

THE ROLE OF ENVIRONMENTAL MANAGEMENT AND ECO-ENGINEERING IN DISASTER RISK REDUCTION AND CLIMATE CHANGE ADAPTATION

AUGUST 2008



YMPÄRISTÖMINISTERIÖ
MILJÖMINISTERIET
MINISTRY OF THE ENVIRONMENT

ProAct environmental security
network and climate solutions
for civil society



gaia



ISDR

United Nations
International Strategy for Disaster Reduction

Research and co-ordination for this report was undertaken by ProAct Network – a non-profit international network of environmental professionals and partners that promotes environmental security and solutions to climate change through sound environmental management. Its ultimate objective is to reduce disaster vulnerability and to help minimise the impact of disasters on communities as well as to help ensure that neither peoples’ livelihoods nor the environment are unnecessarily impaired during disaster recovery and rehabilitation. ProAct would like to extend its gratitude to colleagues at the Ministry of Environment, Finland, the UN/ISDR secretariat and the Gaia Group for the opportunity to work together on this initiative.

This report – and accompanying case studies – can be downloaded from www.proactnetwork.org/

THE ROLE OF ENVIRONMENTAL MANAGEMENT AND ECO-ENGINEERING IN DISASTER RISK REDUCTION AND CLIMATE CHANGE ADAPTATION

AUGUST 2008



YMPÄRISTÖMINISTERIÖ
MILJÖMINISTERIET
MINISTRY OF THE ENVIRONMENT

ProAct environmental security
network and climate solutions
for civil society



gaia



United Nations
International Strategy for Disaster Reduction

FOREWORD

The new millennium is still in its infancy, yet within less than a decade, we have witnessed some of the most devastating natural disasters ever recorded in human history. These catastrophic events have once again demonstrated the degree of human vulnerability to natural hazards, bringing into question many of the concrete actions and development schemes put in place, at least in certain countries, to prevent and counteract such events.

Few can seriously doubt that the Earth's climate is changing and changing at a pace that has caught many unprepared. Current predictions suggest that natural hazards – many of which will be climate-related – are expected to increase both in scale, frequency and severity in the coming decades, affecting many different parts of the globe, but affecting some regions worse than others.

There is an urgent need for action – action though that may not be the “business as normal” practice of the past. Examples highlighted in this report show that new wisdom is being applied to current thinking about hard engineered defence systems such as sea walls, levees and riverine canals. These are expensive undertakings in the first instance and often have negative social and environmental consequences, to the extent of even leading people into a false belief that they

are safe behind such barriers. Several recent hurricanes, however, have showed the fragility of such thinking.

Dispensing with such traditional approaches, a new wave of innovation is being quietly practiced in a number of countries, mostly in the northern hemisphere thus far. Recognising the potential benefits of intact or well-managed ecosystems as buffers against natural hazards is slowly gaining recognition. Forests of a certain age, for example, play a vital protective role on steep slopes, protecting against potential landslides and avalanches. Forest vegetation also promotes sub-surface flow paths, thus delaying the travel time of storm flow to streams, reducing the risk of flooding and dissipating flood peaks.

In a similar manner, coastal vegetation, coral reefs and sand dunes can protect against hazards such as wave impact. Natural geological processes such as sedimentation and long-shore drift can be harnessed to encourage the development of barrier islands, providing added protection to vulnerable coastal communities. Wetland ecosystems on floodplains can be managed to reduce the impact of floods and to regulate water flow, while wild fires can be reduced through the establishment of firebreaks and early season burning, as well as the removal of alien invasive species that promote fires because they are themselves fire adapted.

These are but some of a growing list of examples where quantitative, scientific evidence – not anecdotal snippets – based on sound environmental management can be shown to have a positive impact on reducing the scale and occurrence of certain hazards. As this report cautions, however, this approach will not likely be suitable for every instance: there are, and will be, some instances where a combination of hard engineering and eco-engineering can be integrated to provide more appropriate defence systems than what has been the norm so far. This opens up a whole new area of applied planning, management and knowledge learning and sharing.

The report – and a series of accompanying case studies – offers practical and proven approaches that can, in large, be tailored for different situations. This is important if the benefits of what this report highlights are to become shared and used more extensively. Planners and landscape managers must apply their experiences in broader settings, professionals engaged in disaster risk reduction need to converse more closely with climate change and environmental management professionals. Decision-makers too have a vital role to play in highlighting the many advantages that this avenue of easily applied science offers. Even donor organisations have a pivotal role to play in this context in the coming years as innovative means of financing initiatives relating to climate change adaptation and mitigation are increasingly being sought.

The picture, however, will never be complete if adequate and meaningful support is not provided to those most at risk from potential natural hazards, even those who may have recently been exposed to certain disasters since the latter may have no choice but to plunder a protective mangrove forest for wood to reconstruct their houses. Until viable alternatives are found for situations like this, already weakened communities may sadly be exposing themselves to greater impacts when the next disaster strikes.

Vulnerable communities around the world need to be included in the disaster risk reduction dialogue, and enabled to participate in designing and implementing responses. Engaging such stakeholders in environmental management is an ideal opening for such action: many are already doing so and may have done so for generations. The impending shadow of climate change, however, might mean that certain traditional approaches to environmental resilience or livelihood security may not be sufficient to withstand the scale of some recent hazards.

The Ministry of Finland is grateful to ProAct Network and the Gaia Group for having undertaken this review, which is both timely and appropriate to current and forthcoming international debates on disaster risk reduction and climate change. Specific thanks are expressed also to colleagues at UN/ISDR for their input and guidance to the review and to the many professionals who have contributed detailed case studies, highlighting their innovativeness and sharing with us – many for the first time – their findings in relation to environmental management and disaster risk reduction.



Jukka Uosukainen
Director General, International Affairs
Ministry of Environment
Finland

ACKNOWLEDGEMENTS

This review would not have been possible without the generous support of the Ministry of Environment, Finland. Special thanks are also due to Mr Salvano Briceño and colleagues from the International Strategy for Disaster Reduction (UN/ISDR) secretariat for their backing of this initiative.

In compiling this review, case studies were commissioned from a number of international experts from around the world. We hope that the information provided here helps highlight the innovativeness and importance of their work. In this respect, sincere thanks are extended to the following people for their contributions: Professor Roy Sidle, Japan; Professor Maciej Zalewski, Poland; Professor S.S. Hettiarachchi, Sri Lanka; Dr Perry Bartelt, Switzerland; Dr Jeremy Russell-Smith, Australia; Dr Tom Spencer, UK; Dr Iris Möller, UK; Ms Carmen Lacambra S, UK; Mr Daniel Freiss, Dr David Pithart, Czech Republic; Dr Julian Caldecott, UK; Mr Andrew Jones, Australia; and Mr Geoff Lawton, Australia.

The following individuals and organisations are also acknowledged for their added technical and advisory inputs: Dr Charles Ehrhart (CARE International); Mr Neville Ash, Mr Mahmood Akhtar Cheema and Ms Karen Sudmeier (IUCN); Mr Glenn Dolcemascolo (UNEP); Ms Margaret Arnold (ProVention); Dr Alfredo Quarto and Mr Jim Enright (Mangrove Action Project); Dr Saleem Huq (IIED); Ms Jessica Ayers (IIED/LSE); Dr Peter Bebi and Mr Benjamin Zweifel (WSL/SLF); Mr Nyoman Suryadiputra (Wetlands International); Dr Paul Venton, Mr Joachim Saalmuller (WMO); and Mr Patrick Durst and Mr Jeremy Broadhead (FAO).

Co-ordination of this review was led by Ms Nina Saalismaa, with support from Mr Jon Godson, Mr Pasi Rinne and Mr David Stone (ProAct Network) and Mr Juha Vanhanen (Gaia Group). Layout was undertaken by Ms Maoya Bassiouni (ProAct Network).

