of the local environment. Despite numerous popular accounts, scientific data on erosion and landslide processes in the Himalaya is scarce. Two reviews however point to the clear links between deforestation and landslides. In the late 1980s a review of quantitative studies of erosion in Nepal concluded that deforestation was linked to surface erosion, gullying and shallow landslides; and that land slides in the Middle Mountains may be due to loss of root reinforcement[591]. The effect of human interference on the environment, and in particular depletion of the forest cover, was studied in relation to landslides around Dehra Dun and Mussoorie in Uttar Pradesh in the Indian part of the Himalaya. Land use and land cover data for a period of 60 years were analysed. The results found that forested areas accounted for only nine per cent of landslide occurrence; whilst about 60 per cent of the landslides were in non-forested areas that were forested in 1930[592].

This link between deforestation and landslides has been observed elsewhere. For example, a study of a decade's data on landslides from steep, slide-prone slopes and analysis of a regional landslide in the Pacific Northwest of America confirmed that forest clearing increases regional landslide frequency[593]. A much longer term view can be seen from studies in the western Swiss Alps, a region that was affected by numerous landslides during the Holocene. The vegetation history of one catchment area was reconstructed and investigated to identify possible impacts on slope stability. The pollen record provided strong evidence of anthropogenic forest clearance and agricultural activity which appear to be correlated with increased landslide activity in the lake's catchment[594].

The dramatic loss of forest cover in Pakistan apparently increased the already devastating impacts of the 2005 earthquake by increasing the scale and severity of the resulting landslides. Unfortunately the restoration of vegetation cover will take a long time to decrease landslide risk. A study of the environmental changes in three severely degraded watersheds in the Chamoli district (Central Himalaya) has concluded that even after 20 years of restoration, there is only a marginal reduction in landslide activity. In this case, the stabilisation process of the active landslide zones seems to have been quite slow due to the presence of sheared carbonate rocks and the proximity of watersheds[595]. Any restoration of forest areas in these highly vulnerable areas will thus have to consider the best way to ensure stabilisation can be achieved as quickly as possible. Experts have suggested that although natural regeneration should be used as far as possible the plantation and direct sowing of trees, shrubs and pasture herbs and grasses will enhance the re-vegetation process of the bare soil[596].

The future – what role can protected areas play in hazard mitigation?

A review of the earthquake history of the region found that although the 2005 earthquake was large by normal standards, it could only be considered 'moderate' when viewed in the context of the earthquake generation potential of the region. Of concern is that theoretical studies indicate that the energy stored along the Himalayan arc suggest a high probability of several massive earthquakes of magnitude above 8.0 in the future[597]. It is estimated that these earthquakes may result in as many as 150,000 fatalities, 300,000 people injured and typically 3,000 settlements affected in each event[598].

The actual and potential human and economic losses from earthquakes in the Himalayas are so high in a large part because of lack of enforcement of building codes, unsafe land use patterns and poor construction practices[599]. However despite being prone to a variety of natural hazards and the dire warning of the likelihood of further events, Pakistan has an *ad hoc* approach to dealing with hazard risk management. Interventions are primarily focused on relief and response as opposed to mitigation.

The reduction in forest cover over the last decade is likely to exacerbate the adverse impacts of any future earthquakes, just as it did in October 2005. This risk could be increased even further if timber demand for reconstruction results in further forest destruction[600]. Land use planning is therefore a key issue in helping ensure any kind of environmental stability in the area. Environmentalists were thus shocked by a recent statement by the AJK Prime Minister, Sikandar Hyat's, in which he said his government would develop a new Muzaffarabad city in the nearby forest area after clearing the trees there[601]. In light of the devastation caused by the 2005 earthquake, a more comprehensive hazard risk management approach is clearly needed[602].

Although restoration of forest resources is important, one of the most important land use decisions which needs to be made is to ensure the effective protection of the forest cover that remains. Only around four per cent of the land area in AJK has been declared as a protected area (see Table 8 below). The Machiara National Park is located in the heart of the earthquake affected area[603]. The park is being developed with a US$3.18 million grant from the Global Environment Facility. In NWFP, about seven per cent of the land area is designated as protected (see Table 9 below). The majority (39) of which are game reserves; all protected areas are managed by the NWFP government[604]. Ayubia National Park is located at the periphery of the earthquake affected zone.

Table 8: **Land area is designated as protected in AJK and NWFP[605]**

Area	National Parks	Wildlife Sanctuaries	Game Reserves	Un-classified	Total PAs	PA hectares	PA as % of area
AJK	1	0	8	0	9	51,998	3.91
NWFP	5	6	39	5	55	470,675	6.30

In Pakistan, wildlife sanctuaries offer greater protection than national parks, while game reserves provide no protection to habitat but merely regulate hunting. As a result, the value of a game reserve for long-term conservation of biodiversity and ecosystem functioning is limited. In general protected areas have not been very effective in protecting the fragile environment of the Pakistani Himalayas, with some of the main problems being that:

- ✓ Protected areas are generally small and thus do not provide adequate protection for biodiversity.
- ✓ Legislation does not provide an adequate framework for conservation management
- ✓ Provincial wildlife departments lack the capacity to manage effectively
- ✓ Most protected areas in Pakistan lack comprehensive management plans, and where plans do exist they are not fully implemented
- ✓ Local communities rarely have any role in the management of protected areas and therefore have little incentive to prevent illegal resource use[606].

This last point is particularly important as sizable human populations exist within many of the protected areas and management approaches, which tend not to involve local communities or take note of their needs and resource use practices, have created social conflicts and in some cases jeopardised conservation efforts[607].

There are however good models of conservation projects in the region (see box) and there are indications that those areas with more natural land cover did see less destruction following the earthquake. There is now a need for these links to be better understood and communicated to the people and policy makers in Pakistan.

Palas Valley: Livelihoods and disasters

"*The people of Palas are aware that their forests saved them from the kind of devastating landslides suffered in deforested areas, where whole chunks of the mountainsides crashed into the valleys.*"
Rab Nawaz, Coordinator, Palas Conservation & Development Programme [608]

The Palas Valley in Pattan Tehsil, Kohistan District in NWFP, lies east of the River Indus in the western Himalaya. Altitudes range from around 1,000 to 5,150 metres and the topography is mostly rugged and precipitous. The forests of the Western Himalaya, particularly the temperate forests, are a `biodiversity hotspot'. Surveys between 1987 and 1995 concluded that the Palas forests represent Pakistan's most outstanding remaining tract of temperate forests[609].

Relatively little of Palas is cultivated; the 40,000 people who live in the valley are almost entirely dependent on the natural resources of the valley. Livestock rearing is an important part of most households' livelihoods and the traditional Palasi lifestyle involves most of the population moving with their livestock between winter villages and summer pastures. Much of the local trade depends on non-timber forest products (NTFPs) such as mushrooms, honey and herbs. Some villagers rank NTFPs as a more important source of income than agriculture, livestock or timber harvesting[610], and morel mushrooms and medicinal herbs can provide 50 per cent or more of household income. Despite its biological richness, Palas is one of the least developed and poorest parts of Pakistan[611].

BirdLife International and WWF have been working in the Palas Valley since 1991, most recently through the Palas Conservation and Development Project (PCDP). The PCDP's goals are to safeguard the biodiversity of the Palas Valley by enabling local communities to tackle the linked causes of poverty and natural resource degradation. The project has six main programmes:

- ✓ social organisation and participation
- ✓ infrastructure rehabilitation (of bridges, water mills and irrigation channels)
- ✓ natural resource management

- ✓ biodiversity survey and monitoring
- ✓ forest management
- ✓ improvement of health, nutrition and sanitation[612].

Although the Palas Valley is not at present recognised as a protected area, it is hoped that the area will be recognised as a Man and Biosphere reserve in the future.

Palas is not far from the epicentre of the earthquake. An estimated 80 people were killed and over 100 badly injured[613], 30,000 residents are thought to have lost their homes and much of the valley's infrastructure has been destroyed[614]. Although terrible this loss was less than in many earthquake affected areas and the conservation efforts in the Valley meant that the local people still had the means for survival. Rab Nawaz, who runs the PCDP reports that people quickly returned to gathering NTFPs products after the earthquake, stating that "*This shows the vital role non-timber forest products play in the economy and livelihoods of local people after a disaster like this, when livestock and crops have been damaged and lost.*"[615]

Chapter 6: The future

"Learning how the environment itself possesses protective mechanisms can significantly reduce hazard impacts. These mechanisms need to be identified, and understood more readily, but more importantly they have to be developed and maintained in practice as public policies to secure overall environmental protection"
World Conference on Disaster Reduction, 18-22 January 2005, Kobe, Hyogo, Japan[616]

Conclusions

All the evidence suggests that the intensity of some hazards (in particular extreme weather events) and the vulnerability of human communities to natural disasters are increasing. This means that there are more natural hazards and also that a larger proportion of these hazards develop into serious disasters. The economic and human costs are rising sharply, despite increased investment in disaster prevention and relief. The poorest people are usually the most vulnerable, both because they tend to live in marginal, disaster-prone areas and because they do not have the resources to recover from disasters.

Our vulnerability to disaster has been increased by environmental destruction and the consequent losses of ecosystem services. Many natural systems – including floodplains, forests, coastal mangroves and coral reefs – have the potential to reduce natural hazards.. They do not provide total protection – the largest disasters will usually overwhelm natural defence systems – but they can and do play a role in reducing the number of lives lost and the economic costs of climate related hazards and earthquakes.

Despite this, ecosystems continue to be degraded and destroyed, along with the services that they provide. Climate change will make things worse, both by increasing climatic extremes and by degrading or removing natural ecosystem buffers. These problems occur all over the world but are most acute in developing countries (where lives lost and economic impacts of disaster are also greatest).

Recognition of the role that ecosystem services can play in disaster mitigation is mixed. Many local people instinctively link declining environmental quality with increasing vulnerability to hazards, but these links have often not been made explicit in local planning, or governments have been ineffective in controlling the causes of environmental decline. Continuing debate about the role of ecosystem services is to some extent undermining efforts to develop a concerted response aimed at protecting and improving environmental services against natural hazards.

There has been considerable and welcome recognition of the role of ecosystem services in disaster mitigation by many governments and international organisations (see appendix 1). Unfortunately there is still little best practice guidance to help implement the various declarations and agreements that have resulted and development of such management tools remains an important gap to be filled.

There is more generally an urgent need to stop the degradation of ecosystem services and to ensure their long-term protection. In the context of this report, the need is most acute where high risk of disaster coincides with environmental degradation. Protection and restoration of ecosystems will sometimes require trade-offs: e.g. restoration of natural flood plains may help control floods but may also mean relocation for some families. Similarly, protection of coastal habitats can protect against storm surge but may reduce valuable tourism projects. Such losses need to be balanced against reduced damage and loss of life from floods and landslides and more sustainable local development.

Protected areas have a key role to play by maintaining strategic natural habitats to protect against natural disasters. These functions deserve wider recognition and should be included in protected area system and site planning and in their funding strategies.

An Action Plan for Integrating Disaster Mitigation Planning into Protected Areas

The following outlines a twelve point plan to increase the effectiveness with which natural ecosystems can be used to mitigate natural hazards, using protected areas as a tool.

Research

1. A great deal is already known about the role of natural ecosystems in mitigating disaster. Further research should now focus on the scale of disasters for which natural ecosystems can provide effective mitigation strategies. Appropriate natural resource management strategies should be identified.
2. Additional tools are needed to help planners identify the most valuable places where natural ecosystems need to be protected and/or restored to provide disaster mitigation services – through, for example, overlaying ecosystem data with hazard mapping in an opportunity analysis.

Planning

3. At a national and regional/transboundary scale opportunity analyses should be used to identify places where natural systems could mitigate disasters and to develop associated protection strategies, including the establishment of new protected areas.
4. At a protected area scale, some protected area authorities may consider revising their management objectives and management plans to better reflect and conserve the contribution of their protected areas in providing ecosystem services, including mitigating disasters.

Policy

5. The links between protected areas and disaster mitigation need to be made explicit when implementing or revising the various disaster reduction initiatives reviewed in Appendix 1.
6. Similarly, lending agencies and donors supporting protected area establishment and management should consider the disaster mitigation role of protected areas in project planning and implementation and facilitate the integration of environment and disaster management professionals.
7. Protected area managers and agencies need to build a working relationship with those working on disaster management before disasters happen to maximise synergies and opportunities.
8. Effective examples of where land and sea-use management are contributing to disaster mitigation need to be identified, application of management options field-tested and results disseminated to help other protected area mangers and agencies as well as disaster recovery agencies.
9. The underlying causes of the increase in hazard and disaster occurrence, such as climate change, forest loss and hydrological disturbance, should be addressed as part of a preventative strategy.

Funding

10. Further development is needed on economic evaluation of protected area contribution towards disaster mitigation and to investigate funding options for maintenance of natural defence systems, including innovative use of Payment for Environmental Services schemes and use of insurance premiums to maintain strategically important ecosystem services.
11. The effectiveness of protected areas in disaster mitigation is closely linked to management success, so that some of the funds available for disaster mitigation should be allocated to improve management effectiveness of protected areas.

Management

12. Once plans have been developed, protected area managers need to ensure that steps needed to maximise disaster reduction potential are included in day-to-day work programmes and priorities including relationship building with local disaster response agencies.

Appendix 1: International agreements linking ecosystem management to disaster reduction

"We believe that the aim of the international community should be to reduce the vulnerability to the threat of disasters.'[617]

The participants at the July 2005 Gleneagles G8 Summit

Until the 1970s, the international community considered disasters as exceptional circumstances – the once in a hundred year events which local capacity alone could not be expected to cope with and where external emergency relief was essential. The concept of disaster preparedness was developed during the 1970s and 1980s and truly established in the 1990s, which was declared the International Decade for Natural Disaster Reduction, one of the principal goals of which was to institutionalise the culture of disaster prevention. This goal has been aided by the UN establishing the International Strategy for Disaster Reduction (ISDR), as a global platform aimed at helping all communities to become resilient to the effects of natural disasters and to proceed from protection against hazards to the management of risk through the integration of risk prevention into sustainable development[618].

Complementing this change in attitude and strategies towards disasters have been many agreements, strategies, frameworks and resolutions signed by governments over the years to encourage application of best practice in terms of disaster management. Most of these have made the links between protecting the environment and the ecosystem services it provides, although few have suggested practical steps towards reaching these targets.