TABLE OF CONTENTS

FOREWORD	II
ACKNOWLEDGEMENTS	IV
CASE STUDIES	VII
ACRONYMS AND ABBREVIATIONS	VIII
EXECUTIVE SUMMARY	1
1. REDUCING THE RISK OF DISASTERS AND ADAPTING TO CLIMATE CHANGE	5
1.1. INTRODUCTION	5
1.2. NATURAL HAZARDS, CLIMATE CHANGE AND MULTIPLYING DISASTERS	6
1.3. THE BENEFITS OF INTACT OR WELL-MANAGED ECOSYSTEMS	8
1.4. POTENTIAL FUNDING FOR DISASTER RISK REDUCTION AND CLIMATE CHANGE ADAPTATION	11
2. THIS REPORT	14
2.1. BACKGROUND TO THE REPORT	14
2.2. BASIS OF THE REPORT	15
3. SEVERE STORMS	16
3.1. OVERVIEW	16
3.2. CASE STUDY: TROPICAL COASTAL ECOSYSTEMS AS DEFENCE MECHANISMS	17
4. TSUNAMI	20
4.1. OVERVIEW	20
4.2. CASE STUDY: DISASTER MITIGATION AND PREVENTION THROUGH RESTORATION OF LITTORAL VEGETATION, SRI LANKA	21
5. EARTHQUAKES	23
5.1. OVERVIEW	23
5.2. CASE STUDY: STRENGTHENING DECISION-MAKING TOOLS FOR DISASTER RISK REDUCTION, NORTHERN PAKISTAN	24
6. LANDSLIDES AND AVALANCHES	26
6.1. OVERVIEW	26
6.2. CASE STUDY: SLOPE STABILITY: BENEFITS OF FOREST VEGETATION IN CENTRAL JAPAN	26
6.3. SNOW AVALANCHES	28
6.4. CASE STUDY: QUANTIFYING THE PROTECTIVE CAPACITY OF FORESTS AGAINST SNOW AVALANCHES, SWITZERLAND	29
7. FLOODING	31
7.1. OVERVIEW	31
7.2. CASE STUDY: MANAGED RE-ALIGNMENT AND THE RE-ESTABLISHMENT OF SALTMARSH HABITAT, UK	32
7.3. CASE STUDY: ECOSYSTEM SERVICES OF A FLOODPLAIN WITH A PRESERVED HYDROLOGICAL REGIME, CZECH REPUBLIC	34

8.	FIRE	37
	8.1. OVERVIEW	37
	8.2. CASE STUDY: WEST ARNHEM FIRE MANAGEMENT AGREEMENT, AUSTRALIA	38
9.	DROUGHT AND DESERTIFICATION	40
	9.1. OVERVIEW	40
	9.2. CASE STUDY: PERMACULTURE IN THE JORDAN VALLEY	41
	9.3. CASE STUDY: SAND STORMS	42
10.	CONCLUSIONS AND RECOMMENDATIONS	44
	GLOSSARY	47
	BIBLIOGRAPHY	51

CASE STUDIES

The following case studies were commissioned specifically for this report. Full texts can be downloaded from www.proactnetwork.org/ Reference to materials in any of the studies should credit this report and specifically the author(s) of the respective case studies.

Tropical Coastal Ecosystems as Defence Mechanisms

Prepared by Carmen Lacambra, Dr Tom Spencer, Dr Iris Moeller, Cambridge Coastal Research Unit, University of Cambridge, UK

Disaster Mitigation and Prevention through Restoration of Littoral Vegetation, Sri Lanka

Prepared by the Mangrove Action Project

Strengthening Decision-making Tools for Disaster Risk Reduction, Northern Pakistan

Prepared by IUCN Pakistan

Slope Stability: Benefits of Forest Vegetation in Central Japan

Prepared by Dr Roy Sidle, Disaster Prevention Research Institute, Kyoto University, Japan

Quantifying the Protective Capacity of Forests against Snow Avalanches, Switzerland

Prepared by Dr Perry Bartelt, SLF, Switzerland

Managed Re-alignment and the Re-establishment of Saltmarsh Habitat, UK

Prepared by Daniel Friess, Dr Iris Möller, Dr Tom Spencer, CCRU, Cambridge University, UK

Ecosystem Services of a Floodplain with a Preserved Hydrological Regime, Czech Republic

Prepared by Dr David Pithart, Academy of Sciences, Czech Republic

West Arnhem Fire Management Agreement, Australia

Prepared by Tropical Savannas CRC, Australia

Permaculture in the Jordan Valley

Prepared by Permaculture Research Institute of Australia

Sand Storms

Prepared from a literature review by ProAct Network

ACRONYMS AND ABBREVIATIONS

AdMit	“Adaptation with a mitigation component”
CBD	Convention on Biological Diversity
CCA	Climate Change Adaptation
CDM	Clean Development Mechanism
CO ₂	Carbon dioxide
DRR	Disaster Risk Reduction
GEF	Global Environment Facility
GHG	Greenhouse gas
Ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
ISDR	International Strategy for Disaster Reduction
JVP	Jordan Valley Project
km ²	Square kilometre
m	Metre
MitAd	“Mitigation with an adaptation component”
Mw	Moment magnitude
REDD	Reducing emissions from deforestation and forest degradation
tCO ₂ e	Tonnes of carbon dioxide equivalent
UNFCCC	United Nations Framework Convention on Climate Change
UN/ISDR	Secretariat of the International Strategy for Disaster Reduction

EXECUTIVE SUMMARY

Extreme weather events, driven largely by rising global temperatures, are increasing in both their frequency and impact. In the coming years, climate change is expected to further increase the severity and frequency of weather-related natural hazards such as storms, intense rainfall, floods, droughts and heat-waves. From 1997 to 2006, more than 2.6 billion people were affected by hazards mostly related to weather extremes, causing over 1.2 million deaths and damage costing some US\$800 billion. Future predictions are that this situation is likely to worsen.

While most of society is likely to be affected to some degree by the predicted changes, it is likely that the brunt of these climate-related impacts will be borne by already vulnerable communities, particularly the poor and marginalised groups who may depend largely on farming and marine resources for their livelihoods, and who may live in areas already prone to recurrent disasters such as flooding or cyclones.

Traditional efforts to protect people and physical installations from disasters have tended to involve 'hard' engineering solutions such as dams, levees and the construction of sea walls. These have proved to be very expensive and, in certain cases at least, have not worked as well as expected, often with unforeseen negative consequences. In addition to the cost and the environmental damage some cause, they also have a tendency to create an over-reliance on these physical structures which, should they fail, can have catastrophic results.

The past few years have witnessed an increasing interest in finding alternative means to reduce the threats by and impacts from many natural hazards, promoting instead environmental sustainability and security. As such, attention has focussed on the use of 'soft' or ecological engineering approaches, in which natural ecosystems or artificially assisted planting provide the structure for defence, instead of shifted rocks, steel fabrications or poured concrete.

This report by ProAct Network and Gaia Group reviews a growing body of evidence that sound environmental management has a potentially important role to play in reducing many of the risks posed by natural hazards. Many ecosystems – if they are intact and/or well managed – act as natural, dynamic barriers that absorb the force of certain hazards, protect vulnerable communities and their

assets while at the same time preserve local biodiversity and encourage ecological productivity. Natural ecosystems thus play an important protective and productive role in many instances.

Such measures are potentially inexpensive – though restoring degraded ecosystems is much more expensive than maintaining them in the first place – are environmentally friendly, have significant social and economic benefits and have the added benefit of absorbing and storing greenhouse gases. This last point means that climate change funds could, in principle, provide opportunities to advance disaster risk reduction. Some insurance schemes have also begun to provide lower premiums for those communities that preserve or enhance ecosystems.

This report provides an overview of practical experiences that deal with environmental management in relation to climate change, disaster risk reduction and climate change adaptation. It is essentially a collection of field data and literature that has a highly practical flavour, highlighting the multiple benefits that adaptation can offer. The report is not a policy statement but it is anticipated that its findings will serve as a useful platform for further discussions, forthcoming international negotiations and policy development, as well as inspiring uptake of some of the practices at a more localised level. This report should therefore be seen as a first stage of ongoing work and deliberations with a number of key partners.

In documenting this information, specific sections of this report are devoted to a selection of natural hazards, each of which provides an initial overview of the hazard's characteristics and global significance. A series of case studies then provide specific first hand accounts of how different environmental management and eco-engineering techniques have been tried and tested under different conditions and situations – although to date with an emphasis on developed countries. Nonetheless, it is anticipated that through highlighting the practicality and versatility that engineers and planners can apply to eco-engineering approaches, the rich information contained in this report can and will be replicated elsewhere.

While emphasis is placed on the use of environmental management and eco-engineering in this report, the findings below also caution that in some instances there might well still be a need for at least some complementary form of hard engineering, as well as locally tailored early warning systems. Opportunities for combining these complementary approaches should be further explored in the future.

The main recommendations of this review (see Section 10 for a more detailed description) are as follows.

Actively promote **ENVIRONMENTAL MANAGEMENT AND ECO-ENGINEERING AS PRACTICAL AND APPROPRIATE MEANS OF DISASTER RISK REDUCTION:**

- ★ Recognise that many traditional forms of hard defences will not be able to cope with the growing threats from climate change.
- ★ Acknowledge those initiatives that have replaced hard engineered structures with naturally functioning ecosystems.
- ★ Invest further in site- and hazard-specific research – particularly where vulnerable communities and regions can already be identified – to determine how communities might become more involved in and responsible for environmental management as a natural buffer.

- ★ Promote the protective role of intact and well management ecosystems, using available tools and mechanisms including United Nations conventions, regional co-operation agreements and ongoing development programmes

In response to the current **LACK OF AWARENESS AND UNDER-USED POTENTIAL OF NATURAL BUFFERS:**

- ★ Sensitise policy-makers and donors on the measurable adaptation and mitigation effects of well-managed ecosystems.
- ★ Actively promote natural buffers and other soft protection measures – not as new technologies, but technologies and approaches that may simply need to be adjusted to local conditions and requirements.
- ★ Encourage and enable technology transfer so that a medley of best practices and lessons learned can be tailored and applied to specific situations.
- ★ Give particular attention to supporting national and local actions that link disaster risk reduction and climate change adaptation agendas, highlighting the added potential for social and economic benefits.

Acknowledging the **MULTIPLE BENEFITS OF ENVIRONMENTAL MANAGEMENT AND ECO-ENGINEERING FOR CLIMATE CHANGE ADAPTATION AND DISASTER RISK REDUCTION:**

- ★ Utilise lessons from this report in negotiations for a post-2012 climate agreement, including the formulation of an inclusive and equitable climate change adaptation scheme.
- ★ Develop practical guidance on advancing climate change adaptation through ecosystem and environmental management.
- ★ Engage in policy development at the national and international levels to take full advantage of the climate change adaptation and mitigation potential of environmental management.
- ★ Give greater recognition to the cost-effectiveness of eco-engineering approaches – including the social, economic and environment-related services attached with this – in national accounting.
- ★ Provide added incentives for environmental management measures that also have the potential to both reduce disaster risk, help adapt to climate change and capture CO₂.

To develop **CLIMATE FUNDING POTENTIAL:**

- ★ Explore financing opportunities through climate change funding in order to facilitate implementation of disaster risk reduction projects combining adaptation with mitigation.
- ★ Conduct an in-depth assessment of potential financial mechanisms from climate funds, including the potential engagement of the private sector for environmental management as an approach to climate change adaptation.

In order to **BROADEN STAKEHOLDER ENGAGEMENT:**

- ★ Enhance the establishment of communities of practice on natural buffers in disaster risk reduction should be enhanced. This will foster a network of professionals who can help build capacity, engage stakeholders in a dialogue and assist in technology transfer on issues relating to disaster risk reduction.

Encourage and support those **PRACTICAL ACTIONS THAT NEED TO BE TAKEN IN RELATION TO PLANNING AND MANAGEMENT:**

- ★ Development interventions by international and national agencies need to enhance the defensive capacities of ecosystems rather than degrade them. This should include appropriate elements of awareness raising and introducing viable alternative prevention and reconstruction options, such as using environmentally appropriate construction materials.
- ★ Implement pilot projects in some of the most vulnerable areas, with the full inclusion of local communities.
- ★ Reconstruction after a disaster places high pressure on important ecosystems, such as mangrove forests: post-disaster reconstruction needs to be ecosystem-sensitive.

To address the **NEED FOR ADDITIONAL RESEARCH AND MONITORING:**

- ★ Support additional research into environmental management, the broader potential use of ecosystem goods and services and, in particular, further evidence of quantitative data in relation to ecosystems and their role in disaster risk prevention and reduction.
- ★ Support long-term monitoring – currently almost non-existent – on the use and management of natural buffers, ensuring also that disaster risk reduction monitoring is integrated within ecosystem projects.
- ★ Broaden the geographic coverage of research in order to understand better local specificities.
- ★ Establish a clearing mechanism to make relevant information more readily available and applicable, providing information on technologies, costs, performance, availability, implementation requirements and so forth.

Acknowledging that **ENVIRONMENTAL MANAGEMENT IS NOT AN ALL-ENCOMPASSING SOLUTION:**

- ★ Encourage and enable technology transfer and dialogue between planners and practitioners from the hard engineering and eco-engineering domains.
- ★ Provide incentives for the systematic integration of natural buffers with other risk management components, such as early warning systems and awareness raising.
- ★ Monitor future joint applications and provide lessons learned for broader dissemination.

1. REDUCING THE RISK OF DISASTERS AND ADAPTING TO CLIMATE CHANGE

1.1. INTRODUCTION

As a species we are adapted to conditions that have prevailed within the biosphere over the past few hundred thousand years. As a global human population, however, our own adaptation has largely been to prevailing conditions over the past 500 years or so. That this has been a spectacular “success” so far is shown by the sudden and rapid growth in our numbers to become the most abundant large mammal that has ever existed on Earth.

But, having multiplied towards seven billion people, we now find that prevailing conditions within the biosphere are starting to change. Having adapted to one set of conditions we – like any other species faced with change – are becoming vulnerable. Among the causes of such change is the fact that every year we have been burning at least one million years’ worth of stored solar energy in the form of fossil fuels. If this was not damaging enough, we have compounded the situation by ruthless over-exploitation and consumption of diverse natural resources, damaging most of the biosphere’s constituent ecosystems through over-exploitation, pollution and wanton waste.

The consequences of our actions pose risks to all of humanity, but particularly to those people who live in already vulnerable circumstances and locations. The burning of fossil fuels for energy and the unrelated increase in global forest fires, in particular, have released vast quantities of greenhouse gases such as carbon dioxide (CO₂) into the atmosphere. In addition to causing health concerns, this traps solar energy on Earth and causes global warming. A warmer globe means warmer oceans which, in turn, changes climate and destabilises weather patterns to promote storms, droughts and floods at new and unpredictable times, scales and places, thereby undermining human security. Through its influence on disaster risk, climate change now also poses an additional challenge to our efforts to make a secure world where people might enjoy better and more equitable living conditions.

The causes of the disasters we witness have been painfully clear for at least half a century. The means to resist them and repair at least some of the damage being caused are now being sought with increasing urgency. This publication offers a menu of options on how to address disaster risk reduction (DRR) and climate change adaptation (CCA) from an environmental management perspective. The experiences described in the following sections are drawn from a small,

global body of expertise on this subject. Their observations should be considered and accompanying recommendations implemented as an appropriate means of addressing the real threat posed by climate change through effective, cost-efficient and environmentally and socially appropriate actions.

1.2. NATURAL HAZARDS, CLIMATE CHANGE AND MULTIPLYING DISASTERS

Natural hazards are phenomena that may threaten human interests – our lives, health, livelihoods, dwellings, investments and transportation and communication links. They may manifest themselves with or without warning, suddenly or slowly, briefly or persistently. Some are linked with meteorological events but others may be geophysical or biological in origin.

Such hazards are hard to classify in an unambiguous way since they often overlap and interact. An earthquake, for example, can cause a landslide, tsunami and/or avalanche (see Section 5), but it may also be associated with a volcanic eruption. Similarly, a storm can result in landslides, flooding, wave surges and wind damage.

Human activities can aggravate or even create hazards. Excessive watering of agricultural lands in arid conditions can deplete aquifers and result in a build-up of salts in the soil, causing a long-term collapse in agricultural production. Clear felling of forests or overgrazing in catchments can precipitate landslides and floods, while inappropriately sited and constructed roads and trails can exacerbate disaster risk during earthquakes, landslides, floods and tsunamis.

This report examines a selection of hazards that have the potential to cause disasters – intense, widespread and significant damage to the interests of large numbers of people and

the broader environment. These are examined from the point of view of how environmental management can be used to reduce the potential of each type of hazard to trigger disasters among vulnerable populations, which is the essence of DRR in a dangerous and changing world.

The majority of the hazards described are climate related – climate change can cause severe adverse impacts to all terrestrial, wetland and coastal ecosystems – but this is not intended as an exhaustive review. Changes in rainfall patterns over vast areas of continents, disrupted agricultural systems, an increased range of disease vectors and coastal areas rendered vulnerable to inundation by the sea are just some of the phenomena experienced to date. Such changes have and will continue to adversely affect the poor and the marginalised who depend largely on farming and marine resources for their livelihoods: some may even become environmentally displaced persons (Oxfam, 2007 a, b).