The review below considers some of the most recent agreements and the specific environmental/ecosystem recommendations they contain (all emphasis, i.e. text in bold and underlined, has been added by report authors).

Agreement	Details
United Nations (UN) Agenda 21 (United Nations Conference on Environment and Development, 1992) and Johannesburg Plan of Implementation of the (World Summit on Sustainable Development, 2002)	*Agenda 21* was adopted by more than 178 Governments at the popularly named Earth Summit held in Rio de Janerio, Brazil, in June 1992. As the whole of Agenda 21 is about the linkages between environment and development it is not surprising that there are many relevant sections in the document relating to disaster management: from addressing the uncertainties of climatic change (Chapter 9), to specific actions to manage fragile environments (i.e. Chapter 13 on Mountains, which includes an objective, paragraph 13.5, to generate information to establish databases and information systems to facilitate an evaluation of environmental risks and natural disasters in mountain ecosystems). Overall the most relevant chapter is the one on Promoting Sustainable Human Settlement Development (Chapter 7) which refers to *developing a "culture of safety" in all countries, especially those that are disaster-prone* (paragraph 7.60). Specific activities include, for example,: *7.29. All countries should consider, as appropriate, undertaking a comprehensive national inventory of their land resources in order to establish a land information system in which land resources will be classified according to their most appropriate uses and* ***<u>environmentally fragile or disaster-prone areas will be identified for special protection measures</u>***[619].

Agreement	Details
	In September 2002, representatives of 191 governments gathered in Johannesburg for the World Summit on Sustainable Development (WSSD). The aim was to examine progress in achieving the outcomes of the 1992 Earth Summit, and to reinvigorate global commitment to sustainable development. The result was a 54-page agreement called the *Johannesburg Plan of Implementation* which sets out new commitments and priorities for action on sustainable development in areas as diverse as poverty eradication, health, trade, education, science and technology, regional concerns, natural resources and institutional arrangements. Paragraph 37 (IV. Protecting and managing the natural resource base of economic and social development) states the need for: *An integrated, multi-hazard, inclusive approach to address vulnerability, risk assessment and disaster management, including prevention, mitigation, preparedness, response and recovery, is an essential element of a safer world in the 21st century.* The paragraph has several action points including: (d) *Reduce the risks of flooding and drought in vulnerable countries by, inter alia, promoting **wetland and watershed protection** and restoration, improved land-use planning, improving and applying more widely techniques and methodologies for assessing the potential adverse effects of climate change on wetlands and, as appropriate, assisting countries that are particularly vulnerable to these effects*[620]
Convention to Combat Desertification (1994)	In 1977, the UN Conference on Desertification (UNCOD) adopted a Plan of Action to Combat Desertification (PACD). The plan had little effect, so the Earth Summit supported a new approach to the problem of desertification, by calling on the UN General Assembly to prepare a *Convention to Combat Desertification*, particularly in Africa. The Convention was adopted in Paris in June 1994 and over 179 countries were Parties to the Convention by 2002[621]. This is the only example of convention aimed specifically at mitigating one specific type of disaster (i.e. drought). In terms of the links between natural disasters and drought Article 4 (General obligations) of Part II of the Convention (on General provisions), paragraph 2, states that*: In pursuing the objective of this Convention, the Parties shall: (d) promote cooperation among affected country Parties in the fields of **environmental protection and the conservation of land and water resources**, as they relate to desertification and drought*[622].
United Nations Framework Convention on Climate Change (UNFCCC) (1994) and Kyoto Protocol (1997)	In 1994, 191 countries signed up to the *UNFCCC* agreeing to both consider what could be done to reduce global warming and to cope with whatever temperature increases are inevitable. The Convention notes that Parties should take what ever actions are necessary, i.e. funding, insurance and the transfer of technology, to meet the specific needs and concerns of developing countries who will have to cope with the adverse effects of climate change especially countries with areas prone to natural disasters (article 4: Commitments, paragraph 8).

Agreement	Details
	In 1997 the *Kyoto Protocol* significantly strengthened the Convention by committing Parties to individual, legally-binding targets to limit or reduce their greenhouse gas emissions. However no specific mention to natural disasters is included in the Protocol[623].
World Conference on Natural Disaster Reduction (Yokohama, Japan, 1994)	The "*Yokohama Strategy and Plan of Action for a Safer World: Guidelines for Natural Disaster Prevention, Preparedness and Mitigation*" includes one principle (9) relating to the environment: ***Environmental protection**, as a component of sustainable development and consistent with poverty alleviation, is imperative in the prevention and mitigation of natural disasters[624].*
World Conference on Disaster Reduction (Kobe, Japan, 2005)	In effect an updating of the Yokohama Strategy, the conference culminated in the signing by 168 governments of a plan of action to reduce the impact of natural hazards on populations. Since its adoption the "*Hyogo Framework for Action 2005-2015: Building the resilience of Nations and Communities to Disasters*", has led to many countries revising their policies to put disaster risk reduction at the top of their political and development agendas[625]. The Hyogo Framework includes in section B (Priorities for action), section (4) on reducing underlying risk factors, which states: *(i) Environmental and natural resource management* *(b) Implement integrated environmental and natural resource management approaches that incorporate disaster risk reduction, including structural and non-structural measures, such as integrated flood management and **appropriate management of fragile ecosystems**[626].*
International Disaster Reduction Conference (IDRC) (Davos, Switzerland, 2006)	Co-organised by UNEP and the Swiss Federal Institute for Forest, Snow and Landscape Research, the IDRC closed with the adoption of a declaration by the more than 600 participants. The *IDRC Davos 2006 Declaration* focused on the five priorities in the Hyogo Framework, while involving a larger group of risk management experts, practitioners and scientists. One of six themed findings/recommendations, the topic on environmental vulnerability stressed that the **protection of vital ecosystem services is fundamental to reducing vulnerability to disasters and strengthening community resilience**. The declaration thus noted that it is essential to recognise : ✓ Environmental management as an integral part of disaster risk reduction. ✓ That some disaster reduction and recovery efforts can have adverse environmental consequences that could be avoided. ✓ That ecosystems based management, environmental engineering solutions, mitigation of greenhouse gases and climate change adaptation, and integrated water resource management all support the goals of disaster risk reduction[627].
Ramsar Convention on Wetlands (COP 9, Kampala, Uganda, 2005)	The *Convention on Wetlands*, signed in Ramsar, Iran, in 1971, is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. There are presently 155 Parties

Agreement	Details
	(countries) to the Convention and 1,675 wetland sites, totalling 150 million ha, designated for inclusion in the Ramsar List of Wetlands of International Importance. The Ramsar Convention has dealt with the issue of natural disasters at several of the Conference of the Parties (COP) (e.g. Resolution VIII.35 on the impact of natural disasters, particularly drought, on wetland ecosystems). But the 9th COP in 2005 had perhaps the most expansive discussion of the issue to date as recorded in Resolution IX.9. Just one of the most pertinent of the 22 paragraphs of the resolution is repeated here. *Resolution IX.9: The role of the Ramsar Convention in the prevention and mitigation of impacts associated with natural phenomena, including those induced or exacerbated by human activities* *Para 14: "ENCOURAGES Contracting Parties and River Basin Authorities to ensure that* ***wetland ecosystems are managed and restored****, as part of contingency planning, in order to mitigate the impacts of natural phenomena such as floods, provide resilience against drought in arid and semi-arid areas, and contribute to wider strategies aimed at mitigating climate change and desertification and thus reduce the incidence or magnitude of natural phenomena induced or enhanced by such change*[628]*.*
2010 Biodiversity Target of the Convention on Biological Diversity (1992) (COP 6, the Hague, the Netherlands, 2002) and Millennium Development Goals (United Nations Millennium Summit, 2000)	The Convention on Biological Diversity (CBD) has been ratified by 190 Parties. In decision VI/26 (2002), the COP adopted the Strategic Plan for the CBD. In the Plan's mission statement, Parties committed themselves to a more effective and coherent implementation of the three objectives of the Convention, to achieve by "2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth". This so-called *2010 Biodiversity Target* was subsequently endorsed by the World Summit on Sustainable Development and the United Nations General Assembly at the 2005 World Summit. The Summit also highlighted the essential role of biodiversity in meeting the *Millennium Development Goals* (MDG), and thus the 2010 Biodiversity Target is one of four new targets being incorporated into the MDGs, as proposed by the UN Secretary-General in his report to the 61st General Assembly. Agreed in 2000, the MDG's are a set of timebound and measurable goals and targets for combating poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women. The MDG's were agreed in the United Nations Millennium Declaration (General Assembly resolution 55/2) and were formally adopted by all 189 Member States of the United Nations).

Agreement	Details
	To assess progress in achieving the goals of the Strategic Plan and the 2010 Biodiversity Target, a framework of seven focal areas was adopted along with accompanying indicators of biodiversity status and trends, goals and targets. Of relevance here is the focal area of: *maintaining ecosystem integrity, and the provision of goods and services provided by biodiversity in ecosystems, in support of human well-being*; and the specific indicator of: *Incidence of human-induced ecosystem failure*[629]. There is however no methodology currently available to measure this indicator[630].

Appendix 2:
Review of information and guidance material available to protected area managers relating to disaster mitigation

The following short review includes some key documents and resources which may be of use to protected area managers when considering the role of protected areas and disasters mitigation.

✓ **Identifying hotspots**

A global analysis of disasters hotspots has been carried out by the World Bank; the publication, *Natural Disaster Hotspots: A Global Risk Analysis* by Maxx Dilley, Robert S. Chen, Uwe Deichmann, Arthur L. Lerner-Lam and Margaret Arnold, can be purchased from the World Bank (http://publications.worldbank.org/ecommerce/) and a web site and online tool is available at http://geohotspots.worldbank.org/hotspot/hotspots/disaster.jsp. Six major natural hazards: cyclones, drought, earthquakes, floods, landslides and volcanoes have been assessed and the online tool provides a basis for identifying geographic areas of highest relative disaster risk potential. The data and tool can be used to prioritise disaster risk reduction investments and better inform development and research efforts, but the data is not detailed enough to be suitable for land use planning.

✓ **Economic evaluation**

Ramsar and the CBD have jointly published *Valuing wetlands: Guidance for valuing the benefits derived from wetland ecosystem services* by Rudolf de Groot, Mishka Stuip, Max Finlayson and Nick Davidson which can be downloaded from http://www.biodiv.org/doc/publications/cbd-ts-27.pdf. The report outlines a framework to should assist those wanting to conduct an integrated assessment of wetland ecosystem services and provides detailed guidance on the steps involved in undertaking a wetland valuation assessment.

✓ **Ecosystem management**

IUCN's *Ecosystem Management: Lessons from around the World. A Guide for Development and Conservation Practitioners* edited by Jean-Yves Pirot, Peter-John Meynell and Danny Elder can be accessed from: http://www.iucn.org/themes/wetlands/ecosystemmanagement.html. The volume includes a discussion of tools that can be used to formulate and implement ecosystem-based management activities and a set of guidelines on how to integrate ecosystem-based management approaches into development projects.

✓ **Mitigating floods**

Guidelines for reducing flood losses edited by Paul J. Pilon, downloadable from www.un.org/esa/sustdev/publications/flood_guidelines.pdf, are focussed on the needs of the decision-makers. The guidelines review the range of mitigation options that should to be considered when trying to reduce losses from flooding. The guidelines include sections on risk management and flood plains and flood plain and watershed management in general.

References

[1] Millennium Ecosystem Assessment (2005); *Ecosystems and Human Well-being: Synthesis*, Island Press, Washington, DC, USA

[2] Toepfer, K (2006); Nature's capital: the key to poverty eradication, in *Environment Edge on the 2005/06*, UNEP-WCMC/New Hall/St Edmund's College/British Antarctic Survey 2006, UK

[3] Pryor, L D (1982); *Ecological mismanagement in natural disasters*, IUCN, Switzerland

[4] World Conference on Disaster Reduction, 18-22 January 2005, Kobe, Hyogo, Japan, Hyogo Declaration, Extract from the final report of the World Conference on Disaster Reduction. (A/CONF.206/6) www.unisdr.org/wcdr, pg 77

[5] ISDR (2004); *Living with Risk: A global review of disaster reduction initiatives*, UN/ISDR, Geneva, Switzerland

[6] ibid

[7] ibid

[8] http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm (accessed 10/2/07)

[9] Dilley, M , R S Chen, U Deichmann, A L Lerner-Lam and M Arnold (2005); *Natural Disaster Hotspots: A Global Risk Analysis*, The World Bank, Washington

[10] International Council for Science (ICSU) (2005); Scoping Group on Natural and human-induced environmental hazards, Report to ICSU General Assembly, Suzhou, October 2005, www.icsu.org/Gestion/img/ICSU_DOC_DOWNLOAD/865_DD_FILE_**Hazards**_Report_Final.pdf (accessed 10/2/07)

[11] Abramovitz, J (2001); *Unnatural Disasters*, WorldWatch paper 158, October 2001, WorldWatch Institute, Washington DC, USA

[12] McGregor, G R, C A T Ferro and D B Stephenson (2005); Projected Changes in Extreme Weather and Climate Events in Europe, in W Kirch, R Bertollini and B Menne (eds), *Extreme Weather Events and Public Health Responses*, Springer, Germany

[13] http://www.emc.ncep.noaa.gov/gmb/ens/target/ens/albapr/albapr.html (accessed 12/4/08)

[14] Swiss Re (2001); *Sigma*, **2**:2001, Swiss Re, Zurich, Switzerland

[15] Swiss Re (2002); *Sigma*, **1**:2002, Swiss Re, Zurich, Switzerland

[16] http://neic.usgs.gov/neis/eq_depot/2001/eq_010126/ (accessed 12/12/07)

[17] Swiss Re (2003); *Sigma*, **2**:2003, Swiss Re, Zurich, Switzerland

[18] http://neic.usgs.gov/neis/eq_depot/2002/eq_020325/ (accessed 12/12/07)

[19] Swiss Re (2004); *Sigma*, **1**:2004, Swiss Re, Zurich, Switzerland

[20] Swiss Re (2005); *Sigma*, **1**:2005, Swiss Re, Zurich, Switzerland

[21] Swiss Re (2006); *Sigma*, **2**:2006, Swiss Re, Zurich, Switzerland

[22] http://www.ncdc.noaa.gov/oa/climate/research/2006/jan/hazards.html#Drought

[23] Swiss Re (2007); *Sigma*, **2**:2007, Swiss Re, Zurich, Switzerland

[24] Anon (2005); *Natural Disaster and Disaster Risk Reduction Measures: A Desk Review of Costs and Benefits*, DIFD, UK

[25] http://www.em-dat.net/who.htm (accessed 4/2/07)

[26] Nadim, F, O Kjekstad, P Peduzzi, C Herold and C Jaedicke (2006); Global landslide and avalanche hotspots, *Landslides* **3**:159–173

[27] Christian Aid (2007); *Human tide: the real migration crisis*, Christian Aid, London

[28] Figures calculated using http://www.em-dat.net/ on 21/2/07

[29] UNEP (2002); *Global Environment Outlook 3,* UNEP, Nairobi, Kenya

[30] UNEP (2002); *op cit*

[31] Pilon, P J (Ed) (1998); *Guidelines for Reducing Flood Losses*, ISDR, Geneva, Switzerland

[32] Munich Re (2003); *topics: Annual Review: Natural Catastrophes 2002*, Germany

[33] Anon (undated); General information about trends of natural disasters, UN/ISDR Fact Sheet

[34] UNEP (2002); *op cit*

[35] UNEP (2002); *op cit*

[36] Anon (undated); *op cit*

[37] Pilon, P J (Ed) (1998); *op cit*

[38] Anon (2005); *Natural Disaster and Disaster Risk Reduction Measures: A Desk Review of Costs and Benefits*, DIFD, UK

[39] Cosgrove, W (2003); Number of Killer Storms and Droughts Increasing Worldwide, Press Release World Water Council, www.mindfully.org/Air/2003/Storms-Droughts-Increasing27feb03.htm (accessed 4/2/07)

[40] UNEP (2002); *op cit*

[41] http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm (accessed 10/2/07)

[42] Blaikie, P, T Cannon and I Davis (1994); *At risk: natural hazards, people's vulnerability and disaster*, Routledge, London, UK and New York, USA

[43] IPCC (2007); *Climate Change 2007 - The Physical Science Basis: Summary for Policymakers*, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report: Climate Change 2007

[44] IPCC (2001); An Assessment of the Intergovernmental Panel on Climate Change 2001: Synthesis Report for Summary for Policymakers

[45] IPCC (2001); *op cit*

[46] van Aalst, M K (2006); The impacts of climate change on the risk of natural disasters, *Disasters,* **30**:1, 5-18

[47] Sudmeier-Rieux, K, H Masundire, A Rizvi and S Rietbergen (eds) (2006); Ecosystems, Livelihoods and Disasters: An integrated approach to disaster risk management, IUCN, Gland, Switzerland and Cambridge, UK

[48] Cosgrove, W (2003); Number of Killer Storms and Droughts Increasing Worldwide, Press Release World Water Council, www.mindfully.org/Air/2003/Storms-Droughts-Increasing27feb03.htm (accessed 4/2/07)

[49] Shaluf, I M and A Fakhru'l-Razi (2006); Disaster types in Malaysia: an overview; *Disaster Prevention and Management*, **15**:2, 286 - 298

[50] Dore, M H I (2005): Climate change and changes in global precipitation patterns: What do we know? *Environment International*, **31**:8, 1167-1181

[51] Huq, S, S Kovats, H Reid and D Satterthwaite (2007); Editorial: Reducing risks to cities from disasters and climate change, *Environment and Urbanization* **19**:3

[52] van Aalst, M K (2006); The impacts of climate change on the risk of natural disasters, *Disasters,* **30**:1, 5-18

[53] UNEP (2002); *op cit*

[54] AIACC (2004); *It's raining, it's pouring... It's time to be adapting*, Report of the Second AIACC Regional Workshop for Latin America and the Caribbean Buenos Aires, Argentina 24-27 August 2004, Assessment of Impacts and Adaptations to Climate Change (AIACC), Washington DC, USA

[55] State Environmental Protection Administration (2005); 2005 Report on the State of the Environment in China, China

[56] Cosgrove, W (2003); *op cit*

[57] ISDR (2004); *op cit*

[58] FAO (2005); *Global Forest Resources Assessment 2005: Progress towards sustainable forest management*, FAO, Rome

[59] ibid

[60] Swanson, F. J. and C. T. Dyrness (1975); Impact of clear-cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon, *Geology* **3**, 393-396

[61] Bruijnzeel L. A. (2001); Hydrology of tropical montane cloud forests: A Reassessment. *Land Use and Water Resources Research* **1**:1.1-1.18

[62] Information from site managers in Malaga, in Dudley, N. and M. Aldrich (2007); *Five Years of Implementing Forest Landscape Restoration*: Lessons to date, WWF International, Gland, Switzerland

[63] Kaimowitz, D (2004); Useful Myths and Intractable Truths: The Politics of the Link between Forests and Water in Central America; in M. Bonell and L.A. Bruijnzeel (eds.) *Forests, Water and People in the Humid Tropics: Past, Present, and Future Hydrological Research for Integrated Land and Water Management*, Cambridge University Press

[64] Tognetti, S (2002): Synthesis report of the FAO electronic workshop, in FAO *Land-Water Linkages in Rural Watersheds*, FAO, Rome

[65] Dolcemascolo, G (2004); *Environmental Degradation and Disaster Risk*, Embassy of Sweden/Sida Bangkok/Asian Disaster Preparedness Center, Indonesia

[66] Kiersch, B (2002); Land use impacts on water resources: a literature review, in FAO *Land-Water Linkages in Rural Watersheds*, FAO, Rome

[67] Kaimowitz, D (2004); *op cit*

[68] Perotto-Baldiviezo, H L, T L Thurow, C T Smith, R F Fisher and B Wu (2004); GIS-based spatial analysis and modeling for landslide hazard assessment in steeplands, southern Honduras, *Agriculture, Ecosystems & Environment*, **103**:1, 165-176

[69] Brown, O, A Crawford and A Hammill (2006); Natural Disasters and Resource Rights: Building resilience, rebuilding lives, International Institute for Sustainable Development, Manitoba, Canada

[70] http://news.bbc.co.uk/1/hi/world/asia-pacific/3242775.stm (accessed 2/1/08)

[71] Hammill, A, O Brown and A Crawford (2005); Forests, Natural Disasters and Human Security, *Arborvitae* 27, IUCN-WWF, Gland, Switzerland

[72] Simms, A, J Magrath and H Reid (2004); *Up in smoke? Threats from, and responses to, the impact of global warming on human development*, new economics foundation, London

[73] Abramovitz, J (2001); *op cit*

[74] Greenpeace (2002); *Look Before You Log: The Use of Logging Moratoria to Support Ancient Forest Conservation and Sustainable Use*; Greenpeace International, The Netherlands

[75] Cai, S, N W Chan, H Kung and P Liu (2001); Management of Flood Disasters in the Jianghan Plain, China, *Disaster Prevention and Management*, **10**:5

[76] Greenpeace (2002); *op cit*

[77] Yin, H F and C Li (2001); Human Impact on Flood and Flood Disasters on the Yangtze River, *Geomorphology*, **41**:105-109

[78] UNEP (2002); *op cit*

[79] Nillson, C, M Svedmark, P Hansson, S Xiong and K Berggren (2000); River Fragmentation and flow regulation analysis, *Landscape Ecology*, Umeå University and Dynesius, M and C Nilsson (1994); Fragmentation and Flow Regulation of River Systems in the Northern Third of the World. *Science* **266**: 753-762

[80] Revenga, C and Y Kura (2003); *Status and Trends of Biodiversity of Inland Water Ecosystems*, CBD Technical Series no.11, Montreal, Canada

[81] OECD (1996); *Guidelines for aid agencies for improved conservation and sustainable use of tropical and sub-tropical wetlands*, OECD, Paris

[82] Schuyt, K and L Brander (2004);*The Economic Values of the World's Wetlands*, WWF, Gland, Switzerland

[83] Stuip, M A M, C J Baker and W Oosterberg (2002); *The socio-economics of wetlands,* Wetlands International and RIZA, Wageningen, The Netherlands

[84] Pilon, P J (Ed) (1998); *op cit*

[85] UNEP (2002); *op cit*

[86] Pilon, P J (Ed) (1998); *op cit*

[87] Mascarenhas, A (2004):Oceanographic validity of buffer zones for the east coast of India: A hydrometeorological perspective, *Current Science*, **86**:3

[88] Nicholls, R J and F M J Hoozemans (2005); Global Vulnerability Analysis in M Schwartz (editor), *Encyclopaedia of Coastal Science*, Springer

[89] IPCC (2007); *Climate Change Impacts, Adaptation and Vulnerability: Summary for Policymakers*, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report: Climate Change 2007

[90] Mascarenhas, A (2004): *op cit*

[91] RAMSAR (2002); Draft Thematic Paper on Management of Africa's Wetlands; www.ramsar.org/cop8/cop8_nepad_thematic.doc (10/2/07) and Saeijs, H L F, A J M Smits, W Overmars and D Willems (2004); *Changing estuaries, changing views*, Erasmus University, Rotterdam and Radboud University, Nijmegen, The Netherlands

[92] Wilkie, M L and S Fortuna (2003); *Status and Trends in Mangrove Area Extent Worldwide*, Forest Resources Assessment Working Paper - 63, FAO, Rome, Italy

[93] Danielsen, F, M K Sørensen, M F Olwig, V Selvam, F Parish, N D Burgess, T Hiraishi, V M Karunagaran, M S Rasmussen, L B Hansen, A Quarto and N Suryadiputra (2005); The Asian Tsunami: A Protective Role for Coastal Vegetation, *Science,* **310**

[94] Barbier, E B (2007); Valuing ecosystem services as productive inputs, *Economic Policy*, January, 177-229

[95] ibid

[96] Wilkinson, C (ed) (2004); *Status of Coral Reefs of the World: 2004*, GCRMN/Australian Institute of Marine Science

[97] Burke, L and J Maidens (2004); *Reefs at Risk in the Caribbean*, World Resources Institute, Washington DC, USA

[98] Sheppard, C, D J Dixon, M Gourlay, A Sheppard and R Payet (2005); Coral mortality increases wave energy reaching shores behind reef flats: examples from the Seychelles, *Estuarine, Coastal and Shelf Science* **64**: 223-234

[99] Sudmeier-Rieux, K, H Masundire, A Rizvi and S Rietbergen (eds) (2006); *Ecosystems, Livelihoods and Disasters: An integrated approach to disaster risk management,* IUCN, Gland, Switzerland and Cambridge, UK

[100] Anon (undated); General information about trends of natural disasters, UN/ISDR Fact Sheet

[101] Twigg, J (2004); *Good Practice Review. Natural Risk Reduction. Mitigation and Preparedness in Development and Emergency Programming*, London: Humanitarian Practice Network, Overseas Development Institute, London

[102] Abramovitz, J (2001); *op cit*

[103] UNEP (2002); *op cit*

[104] Brown, O, A Crawford and A Hammill (2006); *Natural Disasters and Resource Rights: Building resilience, rebuilding lives*, International Institute for Sustainable Development, Manitoba, Canada

[105] Abramovitz, J (2001); *op cit*

[106] UNEP (2002); *op cit*

[107] ibid

[108] Borger, J (2007); Climate change disaster is upon us, warns UN, *The Guardian,* Friday October 5 2007

[109] UNEP (2002); *op cit*

[110] World Neighbors (2000); Lessons from the Field – Reasons for Resilience: Toward a Sustainable Recovery after Hurricane Mitch, quoted in Brown, O, A Crawford and A Hammill (2006); Natural Disasters and Resource Rights: Building resilience, rebuilding lives, International Institute for Sustainable Development, Manitoba, Canada

[111] Tearfund (2005); *Dried up, drowned out – voices from the developing world on a changing climate*, Tearfund, Teddington, UK

[112] UNEP (2004); *Environmental Emergencies NEWS*, **3**: 2004, UNEP, Nairobi, Kenya

[113] Anon (2006); Press Release - Huge mudslides from Hurricane Stan were big killers in Central America and southern Mexico, UN/ISDR 2005/27, Thursday 6 October 2005

[114] World Water Council (2003); Number of Killer Storms and Droughts Increasing Worldwide, Press Release 27th February 2003

[115] UNEP (2004); *Environmental Emergencies NEWS*, **3**: 2004, UNEP, Nairobi, Kenya

[116] Pilon, P J (Ed) (1998); *op cit*

[117] ibid

[118] Anon (2007); Press Release - International Strategy for Disaster Reduction, UN/ISDR 2006/02, Monday 30 January 2006

[119] Pilon, P J (Ed) (1998); *op cit*

[120] http://ec.europa.eu/environment/water/flood_risk/index.htm (accessed 2/2/07)

[121] UNEP (2002); *op cit*

[122] ibid

[123] Sudmeier-Rieux, K, H Masundire, A Rizvi and S Rietbergen (eds.) (2006); *Ecosystems, Livelihoods and Disasters: An integrated approach to disaster risk management*, IUCN, Gland, Switzerland and Cambridge, UK

[124] Emanuel, K A (1988); The Dependency of Hurricane Intensity on Climate, *Nature* **326**: 483–485

[125] IPCC (2007); *Climate Change 2007 - The Physical Science Basis: Summary for Policymakers*, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report: Climate Change 2007

[126] WMO (2005); *WMO Statement on the Status of the Global Climate in 2005*, WMO Press Release No. 743, 15th December 2005

[127] Meyer, P (1997); *Tropical Cyclones*, Swiss Re, Zurich, Switzerland

[128] Simms, A, J Magrath and H Reid (2004); *Up in smoke? Threats from, and responses to, the impact of global warming on human development*, new economics foundation, London

[129] Huq, S, S Kovats, H Reid and D Satterthwaite (2007); Editorial: Reducing risks to cities from disasters and climate change, *Environment and Urbanization* **19**:3

[130] ibid

[131] Bruijnzeel, L A (1990); *Hydrology of moist tropical forests and effects of conversion: A state-of-knowledge review*, UNESCO International Hydrological Programme, Paris and Rice, R M (1997); Forest management to minimize landslide risk, in: *Guidelines for Watershed Management*, FAO Conservation Guide, Rome, Italy, 1977. 271-287

[132] Bruijnzeel, L A and C N Bremmer (1989); *Highland-lowland interactions in the Ganges Brahmaputra river basin: A review of published literature*, ICIMOD Occasional Paper, No. 11