Extreme weather events driven by rising global temperatures are increasing in both their frequency and impact (IPCC, 2007a). Climate change is expected to further increase the severity and frequency of weather-related natural hazards such as storms, intense rainfall, flooding, drought and heat waves. From 1997-2006, disasters affected over 2.6 billion people, causing over 1.2 million deaths and damage costing some US\$800 billion (EM-DAT, 2007). Most of these disasters were related to weather extremes (EM-DAT, 2007; ISDR, 2008).

Likely impacts of climate change vary from one location to another. In densely populated, low-lying regions of tropical Asia, for example, they include increased and/or more intense rainfall, increased vulnerability to irregular river flows due to glacial melting, more frequent and/or more severe cyclonic storms, and increased inundation and salt intrusion to surface and ground waters due to a rise in sea level (IPCC, 2007b; EC, 2006).

On a global scale, areas most vulnerable to climate change are small island developing states, sub-Saharan Africa, the polar regions and many of the world's large deltas (IPCC, 2007b; Huq and Ayers, 2007). The delta regions of major rivers are exceptionally vulnerable to rising sea levels, from the combined effects of higher high tides, from more penetrating storm surges, saltwater intrusion, erosion of land by the sea, and from the congestion of river drainage that causes rivers to back up and flood. This special vulnerability applies to regions that are home to hundreds of millions of people (UNDP, 2007), for example in Bangladesh (Ganges/Brahmaputra delta), Burma (Irrawaddy delta), Egypt (Nile delta), Nigeria (Niger delta) and Vietnam (Mekong delta). Climate change and natural hazards also seriously challenge the ability of many countries to meet the targets associated with the Millennium Development Goals (Yohe et al, 2007; MEA, 2005).

Recognising some of these perilous linkages, the Fourth Assessment Report of the UN Inter-governmental Panel on Climate Change concluded in its Summary for Policy-makers that: "Adaptation to climate change will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions" (IPCC, 2007b). The Stern Review on the Economics of Climate Change further confirmed that "Adaptation is the only response available for the impacts that will occur over the next several decades before mitigation measures can have an effect" and that "Adaptation efforts in developing countries must be accelerated and supported, including through international development assistance" (Stern, 2006).

Adaptation is essential also within the broader context of sustainable development, since there are important links between CCA, DRR and development, in general (UNFCCC, 2006; IPCC, 2007b). Climate change threatens vital development issues such as water supplies, food security, human health, the availability of essential natural resources and protection against natural hazards. The adaptive capacity of

countries and communities – often limited by a lack of resources, poor institutions and inadequate infrastructure – is relevant both for CCA and sustainable development.

In view of the increased climate-related risk, the secretariat of the International Strategy for Disaster Reduction (ISDR) stresses the need for integrating DRR management into development and adaptation strategies. International DRR efforts are guided by the Hyogo Framework for Action – adopted in 2005 by 168 governments – which emphasises the importance of DRR in the context of climate change and calls on countries to work for integrated DRR measures through five "Priorities for Action" (ISDR, 2007, 2007; UNFCCC, 2007a) which are to:

- ★ ensure that DRR is a national and local priority with a strong institutional basis for implementation;
- ★ identify, assess and monitor disaster risks, and enhance early warning;
- ★ use knowledge, innovation and education to build a culture of safety and resilience at all levels;
- ★ reduce underlying risk factors; and
- ★ strengthen disaster preparedness for effective response at all levels.

The Hyogo Framework also calls for the integration of DRR and CCA through risk information sharing and use by policy-makers and planners, and the mainstreaming of DRR measures into development assistance programmes, including those relating to adaptation to climate change.

1.3. THE BENEFITS OF INTACT OR WELL-MANAGED ECOSYSTEMS

TRADITIONAL DISASTER RISK REDUCTION AND CLIMATE CHANGE MITIGATION

People have long experimented with ways to reduce the vulnerability of vital assets. In modern times, this has tended to take the form of engineering solutions to protect valuable infrastructure and agricultural land from predictable, recurrent hazards. Dams and levees have been used to control rivers and prevent floods, for example, while stone terraces have been used to stabilise slopes and concrete sea walls have been built to shield coastal areas from storm surges. Such measures, however, have not always worked as well as expected, with some unwanted and unintended effects. Straightened and constrained rivers, for example, can actually accelerate the flow of water and cause flooding downstream, while sea walls may alter the pattern of coastal erosion and deposition, and create new threats elsewhere (see Section 7 of this report for further details).

When hard engineering structures such as dykes and dams fail they can have catastrophic consequences. Extensive flood protection and water control structures in the Mississippi river basin, for example, have reduced sediment transport to the delta (Moench et al, 2007), contributing to a loss of wetlands and land area to the sea. Evidence suggests that this change in itself contributed to the devastating impact of Hurricane Katrina in 2005. New Orleans' flood protection levees area were designed to withstand Category 3 storms, but when a Category 5 storm occurred the failure of the levee system caused massive damages and loss of life, partly because people had invested there under the assumption that the levees would protect them.

As questions are increasingly being asked as to why such systems have failed to protect people and their investments from the hazards they were designed to withstand, a growing body of interest is looking to alternative approaches to achieve the same, or better, results – with less resources and more sustainability, and with fewer environmental drawbacks.

Growing recognition is now being given to “soft” or “ecological engineering”¹ options, in which attention is given to sound environmental management as a form of structural defence, instead of steel fabrications, poured concrete or shifted rocks. Limited, but increasing, evidence now shows that good environmental management can play an important – and cost-effective – role in reducing many of the risks posed by natural hazards. In many cases – as the research summarised in this report and accompanying case studies demonstrates – healthy ecosystems can and do act as natural, dynamic barriers that protect vulnerable communities and foster local biodiversity and ecological productivity.

Compared with hard-engineered alternatives, such measures can be relatively inexpensive, can help to support or enhance livelihoods by sustaining ecological production, and have the added benefit of absorbing and storing greenhouse gases, highlighting the link between CCA measures and climate change mitigation. Some National Adaptation Programmes of Actions have already identified priority climate adaptation projects that are related to DRR and climate mitigation, but the full potential of the opportunities this presents have not yet been realised. Indeed the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) points out that “policy-makers have only recently expressed interest in exploring inter-relationships between adaptation and mitigation” (Klein et al, 2007). Given its importance, however, this link with funding is also explored

¹ *Soft engineering/soft protection* refers to the use of natural structures while *hard engineering/protection* refers to man-made structures in DRR. Note the difference to *soft technology* (knowledge) and *hard technology* (tools, production systems); and *soft* (risk management) and *hard* (physical) *DRR investments*.

in this report (Section 1.4), including how carbon markets could, in principle, provide opportunities to advance DRR – a subject that has to date received relatively little attention.

Natural or Artificial?

A coastal mangrove forest that has been defoliated or partially destroyed by a storm surge will regenerate naturally, while a concrete sea wall will require costly repair work when broken.

A buffering coastal forest allows a portion of a wave to pass through the vegetation with its force gradually attenuated, while a solid wall may be broken apart, lifted up, or overtopped.

Harvested forests on steep terrain that are allowed to regenerate rapidly – through planting or natural regeneration – minimise the period when these sites are susceptible to landslides, as the period of low root strength is only about 15 years.

ENVIRONMENTAL MANAGEMENT FOR PROTECTION AGAINST NATURAL DISASTERS

In addition to their significant social and economic roles, ecosystems, such as mangroves, salt marshes, beach vegetation, seagrass beds and coral reefs are effective buffers against many coastal natural hazards (MEA, 2005). They reduce the magnitude of storm surges and related inundation by absorbing storm energy, reducing flow depths and velocities, and holding sediments in place within root systems. Barrier islands formed by off-shore drift and sedimentation can also offer efficient protection against storm surges and waves. A study of degrading barrier islands in Louisiana, USA, showed that adjacent bays would experience a 700 per cent increase in average wave height if the barrier chain was lost (Stone and McBride, 1998). In the same state, a US\$14 billion wetland restoration programme – “Coast 2050” – aims to protect more than 10,000km² of marsh, swamp and barrier islands, the latter in particular being recognised as the state’s first line of defence against storm surge generated by hurricanes (Bourne, 2000).