[133] Abramovitz, J (2001); *op cit*

[134] Nadim, F, O Kjekstad, U Domaas, R Rafat, and P Peduzzi (2006); Global Landslides Risk Case Study; in Arnold, M, R S Chen, U Deichmann, M Dilley, A L Lerner-Lam, R E Pullen and Z Trohanis (eds); *Natural Disaster Hotspots: Case Studies*, Disaster Risk Management Series No. 6, Washington DC, USA

[135] EERI (2006); *The Kashmir Earthquake of October 8, 2005: Impacts in Pakistan, EERI Special Earthquake Report – February 2006*, Earthquake Engineering Research Institute, California, USA (http://www.eeri.org/lfe/clearinghouse/kashmir/observ1.php)

[136] Nadim, F, O Kjekstad, P Peduzzi, C Herold and C Jaedicke (2006); Global landslide and avalanche hotspots, *Landslides* (2006) 3: 159–173

[137] Barlow, M, H Cullen, B Lyon and O Wilhelmi (2006); Drought Disaster in Asia; in Arnold, M, R S Chen, U Deichmann, M Dilley, A L Lerner-Lam, R E Pullen and Z Trohanis (eds); *Natural Disaster Hotspots: Case Studies*, Disaster Risk Management Series No. 6, Washington DC, USA

[138] http://www.ncdc.noaa.gov/oa/climate/research/2001/ann/ann.html#Gprcp (accessed 1/3/07)

[139] UNEP (2002); *op cit*

[140] IPCC (2007); *Climate Change Impacts, Adaptation and Vulnerability: Summary for Policymakers*, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report: Climate Change 2007

[141] Burke, E J S J Brown and N Christidis (2006); Modelling the Recent Evolution of Global Drought and Projections for the Twenty- First Century with the Hadley Centre Climate Model, *Journal of Hydrometeorology*, **7**:5, 1113–1125

[142] UNEP (2002); *op cit*

[143] Semazzi, F H M and Y Song Y (2001); A GCM study of climate change induced by deforestation in Africa, In: Desanker P (ed) Africa and global climate change, *Climate Research*, **17**:169–182

[144] Desanker, P V and C O Justice (2001); Africa and global climate change: critical issues and suggestions for further research and integrated assessment modelling; *Climate Research*, **17**: 93–103

[145] Anon (2007); Press Release - International Strategy for Disaster Reduction, UN/ISDR 2006/02, Monday 30 January 2006

[146] UNEP (2002); *op cit*

[147] ibid

[148] Flannigan, M D, B J Stocks and B M Wotton (2000); Climate Change and Forest Fires, *The Science of the Total Environment*, **262**, 221-9

[149] UNEP (2002); *op cit*

[150] http://www.davidsuzuki.org/Forests/Forests_101/FIRE/Climate_Change.asp (accessed 1/3/07)

[151] Secretariat of the Convention on Biological Diversity (2001); *Impacts of human-caused fires on biodiversity and ecosystem functioning, and their causes in tropical, temperate and boreal forest biomes*, CBD Technical Series no. 5, Montreal

[152] UNEP (2002); *op cit*

[153] FAO (2003); Press Release, 9 September 2003, FAO, Rome

[154] Dolcemascolo, G (2004); *Environmental Degradation and Disaster Risk*, Embassy of Sweden/Sida Bangkok/Asian Disaster Preparedness Center, Indonesia

[155] FAO (2003); *op cit*

[156] UNEP (2002); *op cit*

[157] McShane, T O and E McShane-Caluzi (1997); Swiss forest use and biodiversity conservation, In *Harvesting Wild Species: Implications for Biodiversity conservation* (ed.) C H Freese, John Hopkins University Press, Baltimore and London

[158] Brändli, U-B and A Gerold (2001); Protection against natural hazards, In Swiss *National Forest Inventory: Methods and Models of the Second Assessment* (eds.) P Brassel and H Lischke, WSL Swiss Federal Research Institute, Birmensdorf

[159] 2004 Swiss National Report to the Convention on Protection and Use of Transboundary Watercourses and International Lakes, available at: www.unece.org/env/water/meetings/ecosystem/Reports/**Switzerland**_en.pdf (accessed 155/8/07)

[160] Lateltin, O, C Haemmig, H Raetzo and C Bonnard (2005); Landslide risk management in Switzerland, *Landslides* **2**: 313–320

[161] ISDR (2004); *op cit*

[162] http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm (accessed 10/2/07)

[163] Abramovitz, J (2001); *op cit*

[164] Royal Haskoning (2003); *Controlling or Living with Floods in Bangladesh*, Agriculture & Rural Development Working Paper 10, World Bank Washington

[165] Simms, A, J Magrath and H Reid (2004); *Up in smoke? Threats from, and responses to, the impact of global warming on human development*, new economics foundation, London

[166]

http://web.worldbank.org/WBSITE/EXTERNAL/NEWS/0,,contentMDK:20169861~menuPK:34457~pagePK:34370~piPK:34424~theSitePK:4607,00.html (accessed 10/2/07)

[167] World Bank (2004); Press Release: Natural Disasters: Counting the Cost, 2 March, 2004, World Bank, Washington DC

[168] Carpenter, S R, B H Walker, J M Anderies and N Abel (2001); From metaphor to measurement: resilience of what to what? *Ecosystems*, **4**:765-781.

[169] Abramovitz, J (2001); *op cit*

[170] CIFOR and FAO (2005); *Forests and floods: Drowning in fiction or thriving on facts?* RAP Publication 2005 03, Forest Perspectives 2, FAO and CIFOR, Rome and Bogor, Indonesia

[171] Brown, O, A Crawford and A Hammill (2006); Natural Disasters and Resource Rights: Building resilience, rebuilding lives, International Institute for Sustainable Development, Manitoba, Canada

[172] Ruitenbeek, J (1992); The rainforest supply price: a tool for evaluating rainforest conservation expenditure, *Ecological Economics* **6**(1):57-78.

[173] Millennium Ecosystem Assessment (2005); *Ecosystems and Human Well-being: Synthesis*, Island Press, Washington, DC, USA

[174] IPCC (2007); *Climate Change Impacts, Adaptation and Vulnerability: Summary for Policymakers*, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report: Climate Change 2007

[175] ISDR (2004); *op cit*

[176] Kumazaki, M, M Tsutsui, K Shimada, M Suzuki and Y Yasuda (eds.) (1991); *Green Forever: Forests and people in Japan*, The National Land Afforestation Promotion Organisation, Tokyo

[177] Anon (undated) *Forest Conservation in Japan*, Government of Japan, Tokyo

[178] Bagader, A A, Al-Chirazi El-Sabbagh, A T, As-Sayyid Al-Glayand, M, Izzi-Deen Samarrai, M Y (1994); *Environmental Protection in Islam* IUCN Environmental Policy and Law paper No. 20. Rev., 1994, IUCN, Gland Switzerland

[179] Pathak, N, T Balasinorwala and A Kothari (2005); *Community Conserved Areas: Lessons from India, for the CBD Programme of Work*, Kalpavriksh, Pune, India

[180] Chape, S, S Blyth, L Fish, P Fox and M Spalding (2003); *2003 United Nations List of Protected Areas*, IUCN The World Conservation Union and UNEP World Conservation Monitoring Centre, Gland and Cambridge

[181] Anon (undated); *Forest Conservation in Japan*, op cit

[182] IUCN, CNPPA and WCMC (1994); *Guidelines for Protected Area Management Categories*, Gland, Switzerland

[183] Edited from Borrini-Feyerabend, G. (2007); Governance of protected areas, a paper for the IUCN Categories task force

[184] Sandwith, T, C Shine, L Hamilton and D Sheppard (2001); *Transboundary Protected Areas for Peace and Co-operation*, IUCN, Gland, Switzerland) and Cambridge, UK. Accessible on http://app.iucn.org/dbtw-wpd/edocs/PAG-007.pdf

[185]. Borrini-Feyerabend, G, A Kothari and G Oviedo, *Indigenous and Local Communities and Protected Areas. Towards equity and enhanced conservation*, IUCN/WCPA Best Practice Series no. 11, IUCN Cambridge (UK), 2004 http://www.iucn.org/themes/ceesp/Publications/TILCEPA/guidelinesindigenouspeople.pdf

[186] CBD *Programme of Work on Protected Areas*: http://www.cbd.int/protected/pow.shtml, (accessed 15/7/07)

[187] For a thorough discussion of the implications see: Dudley, N, K J Mulongoy, S Cohen, S Stolton, C V Barber and S B Gidda (2005); T*owards Effective Protected Area Systems: An action guide to implementation of the Convention on Biological Diversity* Programme of Work on Protected Areas, CBD Technical Series number 18, Secretariat of the Convention on Biological Diversity, Montreal

[188] Kumar, P and S Narayan (2007); *Sink or Swim: Why disaster risk reduction is central to surviving floods in South Asia*, Oxfam Briefing Note, Oxfam International, Oxford, UK

[189] Dyson, M, G Bergkamp and J Scanlon (eds.) (2003); *Flow: The essentials of environmental flows*, IUCN, Gland, Switzerland, p 43

[190]

http://www.nrcs.usda.gov/PROGRAMS/wrp/2006_ContractInfo/Cumulativethru2006/CumulativeContractInfo2006.html (accessed 17/7/07)

[191] *Daily Telegraph* (2008); Restoring wetlands reduces flood risk, 30th January 2008

[192] Chape, C, S Blyth, L Fish, P Fox and M Spalding (2003); *2003 United Nations List of Protected Areas*, UNEP World Conservation Monitoring Centre, WCPA and IUCN, Cambridge UK

[193] Revenga, C and Y Kura (2003); *op cit*

[194] Choudhury, A (2004); *Kaziranga: Wildlife in Assam*, Rupa and Co, New Delhi

[195] Pilon, P J (Ed) (1998); *op cit*

[196] ibid

[197] Dudley, N and M Ashby (2005); Restoring an natural wetland and woodland habitat from a spruce plantation in Wales, UK, in *Beyond Planting Trees*, (eds.) S Mansourian, N Dudley and D Vallauri, Springer

[198] http://europa.eu/scadplus/leg/en/lvb/l28115.htm (accessed 6/8/07)

[199] UNEP (2002); *Global Environment Outlook 3,* UNEP, Naiorbi, Kenya

[200] Nijland, H J (2005); Sustainable development of floodplains (SDF) project, *Environmental Science & Policy* **8 (3): 245-252**

[201] Bekhuis, J, G Litjens and W Braakhekke (2005); *A policy field guide to the Gelderse Poort: A new, sustainable economy under construction*, Stichting Ark and Stroming, The Netherlands

[202] Schuyt, K and L Brander (2004);*The Economic Values of the World's Wetlands*, WWF, Gland, Switzerland

[203] Department of Conservation (2007); *Economic Values of Whangamarino Wetland*, DoC, Auckland, New Zealand

[204] Information from the Directory of Wetlands of International Importance entry for New Zealand 5NZ003 (http://www.wetlands.org/rsis/, accessed 17/7/07)

[205] http://www.unep-wcmc.org/wdpa/sitedetails.cfm?siteid=95533&level=nat (accessed 5/3/07)

[206] http://sea.unep-wcmc.org/sites/pa/1840v.htm (accessed 5/3/07)

[207] http://www.worldwildlife.org/wildworld/profiles/terrestrial/pa/pa0424_full.html (accessed 5/3/07)

[208] Schuyt, K and L Brander (2004);*The Economic Values of the World's Wetlands*, WWF, Gland, Switzerland

[209] Bosch, J M and J D Hewlett (1982); A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration, *Journal of Hydrology*, **55**: 3-23

[210] CIFOR and FAO (2005); *op cit*

[211] Washington Post (2005); October 12

[212] Philippine Star (2005); Nov. 22

[213] Bradshaw, C J A, N S Sodhi, K S-H Peh and B W Brooks (2007); Global evidence that deforestation amplifies flood risk and severity in the developing world**,** *Global Change Biology* **13** (11), 2379–2395

[214] Laurance, W F (2007); Environmental science: Forests and floods, *Nature* **449**, 409-410

[215] Bruijnzeel, L A, A I J M van Dijk, M van Noordwijk, N A Chappell and J Schellekens (2007); Tropical deforestation, people and flooding, unpublished manuscript

[216] Jones, J A A and G E Grant (1996); Peakflow response to clearcutting and roads in small and large basins, Western Cascades, Oregon, *Water Resources Research* **32**(4):959-974

[217] Jones, J A A (2001); Human modification of flood producing processes: The evidence from catchment studies; in Parker, D J (ed) *Flood Hazards and Disasters*, Routledge, London

[218] Anon (2000): Sustainable flood prevention, Meeting of the Parties to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes, Economic and Social Council, UN Economic Commission for Europe, MP.WAT/2000/7

[219] http://www.unep-wcmc.org/wdpa/sitedetails.cfm?siteid=26070&level=nat (accessed 4/2/07)

[220] Kramer, R., D. Richter, S. Pattanayak, and N. Sharma (1997); Ecological and Economic Analysis of Watershed Protection in Eastern Madagascar; *Journal of Environmental Management*; 49: 277-295.

[221] ibid

[222] Perret, S, F Dolf and H Kienholz (2004); Rockfalls into forests: Analysis and simulation of rockfall trajectories — considerations with respect to mountainous forests in Switzerland, *Landslides* **1** (2): 123-130

[223] Rice, R M (1977); Forest management to minimize landslide risk, in: *Guidelines for Watershed Management*, FAO Conservation Guide, Rome, Italy: 271-287

[224] Montgomery, D R, K M Schmidt, H M Greenberg and W E Dietrich (2000); Forest clearing and regional landsliding, *Geology* **28** (4): 311-314

[225] Dapples, F, A F Lotter, J F N van Leeuwen, W O van der Knaap, S Dimitriadis and D Oswald (2002); Paleolimnological evidence for increased landslide activity due to forest clearing and land-use since 3600 cal BP in the western Swiss Alps, *Journal of Paleolimnology,* **27** (2): 239-248

[226] Hervás, J (ed.) (2003); *Lessons Learnt from Landslide Disasters in Europe*, European Commission Joint Research Centre

[227] Glade, T (1998); Establishing the frequency and magnitude of landslide-triggering rainstorm events in New Zealand, *Environmental Geology* **35** (2-3): 160-179

[228] http://www.unep-wcmc.org/wdpa/sitedetails.cfm?siteid=96104&level=nat (5/3/07)

[229] http://www.unep-wcmc.org/sites/wh/juizhaig.html (accessed 4/2/07)

[230] pers.com. WWF China

[231] http://whc.unesco.org/archive/repcom98a4.htm#sc637 (accessed 5/3/07)

[232] http://www.unep-wcmc.org/wdpa/sitedetails.cfm?siteid=10910&level=nat (accessed 1/3/07)

[233] Government of Nepal (2004); Strengthening disaster preparedness capacities in Kathmandu Valley, Draft report for UNDP, www.undp.org/cpr/disred/documents/regions/asia/nepal_preparedness_prodoc.pdf (accessed 1/3/07)

[234] Baidya, B (2004); Oasis in a polluted mountain valley; *Habitat Himalaya*, **XI**: III

[235] http://www.unep-wcmc.org/sites/pa/1095v.htm (accessed 4/2/07)

[236] Danielsen, F, M K Sørensen, M F Olwig, V Selvam, F Parish, N D Burgess, T Hiraishi, V M Karunagaran, M S Rasmussen, L B Hansen, A Quarto and N Suryadiputra (2005); *op cit*

[237] Kathiresan, K and N Rajendran (2005); Coastal mangrove forests mitigated tsunami, *Estuarine, Coastal and Shelf Science* **65** (3): 601-606

[238] Dahdouh-Guebas, F and N Koedam (2006); Coastal vegetation and the Asian Tsunami, *Science* **311**: 37

[239] Bennett, E L and C J Reynolds (1992); The value of a mangrove area in Sarawak, *Biodiversity and Conservation* **2** (4): 359-375

[240] S Sathirathai, S and E B Barbier (2001); Valuing mangrove conservation in southern Thailand, *Contemporary Economic Policy* **19** (2): 109-122

[241] Saenger, P and N A Siddiqi (1993); Land from the Sea: the Mangrove Program of Bangladesh, *Ocean & Coastal Management* **20** (1): 23-39

[242] Field, C D (1999); Rehabilitation of mangrove ecosystems: an overview, *Marine Pollution Bulletin* **37** (8-12): 383-392

[243] Ramsar Convention on Wetlands (2005); www.ramsar.org/values_shoreline.htm

[244] Moberg, F and Folke, C (1999); Ecological goods and services of coral reef ecosystems, *Ecological Economics* 29 (2): 215-233

[245] Frihy, O E, M A El Ganaini, W R El Sayed and M M Iskander (2004); The role of fringing coral reef in beach protection of Hurghada, Gulf of Suez, Red Sea of Egypt, *Ecological Engineering,* **22** (1): 17-25

[246] Mascarenhas, A (2004); Oceanographic validity of buffer zones for the east coast of India: A hydrometeorological perspective, *Current Science*, **86**:3

[247] Wilkinson, C, D Souter and J Goldberg (2006); Status of Coral Reefs in Tsunami affected Countries: 2005, Australian Institute of Marine Science

[248] UNEP-WCMC website http://www.unep-wcmc.org/sites/wh/rioplata.html (accessed 15/8/2007)

[249] Simms, A, J Magrath and H Reid (2004); *Up in smoke? Threats from, and responses to, the impact of global warming on human development*, New Economics Foundation, London

[250] http://www.unep-wcmc.org/wdpa/sitedetails.cfm?siteid=145816&level=int (accessed 17/7/07)

[251] Information from the Directory of Wetlands of International Importance entry for Jamaica 6JM001, http://www.wetlands.org/rsis/ (accessed 17/7/07)

[252] http://sea.unep-wcmc.org/sites/pa/0513q.htm (accessed 17/7/07)

[253] Garrick, L D (1986); The Black River Lower Morass: A threatened wetland in Jamaica, *Oryx*. **20**, 155-160.

[254] Mascarenhas, A (2004):Oceanographic validity of buffer zones for the east coast of India: A hydrometeorological perspective, *Current Science*, **86**:3

[255] http://gisserver.nic.in/tncoast/coastal%20regulation%20zone.htm (accessed 14/9/06)

[256] http://envfor.nic.in/legis/crz/crznew.html (accessed 14/9/06)

[257] Bagader et al (1994); *op cit*

[258] http://www.gtz.de/en/aktuell/16088.htm (accessed 3/2/2008)

[259] http://www.eauxetforets.gov.ma/coservation_de_sols.htm (accessed 3/2/2008)

[260] Berthe, Y (1997); The role of forestry in combating desertification, World Forestry Congress, Antalya, Turkey

[261] UNCCD (2006); *Ten African Experiences: Implementing the United Nations Convention to Combat Desertification in Africa*: Secretariat of the United Nations Convention to Combat Desertification, Bonn, Germany

[262] Sinha, R K, S Bhatia and R Vishnoi (1997); Desertification control and rangeland management in the Thar desert of India, *Case Studies of Rangeland Desertification*, Rala Report number 200, Agricultural Research Institute, Reykjavik Iceland

[263] Belnap, J (1995); Surface disturbances: Their role in accelerating desertification, *Environmental Monitoring and Assessment,* **37** (1-3): 39-57

[264] Schneider, I E and G W Burnett (2000); Protected area management in Jordan, *Environmental Management,* **25** (3): 241-246

[265] FAO (2002); *Guidelines on Fire Management in Temperate and Boreal Forests*, Forest Protection Working Papers, Working Paper FP/1/E. Forest Resources Development Service, Forest Resources Division, FAO, Rome (*unpublished*).

[266] http://www.unep-wcmc.org/wdpa/sitedetails.cfm?siteid=1256&level=nat (accessed 12/12/07)

[267] MacKinnon, K S, G Hatta, H Halim and A Mangalik (1997); *The Ecology of Kalimantan*, Oxford University Press, Oxford UK

[268] Karki, S (2002); *Community Involvement in and Management of Forest Fires in Southeast Asia*, Project Firefight Southeast Asia, Jakarta Indonesia

[269] Mitchell, A T and H R Grau (2004); Globalization, migration, and Latin American ecosystems, *Science*, 24 Sep 2004: p1915

[270] Figures from http://earthtrends.wri.org/searchable_db/index.php?theme=7 (accessed 10/7/07) using data from United Nations Environment Programme - World Conservation Monitoring Centre (UNEP-WCMC), 2004, *World Database on Protected Areas (WDPA)*, CD-ROM

[271] Simms, A, J Magrath and H Reid (2004); *op cit*

[272] Kaimowitz, D (2004); The great flood myth, *New Scientist* June 19 2004

[273] Kaimowitz, D (2004); *op cit*

[274] Haigh, M J, L Jansky and J Hellin (2004); Headwater deforestation: a challenge for environmental management, *Global Environmental Change Part A* **14** (Supplement 1): 51-61

[275] Alcántara-Ayala, I, O Esteban-Chávez and J F Parrot (2006); Landsliding related to land-cover change: A diachronic analysis of hillslope instability distribution in the Sierra Norte, Puebla, Mexico, *Catena* **65** (2): 152-165

[276] Anon (2006); Press Release - Disaster risk reduction is essential for sustainable development, UN/ISDR 2005/13, Tuesday 22 March 2005

[277] Dudley, N, R Schlaepfer, W J Jackson, J-P Jeanrenaud and S Stolton (2006); *Forest Quality*, Earthscan, London

[278] http://www.unep-wcmc.org/sites/wh/pantanal.html (accessed 17/7/07)

[279] Seidl, A F and A Steffens Moraes (2000);Global valuation of ecosystem services: application to the Pantanal da Nhecolandia, Brazil, *Ecological Economics*, **33**:1, 1-6

[280] Schuyt, K and L Brander (2004);*The Economic Values of the World's Wetlands*, WWF, Gland, Switzerland

[281] Hansen, L J, J L Biringer and J R Hoffman eds. (2003); *Buying Time: A user's manual for building resistance and resilience to climate change in natural systems*, WWF US, Washington DC

[282] Bennett, A (2003 2nd edition); *Linkages in the Landscape*, IUCN, Gland, Switzerland

[283] Dudley, N (2003); *No Place to Hide: Effects of climate change on protected areas*, WWF US, Washington DC reviews many research papers describing this phenomenon

[284] Grace, J, J Lloyd, J McIntyre, A C Miranda, P Meir, H S Miranda, C Nobre, J Moncrieff, J Massheder, Y Malhi, I Wright and J Gash (1995); Carbon dioxide uptake by an undisturbed tropical rain-forest in Southwest Amazonia, 1992-1993, *Science* **270**: 778-780

[285] Niles, J O, T Janson-Smith, C Kelly, J Henman, B Stanley, L Verchot, B Locatelli, D Murdiyarso, M Dutschke, A Michaelowa, A Sari, O Tanujaya, M Totten, S Pandya, S Stier and C Romero (2005); *Climate, Community and Biodiversity Project Design Standards* (First Edition). Climate, Communities and Biodiversity Alliance, Washington DC

[286] Emerton, L, J Bishop and L Thomas (2006); *Sustainable Financing of Protected Areas: A global review of challenges and options*, Best Practice Protected Area Guidelines Series number 13, IUCN, Gland

[287] Most references in this table from World Resources Institute database on carbon sequestration projects on http://www.wri.org/climate/sequestration.cfm, accessed 15th August 2007

[288] The Nature Conservancy (undated); Climate Action Project: Rio Bravo Conservation and Management Area, Belize, http://www.nature.org/initiatives/climatechange/work/art4247.html, accessed 15th August 2007

[289] Presentation from The Nature Conservancy (2001); Carbon sequestration and conservation: an NGO perspective, Lexington KY. www.netl.doe.gov/publications/proceedings/01/carbon_seq_terr/stanley.pdf (accessed 15/8/2007)

[290] Kulshreshtha, S N, M Johnston, S Lac and C Kinar (2004) Economic Valuation of Stored Carbon in Canadian National Parks, *The Empirical Economics Letters*, **4**(1): 12-23.

[291] Vitale, B (undated); Supporting the Protection of Madagascar's Northeastern Forests: Conservation Carbon Project, Conservation International, Washington DC

[292] http://www.celb.org/xp/CELB/programs/climate/conservation_carbon_sierramadre.xml (accessed 15/8/2007)

[293] Howard, P. (1995); The economics of protected areas in Uganda: Costs, benefits, and policy issues. PhD dissertation, University of Edinburgh

[294] Noojibail, G and B Conway (2004); Evaluating ecological services and replacement costs of the urban forest in our nation's capital, In J Selleck (ed.), *National Resource Year in Review 2004*, National Parks Service

[295] Carmo Vaz, A (2000); *Coping With Floods – The Experience of Mozambique*, 1st WARFSA/WaterNet Symposium: Sustainable Use of Water Resources, Maputo, 1-2 November 2000

[296] UNEP/UNCHS (Habitat) Joint Mission, Mozambique 2000 Floods; http://ochaonline.un.org/GetBin.asp?DocID=3773 (accessed 14/9/06)

[297] Wiles, P, K Selvester and L Fidalgo (2005); *Learning Lessons from Disaster Recovery: The Case of Mozambique*, Disaster Risk Management Working Paper Series No. 12, World Bank, Washington

[298] UNDP (2004); *Evolution of a Disaster Risk Management System: A Case Study from Mozambiqu*e, UNDP Disaster Reduction Unit, Bureau for Crisis Prevention and Recovery, Geneva, Switzerland, www.undp.org/bcpr/disred/documents/publications/casestudy/mozambique.pdf -

[299] http://www.em-dat.net/disasters/Visualisation/profiles/countryprofile.php (accessed 1/7/07)

[300] UNDP (2004); *op cit*

[301] UNEP/UNCHS (Habitat) Joint Mission, Mozambique 2000 Floods; *op cit*

[302] Fox, C and C Sneddon (2007); Transboundary river basin agreements in the Mekong and Zambezi basins: Enhancing environmental security or securitizing the environment?, *International Environmental Agreements: Politics, Law and Economics*, 7:3

[303] Carmo Vaz, A (2000); *op cit*

[304] Katerere, Y, R Hill and S Moyo (2001); *A Critique of Transboundary Natural Resource Management in Southern Africa*, Paper no.1, IUCN-ROSA Series on Transboundary Natural Resource Management

[305] http://www.africanwater.org/internationalwater.htm (accessed 14/9/06)

[306] http://www.worldwildlife.org/wildworld/profiles/terrestrial/at/at0906_full.html (accessed 14/9/06)

[307] http://www.worldwildlife.org/wildworld/profiles/terrestrial/at/at1402_full.html (accessed 14/9/06)

[308] http://www.worldwildlife.org/wildworld/profiles/terrestrial/at/at0128_full.html (accessed 14/9/06)

[309] http://www.worldwildlife.org/wildworld/profiles/terrestrial/at/at0706_full.html (accessed 14/9/06)

[310] Carmo Vaz, A (2000); *op cit*

[311] UNEP/UNCHS (Habitat) Joint Mission, Mozambique 2000 Floods; *op cit*

[312] UNEP (2004); *Environmental Emergencies News*, **3**: 2004, Disaster Management Branch, Division of Environmental Policy Implementation, United Nations Environment Programme, Nairobi

[313] Steinbruch, F, M Gall and F José (2002); Remote Sensing and GIS for Documentation and Evaluation of the Socio-Economic and Environmental Impact of the Floods 2000 in Central Mozambique, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information*, **34**(6/W6): 59-65

[314] Smithers, J C, R E Schulze, A Pike and G P W Jewitt (2001); A hydrological perspective of the February 2000 floods: A case study in the Sabie River Catchment, *Water SA,* **27**:3, 325-332

[315] UNEP/UNCHS (Habitat) Joint Mission, Mozambique 2000 Floods; *op cit*

[316] Steinbruch, F, M Gall and F José (2002); *op cit*

[317] Wong, C, M Roy and A R Duraiappah (2005); *Focus on Mozambique Connecting poverty & ecosystem services*, UNEP and IISD, Kenya and Canada

[318] Anon (2002); *New Partnership for Africa's Development – NEPAD: Thematic Paper on Management of Africa's Wetlands*, prepared for Developing Further the Draft Action Plan for Managing Africa's Wetlands under the Framework of the Environment Component of Nepad, Valencia, Spain, 17 November 2002, www.ramsar.org/cop8/cop8_nepad_thematic.doc

[319] Munnion, C (2000); Conservationists put the blame on South Africa, *Daily Telegraph*, 3 March 2000, London