The economic value of mangrove forests as coastal defences is considerable. In Malaysia, for example, this role is valued at US\$300,000/km, based on the cost of hard engineering work that would be required to do the same job (Ramsar Convention, 2005). In Vietnam, the planting and protection of 12,000ha of mangroves by the Red Cross cost around US\$1.1 million, but helped to reduce the cost of sea dyke maintenance by US\$7.3 million per year (IFRC, 2002). According to the Millennium Ecosystem Assessment, the value of healthy coastal mangrove ecosystems as nurseries, pollution filters and coastal defences is around US\$1,000/ha, five times their value as prawn ponds (MEA, 2005).

Social and Economic Benefits

In addition to their protective role, ecosystems such as mangroves are also highly productive and of considerable economic benefit to many communities. Mangroves for example can yield an annual harvest per hectare of 100kg of fish, 20kg of shrimp, 15kg of crabmeat, 200kg of mollusc and 40kg of sea cucumber. More than 70 other uses for mangrove products have been documented worldwide, ranging from palm-sugar and honey to tannin and water-resistant poles.

Many coastal and wetland ecosystems have, however, suffered widespread damage and conversion over the past several decades, and their buffering capacity is seriously threatened in many parts of the world. Although major projects to replant mangroves have been initiated in a number of countries, including Thailand, Vietnam, Indonesia, Bangladesh and India, naturally diverse and fully mature mangroves are now scarce, and at least one-third of the coral reefs in the world have already been destroyed. Like damaged mangroves, degraded reefs do not offer the same level of protection as healthy ecosystems.

(References: Pye-Smith and Feyerabend (1994); Hamilton and Snedaker (1984); Ramsar Convention (2005))

In a similar way to mangroves, forests in potential avalanche release areas can reduce the risk of avalanches because trees break up snow cover, prevent wind-blown snow drifts, keep snow under shade and therefore colder and firmer, and their fallen boles and boughs tend to anchor snow and prevent it from moving. The

estimated economic value of forests in preventing avalanches ranges from around US\$100 per hectare per year in open expanses of land in the Swiss Alps to more than US\$170,000/ha/year in areas where valuable assets might be at risk (Bebi, P. Pers. Comm).

The valuable protection offered by ecosystems has now been acknowledged by some governments, and is gradually being factored into national DRR programmes. This is especially true of mountain and coastal ecosystems, the latter particularly since the Indian Ocean tsunami of 2004. This trend is more noticeable in Asia than in Africa and Latin America, however, suggesting a continuing weakness of the international community in promoting and sharing vital knowledge.

Natural protection structures are dynamic and – as long as they are in a healthy and intact state – should be able to adapt to changing conditions such as rising sea levels and local climatic changes. It would be wrong, however, to give the impression that in today's world of competing needs and interests that all is well in relation to the status and health of critical ecosystems. If an ecosystem such as a mangrove forest is to perform its appreciated role, then it must be maintained to a high degree of its original status, otherwise its protective role could well be compromised.

In drawing attention to the above protective services and functions, however, it must also be noted that in certain instances a natural buffer alone will not be capable of preventing some degree of destruction. Once an avalanche has been released and has gained sufficient momentum, neither downhill forests nor artificial protective structures may be able to stop its flow. Likewise, some of the areas most heavily impacted by the Indian Ocean tsunami would at best have received only limited protection from any natural and mechanical buffer, such was the force and magnitude of that event.

Overall, however, given the increasing magnitude of climate change impacts, hard protection structures are not likely to prove viable for the extensive area where protective structures

are needed. Increasing risks cannot be managed solely by building ever-bigger hard-engineered defences, especially in developing countries where the need for DRR is most pressing and resources scarce. At the same time, not every challenge can be met through soft engineering. Combining the two approaches to differing extents is likely to prove the most attractive option in coming years, with the balance perhaps shifting more and more towards soft engineering options and practices as approaches and experiences become better monitored, recorded and appreciated.

USE OF ENVIRONMENTALLY APPROPRIATE PRODUCTS

In addition to maintaining and promoting healthy ecosystems, a range of environmentally appropriate products can also be used to minimise slope failure and soil erosion, for example, by providing structural support. Geotextiles – permeable fabrics that have the ability to separate, filter, re-inforce, protect or drain soils and shallow bedrock – can also be used for surface protection, normally as a temporary support to promote vegetation establishment. Fabrics made from polypropylene or polyester dominate the current geotextile market, which is estimated at US\$2.25 billion annually. Natural geotextile fabrics with similar properties are also available, however, and are often cheaper than synthetics. Natural fabrics made of materials such as coir, jute, hemp, reed and flax account for about 15 per cent of the market (Smith, 2000). These natural geotextiles later degrade to form organic mulch, further encouraging plant growth and soil improvement. Their manufacture and installation may also provide support to local livelihoods.

Natural mats and blankets can be used to minimise soil erosion from embankment, gullies and channels and can be impregnated with seeds or have saplings planted into them for quick establishment of vegetation. Environmentally appropriate products can also be used to provide structural support to vulnerable slopes, including river banks. Slopes can be stabilised by the

harvesting and planting of dormant cuttings and branches arranged in individual stakes (live stakes) or bundles – fascines, brushlayer and brush-mattresses. Slopes can also be stabilised using crib walls with timber beams placed in squares to form boxes, which are then filled with soil and layers of living branches planted at shallow angles. Wattle fences can also be used to retain topsoil and in shallow waters be used to encourage sediment deposition.

Environmentally Appropriate Products vs Hard Engineering

Severe erosion to the tidal river bank adjacent to the Monk Bretton Bridge at Rye, UK, threatened to breach the flood embankment, thus exposing residential properties to life threatening two-metre deep tidal flooding. Hard engineering solutions had been considered for a number of years as the problem developed. However, tidal flows at the site are particularly high and access for undertaking the work was extremely difficult. Project risk from both a technical and health and safety perspective were high.

Brushwood mattresses have been traditionally used in the UK and elsewhere as a method of silt entrapment to protect river banks and structural foundations on soft ground. Working with Cain Bio-Engineering Ltd, a brushwood mattress was developed and installed to provide a soft engineered solution. The project cost was estimated to be 40 per cent of the cost of a hard engineering solution that would have involved sheet piling and rock revetment.

Within six months of completion the mattress had accreted by approximately two-thirds, and the tidal embankment is no longer at risk of scour and collapse. The scheme was recognised by the Institute of Civil Engineers with the Brassey 2005 Environment Award.

(Source: http://www.cainconsultancy.co.uk/case-studies/case_study.php?case=9 (accessed 15 April 2008))

Bamboo is an abundant material in many parts of Asia and has long been used for a variety of engineering purposes, including the re-inforcement of earth structures. By incorporating horizontal layers of bamboo re-inforcement the shear resistance of the soil/fill is increased to

provide additional resisting moment to counteract the sliding moment (Ingold, 1982). Bamboo is also used for stilts to raise houses above flood levels. Contoured log terraces/barriers have also been used to impede avalanche and rock falls. Finally, straw wattles and mulch have been used to minimise soil erosion and floods in Colorado, US, following forest fires (Baxter, 2001).

Although environmentally appropriate products have a limited role in reducing disaster risks directly, they provide a cost-effective means of enabling and supporting the establishment of vegetation, which in turn stabilises slopes, protects riverbanks, and helps minimise soil erosion and run-off. Their additional role in terms of stabilisation as form of DRR should therefore not be overlooked.

1.4. POTENTIAL FUNDING FOR DISASTER RISK REDUCTION AND CLIMATE CHANGE ADAPTATION

CLIMATE CHANGE ADAPTATION FUNDS

The United Nations Framework Convention on Climate Change (UNFCCC) secretariat has estimated that by 2030 developing countries will require US\$28-67 billion to enable adaptation to climate change, and globally tens of billions, possibly US\$100 billion per year are needed for adaptation (UNFCCC, 2007a). Other studies also estimate adaptation costs at tens of billions of dollars per year (Oxfam International, 2007), but only a small fraction of these funds are currently available for adaptation, and procedures for accessing them are lengthy and complex (UNFCCC, 2007a). The Kyoto Protocol's Adaptation Fund, for example, is intended to fund CCA activities in developing countries but by May 2008, had approximately US\$46 million available².