[320] Planet Ark (2000); Mozambique floods worsened by wetland loss, South Africa: March 15, 2000, http://www.planetark.com/dailynewsstory.cfm/newsid/5988/newsDate/15-Mar-2000/story.htm

[321] FAO (2004); *Drought impact mitigation and prevention in the Limpopo River Basin: A situation analysis*, FAO Subregional Office for Southern and East Africa Harare

[322] Molefe, R (undated); Flood catastrophe worsened by reckless; http://psybergate.com/wetfix/Press/Press25/press.htm

[323] Smithers, J C, R E Schulze, A Pike and G P W Jewitt (2001); A hydrological perspective of the February 2000 floods: A case study in the Sabie River Catchment, *Water SA,* **27**:3, 325-332

[324] IUCN (undated);The Sabie River: protecting biodiversity in an internationally Important conservation area, IUCN, Gland, Switzerland, available from www.uicn.org/themes/wani/flow/cases/Sabie.pdf

[325] Christie, F and J Hanlon (2001); *Mozambique and the great flood of 2000*, The International African Institute, James Currey, Oxford and Indiana University Press, USA

[326] O'Connor, T G (2001); Effect of small catchment dams on downstream vegetation of a seasonal river in semi-arid African savanna, *Journal of Applied Ecology*, 38:6, 1314-1325

[327] Carmo Vaz, Álvaro (2000); *op cit*

[328] UNEP/UNCHS (Habitat) Joint Mission, Mozambique 2000 Floods; *op cit*

[329] Smithers, J C, R E Schulze, A Pike and G P W Jewitt (2001); *op cit*

[330] IPCC (2001); *IPCC Third Assessment Report – Climate Change 2001. Working Group II: Impacts, Adaptation and Vulnerability*, World Meteorological Organization and United Nations Environment Programme, Geneva

[331] Davies, B R, R D Beilfuss and M C Thoms (2000); Cahora Bassa retrospective, 1974–1997: effects of flow regulation on the Lower Zambezi River, *Verh. Internat. Verein. Limnol*., **27**:1–9, Stuttgart

[332] Beilfuss, R, D Moore, C Bento and P Dutton (2001); *Patterns of vegetation change in the Zambezi delta, Mozambique*, Program for the sustainable management of Cahora Bassa dam and the lower Zambezi valley, International Crane Foundation, USA

[333] Beilfuss, R (2001); *Patterns of hydrological change in the Zambezi Delta, Mozambique*, Program for the sustainable management of Cahora Bassa dam and the lower Zambezi valley, International Crane Foundation, USA

[334] Beilfuss, R, D Moore, C Bento and P Dutton (2001); *op cit*

[335] pers com Richard Beilfuss, Director, Department of Scientific Services (Gorongosa Research Center), Gorongosa National Park Carr Foundation, Mozambique (1/8/2007)

[336] Davies, B R, R D Beilfuss and M C Thoms (2000); *op cit*

[337] Beilfuss, R (2001); *Prescribed flooding and restoration potential in the Zambezi delta, Mozambique,* Program for the sustainable management of Cahora Bassa dam and the lower Zambezi valley, International Crane Foundation, USA

[338] http://www.reliefweb.int/rw/RWB.NSF/db900SID/OCHA-64CC3U?OpenDocument (accessed 1/7/07)

[339] http://www.reliefweb.int/rw/RWB.NSF/db900SID/ACOS-64BPKB?OpenDocument (accessed 1/7/07)

[340] UNEP/UNCHS (Habitat) Joint Mission, Mozambique 2000 Floods; *op cit*

[341] UNEP (2004); *Environmental Emergencies News*, **3**: 2004, Disaster Management Branch, Division of Environmental Policy Implementation, United Nations Environment Programme, Nairobi

[342] Wong, C, M Roy and A R Duraiappah (2005); *Focus on Mozambique Connecting poverty & ecosystem services: A series of seven country scoping studies*, United Nations Environment Programme and the International Institute for Sustainable Development, Kenya and Canada

[343] UNEP/UNCHS (Habitat) Joint Mission, Mozambique 2000 Floods; *op cit*

[344] Beilfuss, R and C Brown (2006); *Assessing Environmental flows requirements for the Marromeu Complex of the Zambezi Delta: application of the DRIFT model*, Museum of Natural History, Mozambique

[345] Beilfuss, R and C Brown (2006); *op cit*

[346] Pilon, P J (Ed) (1998); *op cit*

[347] UNEP/UNCHS (Habitat) Joint Mission, Mozambique 2000 Floods; *op cit*

[348] Protocol on Shared Watercourse Systems in the Southern African Development Community (SADC) Region

[349] Mittermeier, R A, C F Kormos, C G Mittermeier, P R Gil, T Sandwith and C Besacon (2005); *Transboundary Conservation: A New Vision for Protected Areas*, Cemex

[350] Spenceley, A (2005); *Tourism investment in the Great Limpopo Transfrontier Conservation Area: Scoping report*, Transboundary Protected Areas Research Initiative, University of the Witwatersrand, South Africa

[351] http://gefonline.org/projectDetails.cfm?projID=2173 (accessed 7/7/07)

[352] Huq, S (2001); Climate Change and Bangladesh, *Science*, **294**: 5547, p. 1617

[353] UNEP (2002); *op cit*

[354] IFRC (2000); Bangladesh: Floods, Preliminary Appeal, no:20/2000, 18 August 2000; IFRC (2001); India: Floods, Appeal no. 19/2000, 26 January 2001 and FAO (2000); *Severe Weather Disturbances Seriously Affect Crop and Food Supply Prospects in Asia and Displace Millions - August 2000*, Special Reports and Alerts (GIEWS), **311**, FAO, Rome

[355] Dilley, M , R S Chen, U Deichmann, A L Lerner-Lam and M Arnold (2005); *Natural Disaster Hotspots: A Global Risk Analysis*, The World Bank, Washington

[356] Agrawala, S, T Ota, A Uddin Ahmed, J Smith and M van Aalst (2005); *Development and Climate Change in Bangladesh: Focus on Coastal Flooding and the Sundarbans*, OECD, Paris, France

[357] Ali, A (1996); Vulnerability of Bangladesh to climate change and sea level rise through tropical cyclones and storm surges, *Water, Air, & Soil Pollution*, **92**:1-2

[358] Royal Haskoning (2003); *Controlling or Living with Floods in Bangladesh*, Agriculture & Rural Development Working Paper 10, World Bank Washington

[359] Agrawala, S, T Ota, A Uddin Ahmed, J Smith and M van Aalst (2005); *op cit*

[360] Agrawala, S, T Ota, A Uddin Ahmed, J Smith and M van Aalst (2005); *op cit*

[361] Royal Haskoning (2003); *op cit*

[362] Nicholls, R J (2006); Storm Surges in Coastal Areas, in Arnold, M, R S Chen, U Deichmann, M Dilley, A L Lerner-Lam, R E Pullen and Z Trohanis (eds); *Natural Disaster Hotspots: Case Studies*, Disaster Risk Management Series No. 6, Washington DC, USA

[363] Monirul Qader Mirza, M (2004); Three Recent Extreme Floods in Bangladesh: A Hydro-Meteorological Analysis, *Natural Hazards*, **28**: 1

[364] Royal Haskoning (2003); *op cit*

[365] ibid

[366] Beck, T (2005); *Learning Lessons from Disaster Recovery: The Case of Bangladesh*, Working Paper Series no. 11, World Bank, Washington DC, USA

[367] Chowdhurt, Q I (editor) (2002); *Bangladesh – State of the Environment Report 2001*, Forum of Environmental Journalists of Bangladesh, with support from the Ministry of Environment and Forest, Government of Bangladesh, Dhaka

[368] Agrawala, S, T Ota, A Uddin Ahmed, J Smith and M van Aalst (2005); *op cit*

[369] ibid

[370] IPCC (2007); *Climate Change Impacts, Adaptation and Vulnerability: Summary for Policymakers*, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report: Climate Change 2007

[371] Palmer, T N and J Räisänen (2002); Quantifying the risk of extreme seasonal precipitation in a changing climate, *Nature.* **415**, 512–514.

[372] Alam, M and L A Murray (2005); *Facing up to Climate Change in South Asia*, IIED Gatekeeper series 118, London, UK

[373] Khalil, G M (1992); Cyclones and storm surges in Bangladesh: Some mitigative measures, *Natural Hazards*, **6**:1

[374] IPCC (2001); *Climate Change 2001: Scientific Basis; Summary for the Policy Makers*, IPCC, Geneva, Switzerland

[375] Nicholls, R J and F M J Hoozemans (2005); Global Vulnerability Analysis in M Schwartz (editor), *Encyclopaedia of Coastal Science*, Springer

[376] Nicholls, R J (2006); Storm Surges in Coastal Areas, in Arnold, M, R S Chen, U Deichmann, M Dilley, A L Lerner-Lam, R E Pullen and Z Trohanis (eds); *Natural Disaster Hotspots: Case Studies*, Disaster Risk Management Series No. 6, World Bank, Washington DC, USA

[377] Nicholls, R J and F M J Hoozemans (2005); *op cit*

[378] Royal Haskoning (2003); *op cit*

[379] ibid

[380] Agrawala, S, T Ota, A Uddin Ahmed, J Smith and M van Aalst (2005); *op cit*

[381] Salequzzaman M, P Newman, L Stocker and D Marinova (2003); *Adaptation and Sustainability Issues of Global Warming Consequences in Coastal Bangladesh*, Proceedings of the International Sustainability Conference, Perth, Western Australia

[382] Agrawala, S, T Ota, A Uddin Ahmed, J Smith and M van Aalst (2005); *op cit*

[383] ibid

[384] ibid

[385] Chowdhurt, Q I (editor) (2002); *Bangladesh – State of the Environment Report 2001*, Forum of Environmental Journalists of Bangladesh, with support from the Ministry of Environment and Forest, Government of Bangladesh, Dhaka

[386] Ali, A (1996); Vulnerability of Bangladesh to climate change and sea level rise through tropical cyclones and storm surges, *Water, Air, & Soil Pollution*, **92**:1-2

[387] Chowdhurt, Q I (editor) (2002); *op cit*

[388] FAO (1999); *FRA 2000: Forest resources of Bangladesh, Country report*; Working Paper 15, Forest Resources Assessment Programme, FAO, Rome

[389] Agrawala, S, T Ota, A Uddin Ahmed, J Smith and M van Aalst (2005); *op cit*

[390] Chowdhurt, Q I (editor) (2002); *op cit*

[391] Md. Golam Mahabub Sarwar (2005): Impacts of Sea Level Rise on the Coastal Zone of Bangladesh, Masters Thesis, Lund University, Sweden

[392] Khalil, G M (1992); Cyclones and storm surges in Bangladesh: Some mitigative measures, *Natural Hazards*, **6**:1

[393] Chowdhurt, Q I (editor) (2002); *op cit*

[394] FAO (1999); *op cit*

[395] http://www.adb.org/Documents/News/1998/nr1998078.asp (accessed 24/5/07)

[396] http://www.unep-wcmc.org/sites/wh/sundarba.html and http://www.worldwildlife.org/wildworld/profiles/g200/g139.html (accessed 23/5/07)

[397] http://www.wwfindia.org/about_wwf/what_we_do/tiger_wildlife/our_work/tiger_conservation/sunderbans/index.cfm (accessed 23/5/07)

[398] http://www.worldwildlife.org/wildworld/profiles/g200/g139.html (accessed 23/5/07)

[399] http://www.unep-wcmc.org/sites/wh/sundarba.html (accessed 23/5/07)

[400] RAMSAR (2002); Draft Thematic Paper on Management of Africa's Wetlands; www.ramsar.org/cop8/cop8_nepad_thematic.doc (accessed 10/2/07)

[401] Mascarenhas, A (2004): Oceanographic validity of buffer zones for the east coast of India: A hydrometeorological perspective, *Current Science*, **86**:3

[402] Khalil, G M (1992); Cyclones and storm surges in Bangladesh: Some mitigative measures, *Natural Hazards*, **6**:1

[403] http://www.unep-wcmc.org/sites/wh/sundarba.html (accessed 23/5/07)

[404] http://www.worldwildlife.org/wildworld/profiles/terrestrial/im/im1406_full.html (accessed 23/5/07)

[405] Salequzzaman M, P Newman, L Stocker and D Marinova (2003); *Adaptation and Sustainability Issues of Global Warming Consequences in Coastal Bangladesh*, Proceedings of the International Sustainability Conference, Perth, Western Australia

[406] FAO (1999); *op cit*

[407] Agrawala, S, T Ota, A Uddin Ahmed, J Smith and M van Aalst (2005); *op cit*

[408] Smith, J B, A Rahman and M Q Mirza (1998); *Considering Adaptation to Climate Change in the Sustainable Development of Bangladesh*, Report to The World Bank by Stratus Consulting Inc., Boulder, CO. reported in Agrawala, S, et al (2005); *op cit*

[409] Agrawala, S, T Ota, A Uddin Ahmed, J Smith and M van Aalst (2005); *op cit*

[410] IPCC (2007); *Climate Change Impacts, Adaptation and Vulnerability: Summary for Policymakers*, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report: Climate Change 2007

[411] Monirul Qader Mirza, M (2003): Climate change and extreme weather events: can developing countries adapt?, *Climate Policy*, **3**:3, 233-248

[412] Alam, M and L A Murray (2005); *Facing up to Climate Change in South Asia*, IIED Gatekeeper series 118, London, UK

[413] Beck, T (2005); *Learning Lessons from Disaster Recovery: The Case of Bangladesh*, Working Paper Series no. 11, World Bank, Washington DC, USA

[414] Royal Haskoning (2003); *op cit*

[415] http://www.unep-wcmc.org/sites/wh/sundarba.html (accessed 23/5/07)

[416] FAO (1999); *op cit*

[417] http://www.worldwildlife.org/wildworld/profiles/terrestrial/im/im1406_full.html (accessed 12/12/07)

[418] ibid

[419] McLeod, E and R V Salm (2006); *Managing Mangroves for Resilience to Climate Change,* IUCN, Gland, Switzerland

[420] ibid

[421] www.panda.org/about_wwf/where_we_work/europe/news/index.cfm?uNewsID=74080 (accessed 25/4/07)

[422] Revenga, C, S Murray, J Abramovitz and A Hammond (1998); *op cit*

[423] en.wikipedia.org/wiki/Danube (accessed 25/4/07)