² Calculated on the basis of 2.9 million CER credits with an average price of US\$16. <http://cdm.unfccc.int/Issuance/SOPByProjectsTable.html> (accessed 20 May 2008)

Bilateral contributions for adaptation are thought to have amounted to about US\$100 million per year in 2000–2003. Other financial resources available for adaptation include funds managed by the Global Environment Facility (GEF) Trust Fund, the Least Developed Countries Fund and the Special Climate Change Fund. As of August 2007, these GEF-UNFCCC funds collectively amounted to about US\$275 million. It is clear, however, that there remains a serious deficit in the amount of funding available for adaptation (UNFCCC, 2007b). Quite how funding will be used is also uncertain, but this report would encourage greater consideration be given to environmental management and its role in DRR and CCA.

CARBON MARKETS

As noted above, and in the following sections, ecosystems can be used and/or managed to reduce a number of risks in a changing climate. Note should again also be taken of the connection between the buffering capacity of natural systems and climate change mitigation. While mitigation projects are helping to finance revegetation schemes around the world, the majority do not harness the additional benefits of DRR that natural systems can offer³. The potential is there, however, for natural systems to offset CO₂ emissions and provide barriers to natural hazards.

Climate change mitigation funds are currently dominated by carbon markets based on the 2008–2012 compliance period of the Kyoto Protocol. According to the World Bank's Carbon Finance Unit (Capoor and Ambrosi, 2007), 374 million tonnes of carbon dioxide equivalent (MtCO₂e) were exchanged through projects in 2005, a 240 per cent increase relative to 2004 (110 MtCO₂e).

³ Some exceptions include CARE's Mi Bosque project in Guatemala, which is helping restore forests in poor hillside communities for carbon sequestration, livelihoods and hazard protection (http://www.careclimatechange.org/careclimatechange.org/carbon_for_poverty_programming_/land-use/land-management), and climate change mitigation/avoided deforestation through wild fire management, as explained in Section 8 of this report.

The voluntary carbon offset market is also growing and is projected to reach a value of about US\$4 billion by 2010 (Harvey, 2007). The voluntary mechanism is more accessible to small-scale projects as it has lower transaction costs while also offering greater flexibility. Among the main contributors to voluntary carbon offset funds are private corporations seeking to demonstrate to customers and employees that their operations “do no harm”, and to develop “green” marketing opportunities. Some such corporations are increasingly looking to invest in carbon offset projects that not only reduce greenhouse gas emissions but also have a social component, including DRR.

Under the Clean Development Mechanism (CDM) of the Kyoto Protocol, within the forestry/vegetation sector, only afforestation and reforestation projects are considered: few afforestation projects have been accepted so far. The CDM is only feasible for large-scale projects which makes it unsuitable for many DRR initiatives, though some discussion is underway to a mechanism in the post-Kyoto agreement to compensate countries for reducing emissions from deforestation and forest degradation (REDD).

While direct funding for adaptation should be increased, climate change mitigation funds could provide an additional source of funding for adaptation activities. What is needed is more flexible and transparent funding mechanisms that can meet several mutually beneficial goals.

OTHER SOURCES

Current funding options under the climate-umbrella offer only a limited opportunity for soft protection measures. New and innovative mechanisms need to be explored⁴. Countries such as Costa Rica have developed mechanisms to pay for environmental services such as keeping forests intact and reforesting degraded areas, or protecting important watersheds. First introduced in 1996, payments to participating

⁴ A follow-up to this report is expected to be an in-depth review of barriers to such funding opportunities.

landowners in Costa Rica now range from US\$210-537, the former figure being an annual payment while the latter was a lump sum provided in yearly instalments over a five-year period (Sanchez-Azofeifa et al, 2007). In the United States, for example, flood-prone communities that implement environmental management schemes such as wetland and dune preservation can now benefit from lower insurance premiums.

2. THIS REPORT

2.1. BACKGROUND TO THE REPORT

This report was compiled in response to a major gap in awareness and knowledge concerning the positive role that intact and/or well-managed ecosystems might play in reducing the impact of specific natural hazards. When research and initial data collection started, it was assumed that a wealth of credible, proven scientific knowledge would be available, documenting how and why different ecosystems had – or perhaps had not – functioned as a means of hazard prevention or reduction. This, however, was not to be the case.

Instead, it was found that while indeed there is a certain amount of quality scientific research that can be applied to the argument of environmental management and DRR – as opposed to the more common tendency of hard structured engineering options – this was quite fragmented and dissipated. Published information was available in some select journals, but knowledge of this was limited to a small part of society. Moreover, there was a tendency for people working in this field to focus primarily on their own area of specialisation, which meant that there has been relatively little knowledge sharing of how different environments and environmental management conditions and systems might operate in a wider setting.

This report is intended to highlight a range of some of the best practices that have been developed, applied and tested in field conditions in relation to a number of natural hazards. As such, its findings are primarily intended for planners and field practitioners, people who might benefit from the wealth of proven experiences described in the following sections. At the same time, however, it is anticipated that decision-makers and funders too will benefit from the examples cited below, and that these will to some degree influence future decisions in relation to the choice of intervention taken.

Several governments have already recognised the important social and economic benefits of maintaining healthy environments. The protection role of mangrove and alpine forests, for example are highlighted in the legislation of Malaysia and Switzerland, respectively. Many other countries have also started to take into account the significant role that coastal and floodplain ecosystems, for example, have to play in national security. This growing movement of interest and action is encouraging and it is anticipated that the highlights from the selected natural hazards in the following chapters will add to this growing realisation of the many positive contributions that well managed ecosystems can play in relation to DRR and prevention.

2.2. BASIS OF THE REPORT

The report features an overview of some of the main forms of natural hazards currently experienced, many of which are expected to increase in both frequency of occurrence and scale of impact in coming years as a result of climate-related change. On the basis of documented information available, the chosen topics for this review are:

- ★ Severe storms (Section 3);
- ★ Tsunami (Section 4);
- ★ Earthquakes (Section 5);
- ★ Landslides and avalanches (Section 6);
- ★ Floods (Section 7);
- ★ Fire (Section 8); and
- ★ Drought and desertification (Section 9).

While the order in which these topics are addressed in this report is random, the actual selection of topics is not arbitrary. It reflects: a) recognition that these disasters are responsible for the majority of natural hazards recorded in recent decades; b) proactive anticipation that many of these phenomena are likely to become more common and serious threats in the future; and c) examples where scientific evidence can document tangible, empirical evidence of where some form of sound environmental management can and has played a role in reducing the impact of a specific natural hazard. The latter was a deliberate choice in preparing this report, since much anecdotal evidence exists in relation to certain ecosystems performing some form of service in reducing or mitigating impacts of an ad hoc natural hazard.

The primary purpose of compiling this review was to gather the best available scientific knowledge on this topic from as many credible sources as possible, with a view to presenting this to key audiences, in particular field practitioners such as project planners and managers, as well

as decision-makers at government level and donors.

The report is not a policy statement but it is anticipated that its findings will serve as a useful platform for further discussions, forthcoming international negotiations and policy development, as well as inspiring uptake of some of the practices at a more localised level. The knowledge described in the following sections urgently needs to be disseminated to more people working at the planning and environmental management levels. This report should therefore be seen as a first stage of ongoing work and deliberations with key partners.

This report is based on extensive desk research, supported with a series of commissioned case studies from world leading experts⁵. The majority of the examples cited below come from developed countries, which in itself is significant. Far greater emphasis needs to be given to highlighting the findings and lessons learned from the examples highlighted in the following chapters. Equally, knowledge sharing needs to increase among those scientists and practitioners who are at the forefront of promoting environmental management as a means of disaster prevention and reduction in light of climate change.

In addition to the above-mentioned specific thematic areas, attention is also drawn to two other issues, both of which have significant potential to add to this debate, both of which are currently largely overlooked. These are the potential uses of natural ecosystem goods and services as means of DRR (and recovery in some instances) and the significant potential for funding for natural buffers through, for example, CCA funds.

⁵ The full collection of case studies is available on www.proactnetwork.org/

3. SEVERE STORMS

3.1. OVERVIEW

Severe storms (cyclones, hurricanes, typhoons, and the like) are areas of low atmospheric pressure surrounded by inward-spiralling winds. Over warm seas, these can pick up energy and water vapour to become powerful, rotating, moving storms.