[424] Revenga, C, S Murray, J Abramovitz and A Hammond (1998); *op cit*

[425] Schwarz, U, C Bratrich, O Hulea, S Moroz, N Pumputyte, G Rast, M R Bern and V Siposs (2006); *2006 Floods in the Danube River Basin: Flood risk mitigation for people living along the Danube and the potential for floodplain protection and restoration*, Working paper, Vienna, July 2006, WWF Danube Carpathian Programme, Austria

[426] Revenga, C, S Murray, J Abramovitz and A Hammond (1998); *op cit*

[427] Swiss Re (2002): *Are floods insurable!*, Swiss Re, Zurich

[428] Schwarz, U, C Bratrich, O Hulea, S Moroz, N Pumputyte, G Rast, M R Bern and V Siposs (2006); *op cit*

[429] Wood, N (2006); Floods persuade some to give Danube room, *International Herald Tribune*, 27th April, www.iht.com/articles/2006/04/26/news/danube.php (accessed 6/7/07)

[430] Schwarz, U, C Bratrich, O Hulea, S Moroz, N Pumputyte, G Rast, M R Bern and V Siposs (2006); *op cit*

[431] Schwarz, U, C Bratrich, O Hulea, S Moroz, N Pumputyte, G Rast, M R Bern and V Siposs (2006); *op cit*

[432] WWF Floodplain Institute (2004); *Atlas LDGC 1st edition 2004, 1: 200,000*, Germany

[433] news.bbc.co.uk/1/hi/world/europe/4951728.stm (accessed 23/4/07)

[434] Schwarz, U, C Bratrich, O Hulea, S Moroz, N Pumputyte, G Rast, M R Bern and V Siposs (2006); *op cit*

[435] ibid

[436] Relief Web: Report on April 2006 floods in South Eastern Europe; www.reliefweb.int/rw/RWB.NSF/db900SID/VBOL-6Q4GZJ?OpenDocument (accessed 25/4/07)

[437]www.panda.org/about_wwf/where_we_work/europe/what_we_do/epo/initiatives/agriculture/one_europe_more_nature/index.cfm?uNewsID=66620 (accessed 25/4/07)

[438] European Environment Agency (2005); *EEA Briefing - Climate change and river flooding in Europe*, available at reports.eea.europa.eu/briefing_2005_1/en/ (accessed 6/7/07)

[439] Schwarz, U, C Bratrich, O Hulea, S Moroz, N Pumputyte, G Rast, M R Bern and V Siposs (2006); *op cit*

[440] ibid

[441] ibid

[442] ibid

[443] Declaration on the Cooperation for the Creation of a Lower Danube Green Corridor, www.wwf.de/fileadmin/fm-wwf/pdf_neu/DanubeDeclaration2000.pdf (accessed 15/3/07)

[444]www.panda.org/about_wwf/where_we_work/europe/what_we_do/danube_carpathian/index.cfm?uNewsID=94740 (accessed 15/3/07)

[445]www.panda.org/about_wwf/where_we_work/europe/what_we_do/epo/initiatives/agriculture/one_europe_more_nature/index.cfm?uNewsID=66620 (accessed 25/4/07)

[446] Schwarz, U, C Bratrich, O Hulea, S Moroz, N Pumputyte, G Rast, M R Bern and V Siposs (2006); *op cit*

[447] Schwarz, U, C Bratrich, O Hulea, S Moroz, N Pumputyte, G Rast, M R Bern and V Siposs (2006); *op cit*

[448] http://news.bbc.co.uk/1/hi/world/europe/3124745.stm (accessed 17/5/07)

[449] IM (2004); Caracterização Climática 2003, Relatório Técnico, www.meteo.pt

[450] Trigo, R M, J C Pereira, M G Pereira, B Mota, T J Calado, C C Câmara, and F E Santo (2006); Atmospheric conditions associated with the exceptional fire season of 2003 in Portugal, *International Journal of Climatology*, **26**(13): 1741-1757

[451] Stott, P A, D A Stone and M R Allen (2004); Human contribution to the European heatwave of 2003, *Nature* **432**: 610–614

[452] IPCC (2007); *Climate Change 2007: The Physical Science Basis, Summary for Policymakers; Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Geneva, Switzerland

[453] IM (2004); op cit

[454] ibid

[455] Pereira, J M C, J M B Carreiras, J M N Silva and M J P Vasconcelos (2006); Alguns conceitos básicos sobre os fogos rurais em Portugal; in Pereira, J S, J M C Pereira, F Rego, J M N Silva and T P Silva (Eds.); *Incêndios florestais em Portugal: caracterização, impactes e prevenção*, pp.133-162, ISA Press, Lisboa

[456] Noss, R F, J F Franklin, W L Baker, T Schoennagel and P B Moyle (2006); Managing fire-prone forests in the western United States, *Frontiers in Ecology and the Environment*, **4**: 481–487

[457] Díaz-Delgado, R, F Lloret and X Pons (2004); Spatial patterns of fire occurrence in Catalonia, NE Spain, *Landscape Ecology*, **19**: 731–745

[458] Pereira, M G, R M Trigo, C C Da Câmara, J C Pereira and S M Leite (2005); Synoptic patterns associated with large summer forest fires in Portugal, *Agricultural and Forest Meteorology*, **129**: 11–25

[459] Viegas, D X and M T Viegas (1994); A relationship between rainfall and burned area for Portugal, *International Journal of Wildland Fire*, **4**(1): 11–16

[460] Westerling, A L, A Gershunov, B L Brown, D R Cayan and M D Dettinger (2003); Climate and wildfire in the western United States, *Bulletin of the American Meteorological Society*, **84**: 595–604.

[461] DGRF (2006); *Incêndios Florestais: relatório de 2005*, DGRF-MADRP, Lisbon

[462] ibid

[463] Vieira, P A (2006); *Portugal: o vermelho e o negro*. Publicações Dom Quixote, Lisbon

[464] http://www.em-dat.net/disasters/Visualisation/profiles/countryprofile.php (accessed May 2007)

[465] Tressol, M, J Brioude, C Mari, V Thouret, R Zbinden and J-P Cammas (2006); Impact of Portugal fires on 2003 European pollution, *Geophysical Research Abstracts*, **8**, European Geosciences Union

[466] Pereira J S, A V Correia, A P Correia, T Ferreira, F Godinho, H Freitas and N Onofre (2002); Forests and Biodiversity; in: Santos, F D, K Forbes and R Moita (*Eds.*), *Climate Change in Portugal. Scenarios, Impacts, and Adaptation Measures,* SIAM

[467] ibid

[468] Velez, R (2006); A defesa contra incêndios florestais: estratégias, recursos, organização, In: J S Pereira, J M C Pereira, F C Rego, J S Silva and T P Silva (Eds); *Incêndios Florestais em Portugal: Caracterização, impactes e prevenção*, ISA Press, Lisbon, pp. 355-368

[469] ICN (2005); Incêndios Rurais na rede nacional de áreas protegidas e rede Natura2000 em 2005: Relatório, Instituto Conservação da Natureza, Lisbon

[470] ibid

[471] Filipe Catry, Centre for Applied Ecology/Technical University of Lisbon, personal communication, 2007

[472] UNEP-WCMC (2006); *op cit*

[473] Wilkinson, C, D Souter and J Goldberg (2006); *op cit*

[474] ILO press release, ILO Online, 19 January 2005, www.ilo.org/global/About_the_ILO/Media_and_public_information/Press_releases/lang--en/WCMS_005169 (accessed 18/5/07)

[475] Wilkinson, C, D Souter and J Goldberg (2006); *op cit*

[476] Oxfam (2005); *Back to work: How people are recovering their livelihoods 12 months after the tsunami*, Oxfam Briefing Paper 84, Oxfam, UK

[477] HPN and ODI (2005); *Humanitarian Exchange*, Number **32**, Humanitarian Practice Network (HPN) and the Overseas Development Institute (ODI), UK

[478] Wilkinson, C, D Souter and J Goldberg (2006); *op cit*

[479] ibid

[480] Valiela I, J L Bowen and J K York (2001); Mangrove forests: one of the world's threatened major tropical environments. *BioScience* **51**:10, 807-815

[481] UNEP-WCMC (2006); *op cit*

[482] UNEP (2005); *Maldives, Post-Tsunami Environmental Assessment*, United Nations Environment Programme, Nairobi

[483] Wilkinson, C, D Souter and J Goldberg (2006); *op cit*

[484] ibid

[485] Caldecott, J and W R M S Wickremasinghe (2005); *Sri Lanka: Post-Tsunami Environmental Assessment*, United Nations Environment Programme

[486] ibid

[487] UNEP (2005); *op cit*

[488] ibid

[489] World Bank (2005); *Aceh and Nias One Year After the Tsunami: The Recovery Effort and Way Forward*, World Bank, Washington, USA

[490] Caldecott, J and W R M S Wickremasinghe (2005); UNEP-WCMC (2006); *op cit*

[491] UNEP (2005); *op cit*

[492] Wilkinson, C, D Souter and J Goldberg (2006); *op cit*

[493] UNEP-WCMC (2006); *op cit*

[494] Danielsen, F, M K Sørensen, M F Olwig, V Selvam, F Parish, N D Burgess, T Hiraishi, V M Karunagaran, M S Rasmussen, L B Hansen, A Quarto and N Suryadiputra (2005); *op cit*

[495] Kunkel, K M, R W Hallberg and M Oppenheimer (2006); Coral reefs reduce tsunami impact in model simulations, *Geophysical Research Letters*, **33**

[496] UNEP-WCMC (2006); *op cit*

[497] Harada, K and F Imamura (2005); Effects of coastal forest on tsunami mitigation – a preliminary investigation, in K Satake (ed.), *Tsunamis: Case Studies and Recent Developments*, p279-292, Springer, The Netherlands and Shuto, N (1987); The effectiveness and limit of tsunami control forests, *Coastal Engineering in Japan*, **30**:1

[498] Fernando, H J S, S G Mendis, J L McCulley and K Perera (2005); Coral poaching worsens tsunami destruction in Sri Lanka, *Eos Trans. AGU* **86**:301, 304; and Liu, P. L-F, P Lynett, H Fernando, B E Jaffe, H Fritz, B Higman, R Morton, J Goff and C Synolakis, C (2005); Observations by the International Survey Team in Sri Lanka, *Science*, **308**:1595, quoted in UNEP-WCMC (2006); *op cit*

[499] Dahdouh-Guebas, F, L P Jayatisse, D Di Nitto, J O Bosire, D Lo Seen and N Koedam (2005); How effective were mangroves as a defence against the recent tsunami? *Current Biology* **15**(12):443-447, quoted in UNEP-WCMC (2006); *op cit*

[500] Tanaka, N, Y Sasaki, M I M Mowjood, K B S N Jinadasa and S Homchuen (2007); Coastal vegetation structures and their functions in tsunami protection: experience of the recent Indian Ocean tsunami, *Landscape and Ecological Engineering* **3**:1, Springer Japan,

[501] Department of Marine and Coastal Resources (2006); *The study on Ecosystem and Changes of Coastal Forests Affected by the 2004 Tsunami*, Ministry of Natural Resources and Environment, Thailand

[502] Caldecott, J and W R M S Wickremasinghe (2005); *op cit*

[503] ibid

[504] pers. com. Dr Robbie Robinson, IUCN Tsunami Task Force, 28/5/07

[505] Chang, S E, B J Adams, J Alder, P R Berke, R Chuenpagdee, S Ghosh and C Wabnitz (2006); Coastal Ecosystems and Tsunami Protection after the December 2004 Indian Ocean Tsunami, *Earthquake Spectra*, **22**: S3,S863-S887

[506] Keating, B H and C Helsley (2005); 2004 Indian ocean tsunami on the Maldives islands: initial observations, *Science of Tsunami Hazards*, **23**:2, 19-70

[507] UNEP (2005); *op cit*

[508] Wilkinson, C, D Souter and J Goldberg (2006); *op cit*

[509] Chandrasekar, N, S Saravanan, J Loveson Immanuel and M Rajamanickam (2006); Classification of tsunami hazard along the southern coast of India: an initiative to safeguard the coastal environment from similar, *Science of Tsunami Hazards*, 24:1, 3-23

[510] Danielsen, F, M K Sørensen, M F Olwig, V Selvam, F Parish, N D Burgess, T Hiraishi, V M Karunagaran, M S Rasmussen, L B Hansen, A Quarto and N Suryadiputra (2005); *op cit* and Danielsen, F et al (2005); Response to Letters, *Science*, **311**

[511] Chatenoux, B and P Peduzzi (2005); Analysis of the role of bathymetry and other environmental parameters in the impacts from the 2004 Indian Ocean tsunami. Report for the UNEP Asian Tsunami Disaster Task Force. UNEP/DEWA/GRID-Europe, Switzerland, quoted in UNEP-WCMC (2006); *op cit*

[512] Chatenoux, B and P Peduzzi (2005); *op cit* and Wood, V (2005); *Did Mangrove Forests Reduce the Impact of the Asian Tsunami*? M.Sc Thesis, Imperial College London. 152 quoted in UNEP-WCMC (2006); *op cit*

[513] Chatenoux, B and P Peduzzi (2007); Impacts from the 2004 Indian Ocean Tsunami: analysing the potential protecting role of environmental features, *Natural Hazards*, **40**:2

[514] UNEP-WCMC (2006); *op cit*

[515] ibid

[516] ibid

[517] http://www.iht.com/articles/2006/12/26/opinion/edbaird.php (accessed 1/5/07)

[518] http://www.esa.org/esablog/?p=28 (accessed 1/5/07)

[519] Caldecott, J and W R M S Wickremasinghe (2005); *op cit*

[520] ibid

[521] UNEP-WCMC (2006); *op cit*

[522] Wilkinson, C, D Souter and J Goldberg (2006); *op cit*

[523] UNEP-WCMC (2006); *op cit*

[524] Wilkinson, C, D Souter and J Goldberg (2006); *op cit*

[525] UNEP-WCMC (2006); *op cit*

[526] Alverson, K (2005); Watching over the world's oceans, *Nature* **434**:19-20

[527] http://www.gdrc.org/oceans/tsunami_coastal-guidelines.html (accessed 20/5/07)

[528] see http://www.fao.org/forestry/site/coastalprotection/en/ (accessed 12/12/07)

[529] http://www.gdrc.org/oceans/tsunami_coastal-guidelines.html#three (accessed 20/5/07)

[530] Kender, E (2005); Mike Tidwell, Author of Bayou Farewell, interviewed by Erick Kancler, *Mother Jones Magazine*, October

[531] U.S. Army Corps of Engineers New Orleans District (2004); *Louisiana Coastal Area Ecosystem Restoration* Study, November

[532] National Oceanic and Atmospheric Administration (NOAA) (2005); *Climate of 2005: Summary of Hurricane Katrina*. NOAA National Climate Date Center, Updated September

[533] Burkett, V, D. Zilokoski, D. Hart (undated); *Sea Level Rise and Subsidence: Implications for Flooding in New Orleans, Louisiana*, U.S. Geological Survey Abstract

[534] Elperin, J (2005); Shrinking Louisiana Coastline Contributes to Flooding, *Washington Post*, August 30: A07

[535] http://www.nature.org/wherewework/northamerica/states/louisiana/preserves (accessed June 15)

[536] U.S. Army Corps of Engineers New Orleans District (2004); *op cit*

[537] National Marine Fisheries Service (2007); *Fisheries of the United States 2006*, Fisheries Statistics Division, July.