Such storms vary considerably in scale and intensity. They are even referred to in different ways in different parts of the world. Storms with sustained wind speeds of over 120km/hour are known as hurricanes in the north-eastern Pacific and north Atlantic, typhoons in the north-western Pacific, tropical cyclones in the south-western Indian Ocean, and severe cyclonic storms in the northern Indian Ocean and Bay of Bengal (Caldecott and Karim, 2008). Even stronger storms – with sustained wind speeds of over 220km/hour – are called Category 4 or 5 hurricanes, super typhoons, very intense tropical cyclones or super cyclonic storms, in the respective regions.

These sprawling, spinning storms can create huge waves that can easily drown ships at sea, but the worst outcome is when a hot, high-energy hurricane with extremely fast winds, a huge

burden of cloud-water and a massive internal dome of sea-water impacts upon a settled coast. Although it will quickly slow down over land by shedding its energy, it does this by blasting against the land surface causing vast damage.

Some 80 tropical cyclones form on warm oceans every year and potentially threaten locations inhabited by nearly a quarter of the world's population (Dilley et al, 2005). The most frequently hit areas are in the western Pacific, southern Africa, the Caribbean, the south-eastern USA and the Bay of Bengal. Although many people are killed during hurricanes by wind and the impact of wind-borne objects – and many more by landslides and debris flows that may be unleashed by days of intense rainfall – more dangerous in many cases are storm surges (Nicholls, 2005). These fast-moving, turbulent waves can be 7m or more deep, topped by high waves driven by strong winds. Anyone caught in such an event is at serious risk of drowning: some 200,000 people are believed to have died in this way as a result of Cyclone Nargis – coupled with a lack of warning and preparation – in the Irrawaddy delta in 2008 (Telegraph News, 2008).

3.2. CASE STUDY: TROPICAL COASTAL ECOSYSTEMS AS DEFENCE MECHANISMS⁶

BACKGROUND

More than 60 per cent of the world's population is concentrated in coastal areas or areas influenced by the dynamics of a coastal climate. This figure is likely to increase in coming decades with predicted world population growth. Coastal hazards too are expected to intensify both in frequency and magnitude in the future. As a result of these two phenomena, the number of people likely to be affected by climate-change related incidents such as flooding in coastal areas is expected to affect some 180 to 230 million people.

This literature review of mangrove forests and coral reef ecosystems largely focuses on research conducted on the sea defence value of coastal ecosystems from South-east Asia. While other regions have expressed concern for the state of different coastal ecosystems, the role that such ecosystems play in coastal protection is often neglected, both in research and natural hazard mitigation strategies.

MANGROVE FORESTS

Mangroves are distributed along low energy areas of the tropical and sub-tropical shorelines of the world. Their most distinctive characteristic is their capacity to tolerate tidal flooding, long periods of saltwater inundation and high salinity. Mangroves are often located on deltas or estuaries. While not completely dependent on fresh water, they grow and develop better in the presence of some fresh water.

The coastal defence role performed by mangroves has long been recognised, but became even better appreciated following the 2004 Indian Ocean tsunami. Despite this recognition, wave and wind processes occurring in a mangrove forest during a particular event are still poorly researched and concern has been expressed that many restoration processes are being developed without fully understanding a particular area's coastal dynamics and potential hazards.

Key conditions or attributes thought to relate to the sea defence capacity of mangroves⁷ include:

- ★ Stand width: Several reports from Asia describe a minimum required width for a mangrove forest to serve as an effective buffer, this – not surprisingly – varying from one setting to another. In the Philippines, for example, a green belt of 20m may act as a “general” buffer zone, but may need to be increased to a width of around 50m in storm-prone areas. Storm protection measures in Vietnam's Mekong Delta, include a mangrove belt of between 500m and 1,000m wide, while in Malaysia, a regulation from the 1950s requires a 200m mangrove belt to be established before structures protecting agricultural land.

Mathematical models have also been developed to predict optimal stand width, based on on-site measurements, observations on the importance of width dispersing wave energy and best options for ecosystem management. Conclusions tend to differ with regard to the most appropriate species, ecosystem stem density and the area's physical characteristics, but values for an optimum width range are from 100–1,500m.

- ★ Stand density: This condition is based on the physical basis that the greater the friction a wave encounters the greater the energy that will be dispersed. Several authors consider the

⁶ Summarized from a case study prepared by Carmen Lacambra, Dr Tom Spencer, Dr Iris Moeller, Cambridge Coastal Research Unit, University of Cambridge, UK. and which can be downloaded from www.proactnetwork.org

⁷ Data compiled from: Alongi, 2008; Barbier et al., 2008; Cochard et al., 2008; Danielsen et al., 2005; Eong, 2005; Ewel et al., 1998; Hadi et al., 2003; Hiraishi and Harada, 2003; Iverson and Prasad, 2007; Kerr et al., 2007; Latief and Hadi, 2008; Macintosh and Ashton, 2005; Massel et al., 1999; Mazda et al., 1997, 2006; Otham, 1994; Quartel et al., 2007; Siripong et al., 2005; Tanaka et al., 2007 and UNDP, 2007.

mangrove's density and complex structure to be very important, based on direct observation, on-site measurements, or mathematical models. Density is closely related to the age and size of trees, but different species of mangrove do induce different drag forces.

★ **Stand structure:** This includes all those ecosystems characteristics involved with species composition and distribution, specimen age and size distribution and general structure of the system. Ecosystem structure may be important not only for its role in coastal protection but also for practical purposes, such as giving people something to physically hold onto, as evidenced in the South Asian tsunami of 2004. Other important aspects include distance to shore, vegetation type and structure, habitat fragmentation and exposure.

★ **Species:** Vegetation type has been correlated to the mangrove's capacity to reduce wave energy. In Malaysia, for example, a 50m band of *Avicennia* is sufficient to reduce a wave of 1m height to just 0.3m. Other reports state that a 100m buffer of *Sonneratia* forest can reduce wave energy by up to 50 per cent. Simulation models of the South Asian tsunami show that the most resistant – that with the highest drag forces – species were *Pandanus odoratissimus*, and *Rhizophora apiculata*. This research also concluded that a mosaic of different species was the most desirable as different species have features, growth patterns and strengths, thereby creating different levels of resistance. Some authors additionally note that *Rhizophora* species create greater friction to waves than species without pneumatophores.

★ **Age:** The age of mangroves relates to the size of trees, their diameters and roots, which are also related to stem density and species. Bigger and older trees, however, are more resistant to wave damage. Some authors have particularly related mangrove tree size and age to the ecosystem's capacity to attenuate tsunami waves.

★ **Height:** there are mixed interpretations of the importance of tree height, particularly because the friction caused by ground vegetation, roots and trunk diameter decreases towards the higher canopy. Most of these interpretations, however, are related to a particular source of force or disturbance. Taller trees seem to suffer greater damage from wind, although taller mangrove trees also seem to be more resistant to wave energy. According to some sources, bottom friction – provided by roots and pneumatophores – is less relevant with deeper water or greater wave height. Under such circumstances vertical configuration of leaves and their resistance starts play significant roles in wave energy dissipation.

CORAL REEFS

A reef's capacity to protect shorelines from storms by dissipating wave energy depends on the local reef profile – in particular its depth, slope and shelf width – the degree of reef continuity and its area. In addition, the outer structure of the reef and the topographical variation along the reef can also influence wave dispersion. Broad reef terraces dissipate greater energy than narrow ones, hence wide reefs are likely to produce narrower beaches and wider beaches are normally found behind narrower reefs.

The protective role of coral reefs is more evident during storm events than tsunami, although reports from the Indian Ocean tsunami describe that in areas fringed by coral reefs, run-up waves were only 2-3m high and reached 50m inland, whereas in areas without coral reefs the highest waves were 10m and penetrated 1.5km inland. The most common coral reef attributes impacted by natural disturbance are highlighted below⁸:

★ **Water depth,** which affects the impact of a disturbance on the reef. The greater the water depth, the lower the impact on the reef. Equally, the depth of a reef plays an important

⁸ Data compiled from: Barbier et al., 2008; Brander et al. 2004; Cochard et al., 2008; Salazar-Vallejo, 2002; Sheppard et al., 2005; Sudmeier-Rieux et al., 2006; UNEP-WCMC, 2006; Woodley, 1992 and Woodley et al., 1981.

role on its capacity to protect the coast. Water depth also influences the propagation of waves along the reef, while the same concept applies to prevailing tides.