[538] Kender, E (2005); *op cit*

[539] U.S. Geological Survey (2006); *USGS Reports Latest Land Change Estimates for Louisiana Coast*, USGS News Release, October 3

[540] Burkett, V, D. Zilokoski, D. Hart (undated); *Sea Level Rise and Subsidence: Implications for Flooding in New Orleans, Louisiana*, U.S. Geological Survey Abstract

[541] Kulp, M (2000); *Sand Resources and Shoreline Change Analysis from Point Cheniere Roquille to Grand Bayou Pass: Plaquemines Parish, Louisiana*, National Marine Fisheries Service, TO 40-AA-NF-005575, 24 p.

[542] WWF (2006); Free Flowing Rivers: Economic Luxury or Ecological Necessity? Proj. 2085, February.

[543] Intergovernmental Panel on Climate Change (2001); *Climate Change 2001: Synthesis Report, A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press

[544] Waugh, W and B R Smith (2006); Economic Development and Reconstruction on the Gulf after Katrina, *Economic Development Quarterly*, **20**(3): 211-218.

[545] Burby, R J (2006); Hurricane Katrina and the paradoxes of government disaster policy, *Annals of the American Academy of Political and Social Science*, **604**: 171-191

[546] Lipton, E (2005); On Gulf coast, a conflict over how to rebuild, *The New York Times*; cited in Waugh and Smith (2006), *op cit*

[547] National Oceanic and Atmospheric Administration (NOAA) (2005); *Climate of 2005: Summary of Hurricane Katrina*. NOAA National Climate Date Center, Updated September

[548] Waugh, W and B R Smith (2006); *op cit*

[549] Keller, A and R Blodgett (2005); *Natural Hazards: Earth's Processes as Hazards, Disasters and Catastrophes*, Prentice Hall

[550] http://www.nature.org/wherewework/northamerica/states/louisiana/preserves (accessed 15/6/07)

[551] *Ibid*

[552] Lester, G, S Sorensen, P Faulkner, C Reid, and I Maxit (2005); *Louisiana Comprehensive Wildlife Conservation Strategy*, Louisiana Department of Wildlife and Fisheries, Baton Rouge, 455 pp

[553] Barras, J A (2006); *Land area change in coastal Louisiana after the 2005 hurricanes—a series of three maps*: U.S. Geological Survey Open-File Report 06-1274

[554] Smith, L (2005); Early Assessment of Impacts of Hurricanes Katrina and Rita to Natural Conservancy Lands (TNC-LAOU), October 4

[555] Lester, G, S Sorensen, P Faulkner, C Reid, and I Maxit (2005); *op cit*

[556] Elperin, J (2005); Shrinking Louisiana Coastline Contributes to Flooding, *Washington Post*, August 30: A07

[557] U.S. Army Corps of Engineers New Orleans District (2004); *op cit*

[558] Naqash, A A (2005); Fears for Dwindling Forests in Pakistani Quake Zone, *Reuters*, December 16, 2005 (forests.org/articles/reader.asp?linkid=49578)

[559] Bilham, R, V K Gaur and P Molnar (2001); Himalayan Seismic Hazard, *Science*, **293**:1442-4

[560] UNHCR (2007); *UNHCR Final Report South Asia Earthquake*, Geneva, Switzerland

[561] ibid

[562] Khwendo Kor (Sisters' Home) and Women and Children Development Program (2006); *Hearing their Voices: The Women and Children in the Earthquake Affected Areas of Pakistan*, IUCN Pakistan, Karachi

[563] Pakistan Earthquake Response Key Facts - 28/02/06 – 19/03/06, Oxfam: http://www.unhic.org/usr/ShowContents.aspx?I=1&h=25&sh=-1

[564]http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/0,,contentMDK:21081761~pagePK:146736~piPK:146830~theSitePK:223547,00.html (accessed 20/10/06)

[565] United Nations Office for the Coordination of Humanitarian Affairs and United Nations Environment Programme (2006); *Environmental Emergency Response to the South Asia Earthquake: Consolidated report on activities undertaken through the Joint UNEP/OCHA Environment Unit*, Joint UNEP/OCHA Environment Unit, Geneva, Switzerland

[566] Durran, A J, A S Elnashai, Y M A Hashash, S J Kim and A Masud (2005); *The Kashmir Earthquake of October 8, 2005. A Quick Look Report*, Mid-America Earthquake Center, University of Illinois, USA (http://www.eeri.org/lfe/clearinghouse/kashmir/observ1.php)

[567] Anon (2005); Earthquake highlights ecological assault on the Himalayas, *Daily Times*, Sunday, October 23, 2005, Lahore, Pakistan

[568] Asian Development Bank and World Bank (2005); *Pakistan 2005 Earthquake: Preliminary Damage and Needs Assessment*, Islamabad, Pakistan

[569] Government of Pakistan (2000); *Biodiversity Action Plan for Pakistan: A Framework for Conserving our Natural Wealth*; Government of Pakistan, World Wide Fund for Nature, Pakistan and International Union for Conservation of Nature and Natural Resources, Pakistan.

[570] Asian Development Bank and World Bank (2005); *op cit*

[571] Government of Pakistan (2000); *op cit*

[572] Naqash, A A (2005); Fears for Dwindling Forests in Pakistani Quake Zone, Reuters, December 16, 2005 (http://forests.org/articles/reader.asp?linkid=49578)

[573] WWF (2006); *Proposed new Murree development project: ecological baseline conditions and assessment of ecological significance*, WWF Pakistan

[574] Lyell, C (1853); *Principles of geology; or, the modern changes of Earth and its inhabitants*, London, John Murray, 835 p

[575] Rice, R M (1997); Forest management to minimize landslide risk, in: *Guidelines for Watershed Management*, FAO Conservation Guide, Rome, Italy, 1977. 271-287

[576] EERI (2006); *The Kashmir Earthquake of October 8, 2005: Impacts in Pakistan, EERI Special Earthquake Report – February 2006*, Earthquake Engineering Research Institute, California, USA (http://www.eeri.org/lfe/clearinghouse/kashmir/observ1.php)

[577] Harp, E L and Crone, A J (2006); *Landslides Triggered by the October 8, 2005, Pakistan Earthquake and Associated Landslide-Dammed Reservoirs*: U.S. Geological Survey Open-file Report 2006–1052

[578] United Nations Office for the Coordination of Humanitarian Affairs and United Nations Environment Programme (2006); *op cit*

[579] Naqash, A A (2005); *op cit*

[580] EERI (2006); *op cit*

[581] Anon (2005); Earthquake highlights ecological assault on the Himalayas, *Daily Times*, Sunday, October 23, 2005, Lahore, Pakistan

[582] WWF-Pakistan (2005); Editorial, *Natura*, **31**:4, IUCN Pakistan

[583] IUCN Pakistan (2006); *Earthquake in Pakistan: An Assessment of Environmental Risks and Needs*, IUCN Pakistan, Karachi

[584] ibid

[585] Asian Development Bank and World Bank (2005); *op cit*

[586] IUCN Pakistan (2005); Preliminary Environmental Assessment of the Earthquake in Pakistan: IUCN Field Mission Report, IUCN Pakistan, Karachi

[587] http://news.bbc.co.uk/1/hi/world/south_asia/4385216.stm (accessed 20/10/06)

[588] Asian Development Bank and World Bank (2005); *op cit*

[589] Australian Red Cross (2006) Pakistan Earthquake- One year on, Many survivors still at risk, Press Release, 11 October 2006, www.alertnet.org/thenews/fromthefield/557395/116061008621.htm (accessed 20/10/06)

[590] Anon (2005); *op cit*

[591] Ramsay, W J H (1987); *Deforestation and erosion in the Nepalese Himalaya - is the link myth or reality*? Forest Hydrology and Watershed Management, Proceedings of the Vancouver Symposium, IAHS Publ.no.167

[592] Panikkar, S V and V Subramanyan (1997); Landslide hazard analysis of the area around Dehra Dun and Mussoorie, Uttar Pradesh, *Current Science* **73**: 12, 1117-1123

[593] Montgomery, D R, K M Schmidt, H M Greenberg and W E Dietrich (2000); Forest clearing and regional landsliding, *Geology*, April 2000, 311-314

[594] Dapples, F, A F Lotter, J F N van Leeuwen, W O van der Knaap, S Dimitriadis and D Oswald (2004); Paleolimnological evidence for increased landslide activity due to forest clearing and land-use since 3600 cal BP in the western Swiss Alps, *Journal of Paleolimnology*, **27**:2; 239-248

[595] Kimothi M M and N Juyal (1996); Environmental impact assessment of a few selected watersheds of the Chamoli district (Central Himalaya) using remotely sensed data, *International Journal of Remote Sensing*, 17:7, 1391-1405

[596] United Nations Office for the Coordination of Humanitarian Affairs and United Nations Environment Programme (2006); *op cit*

[597] Durran, A J, A S Elnashai, Y M A Hashash, S J Kim and A Masud (2005); *The Kashmir Earthquake of October 8, 2005. A Quick Look Report*, Mid-America Earthquake Center, University of Illinois, USA (http://www.eeri.org/lfe/clearinghouse/kashmir/observ1.php)

[598] Wyss, M (2005); Human Losses Expected in Himalayan Earthquakes, *Natural Hazards*, **34**:3, 305-314

[599] Asian Development Bank and World Bank (2005); *op cit*

[600] ibid

[601] Anon (2005); An aftershock from Sikandar Hayat! *The International News*, Tuesday October 18, 2005, Pakistan (http://www.pakquake.com/an-aftershock-from-sikandar-hayat.html)

[602] Asian Development Bank and World Bank (2005); *op cit*

[603] ibid

[604] IUCN Pakistan (2006); *op cit*

[605] Government of Pakistan (2000); *op cit*

[606] ibid

[607] IUCN Pakistan (2006); *Cost-Benefit Analysis of Changes in Use of Natural Resources by the Local Communities in the MACP Conservancies: Final draft June 2006*, Mountain Areas Conservancy Project (MACP), IUCN Pakistan, Karachi

[608] http://www.birdlife.org/news/news/2006/03/palas_update.html (accessed 20/10/06)

[609] http://www.palasvalley.org/PCDP/PCDP-overview.htm#loc (accessed 20/10/06)

[610] http://www.palasvalley.org/PCDP/PCDP-overview.htm#loc (accessed 20/10/06)

[611] http://www.birdlife.org/action/ground/palas/index.html (accessed 20/10/06)

[612] http://www.birdlife.org/action/ground/palas/index.html (accessed 20/10/06)

[613] http://www.birdlife.org/news/news/2005/10/palas_devastated.html (accessed 20/10/06)

[614] http://www.birdlife.org/news/news/2005/10/palas_update.html (accessed 20/10/06)

[615] http://www.birdlife.org/news/news/2005/11/palas_update.html (accessed 20/10/06)

[616] World Conference on Disaster Reduction, 18-22 January 2005, Kobe, Hyogo, Japan, Hyogo Declaration, Extract from the final report of the World Conference on Disaster Reduction. (A/CONF.206/6) www.unisdr.org/wcdr, pg 77

[617] International Council for Science (ICSU) (2005); Scoping Group on Natural and human-induced environmental hazards, Report to ICSU General Assembly, Suzhou, October 2005, www.icsu.org/Gestion/img/ICSU_DOC_DOWNLOAD/865_DD_FILE_Hazards_Report_Final.pdf (accessed 10/2/07)

[618] UNEP (2002); *op cit*

[619] http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm (accessed 2/10/06)

[620] http://www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/POIToc.htm (accessed 2/10/06)

[621] http://www.unccd.int/ (accessed 7/7/07)

[622] UN (1994); *Elaboration of an International Convention to Combat Desertification in Countries experiencing Serious Drought and/or Desertification, particularly in Africa*, A/AC.241/27, 12 September 1994

[623] http://unfccc.int/2860.php (accessed 2/10/06)

[624] *Yokohama Strategy and Plan of Action for a Safer World; Guidelines for Natural Disaster Prevention, Preparedness and Mitigation*, World Conference on Natural Disaster Reduction, Yokohama, Japan, 23-27 May 1994, www.undp.org/bcpr/disred/documents/miscellanous/yokohamastrategy.pdf (accessed 2/10/06)

[625] Anon (2007); Press Release - Governments must accelerate their efforts to make disaster risk reduction a national priority, UN/ISDR 2006/01, Wednesday 18 January 2006

[626] World Conference on Disaster Reduction, 18-22 January 2005, Kobe, Hyogo, Japan, Hyogo Declaration, Extract from the final report of the World Conference on Disaster Reduction. (A/CONF.206/6) www.unisdr.org/wcdr

[627] http://www.unesco.org/science/disaster/idrc_davos_conf.shtml and http://www.davos2006.ch/declaration.html (accessed 6/8/07)

[628] http://www.ramsar.org/res/key_res_ix_09_e.htm (accessed 2/10/06)

[629] http://www.cbd.int/2010-target/framework/indicators.shtml (accessed 7/7/07)

[630] WWF (2006); Framework for Monitoring Progress in the Implementation of the Convention and Achievement of the 2010 Target, and Review of the Thematic Programmes of Work (Item 23), Position Paper, 6 March 2006, WWF International

WWF® *for a living planet*®

WWF International

Avenue du Mont-Blanc
1196 Gland
Switzerland

Tel. + 41 22 364 9111
www.panda.org