★ Focus has also centred on distance from the centre of the storm event as another key condition that may influence a reefs' capacity to protect a shoreline, as well as the impact on the reef itself and its capacity to respond and recover. Prior to Hurricane Mitch, the distance from which an event might cause severe damage to branching corals was thought to be around 65km. During Mitch, however, coralline ecosystems almost 1,000km from its origin were severely damaged.

★ Different species have a different resistance to currents and wave energy. Species located at the reef front resist greater wave energy than those located along the more sheltered lagoons and coral platforms.

CONCLUSIONS

In addition to a range of often unrecognised goods and services provided on a day-to-day basis, coral reefs, mangrove forests and other coastal ecosystems not described here do perform important roles and services in coastal protection at a time of natural disturbances. The complexity of these situations is often not realised but it is essential that any environmental management or mitigation programme involving ecosystems such as reefs or mangroves as a tool to protect communities from coastal hazards should be designed in accordance with each area's slope, topography, bathymetry (seafloor topography), drainage, coastal sediment dynamics and their interactions with other ecosystems.

Evidence also shows that some species respond differently to different disturbances, but that no single species can be used as a response to all natural disturbances in coastal areas. Some species are more resistant to wind or waves than others, but there may still be a need to foster and encourage growth of those less resistant species since they may be needed to accelerate the ecosystem regeneration process.

4. TSUNAMI

4.1. OVERVIEW

Tsunami are waves caused by the sudden displacement of water. These, often catastrophic, events are usually induced by underwater earthquakes but may also be caused by volcanic eruptions and landslides into or beneath the water surface. On average, about eight tsunami of magnitude greater than 6.5Mw are recorded each year, at least 80 per cent of which begin in and around the Pacific Basin (International Tsunami Information Centre, 2008).

Exceptionally powerful earthquakes can, however, also generate a tsunami that travels many thousands of kilometres. The most recent such example was the Indian Ocean Tsunami of 26 December 2004, the “great Andaman-Sumatra earthquake” off north-western Indonesia, which had ramifications as far away as the eastern seaboard of Africa. Total fatalities from this incident alone around the Indian Ocean may have been as high as 300,000 people, about 10 times more than the average annual mortality rate from tsunami worldwide (EM-DAT, CRED, 2007). Even the average figure, however, highlights that tsunami are a major hazard for people living in low-lying coastal areas, in and around regions of unstable geology.

Unlike storm surges, the initial impact of a tsunami can be overwhelmingly devastating as enormous quantities of water are suddenly deposited on land. Like storm surges, people and infrastructures are submerged under vast amounts of water and debris. Salt contamination can reach far inland, affecting groundwater reservoirs and agricultural lands for years thereafter. If this were not enough devastation, the reverse drainage of water and collected debris back to sea after a tsunami can be nearly as destructive to property and lives as the initial advance of the wave.

The Indian Ocean Tsunami of 2004 focused much new attention on the role of coastal ecosystems in mitigating environmental hazards (Kathiresan and Rajendran, 2005; Tanaka et al, 2007; Danielsen et al, 2005; and Dahdouh-Guebas et al, 2005). A resulting workshop aimed at bridging gaps in knowledge and resolving debate on the role of coastal forests concluded that coastal forests – if well designed and managed – can provide significant protection against tsunami and storm waves, mainly by dissipating wave energy and force, reducing flow depth and velocity, thereby reducing the area inundated with dangerous waters (Forbes and Broadhead, 2007; FAO 2006). Trees can also provide refuge and an anchor for people who might have been swept

away, but also trap debris that would otherwise swirl around and cause further damage (Tanaka et al, 2007).

4.2. CASE STUDY: DISASTER MITIGATION AND PREVENTION THROUGH RESTORATION OF LITTORAL VEGETATION, SRI LANKA⁹

BACKGROUND

Almost one-third of Sri Lanka's 20 million people live in the coastal zone, where environmental degradation has been widespread over the past several decades. Further ecological, economic and social damage was experienced as a result of the 2004 tsunami, to a certain extent because many of the country's natural sea defences had been overly exploited, degraded and weakened and been left far more vulnerable to sea level rise and storm inundation than in prior history.

As a result of the 2004 tsunami, 40 per cent of the mangroves in the Panama lagoon system were badly damaged, while mangrove and associated vegetation cover were also lost from lagoon shorelines in the Turkkovil lagoon system. This has led to increased coastal erosion which has at the same time been exacerbated by local resource exploitation. In response, the government and its Central Environment Authority started to promote a "Green Belt" along the coastline, an initiative to restore mangroves and other coastal vegetation along the lagoon shores and nearby beaches, now piloted by the Sewalanka Foundation.

OBJECTIVES

Working with communities in Panama and the Turkkovil lagoon systems, the project aims to enhance the adaptive capacity of local communities to extreme climate events and sea level rise through interventions such as land-use zoning and community management, and restoration of degraded littoral vegetation. With assisted regeneration, mangroves and beach vegetation should have re-grown enough to offer significant coastal protection within a 10-year period, while the accretion of sand and sediment should make a significant difference within 15 years.

ACTIVITIES

Nurseries have been set up in both project locations and nursery managers trained and employed. Seeds and propagules are collected from the surrounding area or from other communities if there is a lack of local seeds. Planting only occurs in the correct hydrological zone where there is a lack of propagules which would limit natural regeneration. Planting is also intended to speed up the recover process to provide dense mangroves sooner.

LIMITATIONS

A number of limitations are recognised in relation to the use of mangroves for DRR in Sri Lanka, notably that:

- ★ The mangrove ecosystem comprises of fringing mangroves which – as the tidal range is very low, between 0.4 and 0.6m – typically extend only 10-25m before soils change and more terrestrial vegetation takes hold. The natural zone for mangrove establishment is therefore very limited.
- ★ Due to irrigation practices, there is increased freshwater run-off that affects mangroves in some areas.

⁹ Summarized from a case study prepared by the Mangrove Action Project and which can be downloaded from www.proactnetwork.org

- ★ Planted vegetation needs to mature before it is able to offer significant DRR and storm attenuation services.
- ★ Due to the lack of alternative livelihood options – in part a result of the ongoing conflict in the region – local communities are heavily dependent on natural resources, including mangroves. This dependence could lead to future degradation of mangrove and beach vegetation through over-harvesting. However, in view of the participatory nature of the project and the interest of local communities in improving the coastal vegetation, ongoing community capacity building and environmental education work is likely to minimise such risks.

5. EARTHQUAKES

5.1. OVERVIEW

Earthquakes are mostly caused by the release of energy when the surface plates of the Earth's crust rub together. They are also associated by subterranean events linked to volcanic activity. Impacts of the sudden energy released by an earthquake include shaking, ground rupture, landslides/avalanches and soil liquefaction, a process in which soil loses its strength due to shaking, and becomes a 'heavy liquid'.

Worldwide, some 1.2 billion people live in areas at risk to serious earthquakes – places with a 10 per cent probability of peak ground acceleration of at least 2m/s^2 . Areas of relatively high hazard are the western coast of the USA, Central America, the western coast of South America, southern Europe, Turkey, Iran, central Asia, south-west China, Nepal, Taiwan, Japan, the Philippines and New Zealand (Dilley et al, 2005). Earthquakes – and tsunamis caused by them when they occur beneath the sea bed – killed nearly 400,000 people and affected 40 million others in 1997-2006, and caused US\$120 billion worth of damage (EM-DAT, CRED, 2007). The 2004 Indian Ocean tsunami alone accounted for over 200,000 deaths. Another 70,000 people were killed in the May 2008 earthquake in the Chinese provinces of Sichuan, Gansu and Shaanxi.

Apart from the physical collapse of buildings and other structures – which can be minimised only through proper siting and seismic-safe design and construction methods – earthquakes cause most damage indirectly, through landslides and tsunamis. The June 2008 Tohoku earthquake in Japan, which measured 7.2 on the Richter scale, triggered numerous large, damaging landslides, including one with a total estimated volume of 70 million cubic metres (Sidle, 2008). Mitigation of hazards such as these is discussed below in a Case Study from Pakistan which examines how mountain forest degradation contributed to landslide susceptibility during an earthquake in 2005.

5.2. CASE STUDY: STRENGTHENING DECISION- MAKING TOOLS FOR DISASTER RISK REDUCTION, NORTHERN PAKISTAN ¹⁰

BACKGROUND

The 8 October 2005 earthquake in Northern Pakistan, measuring 7.6 on the Richter scale, led to around 73,000 deaths and left hundreds of thousands of people without adequate shelter and food to survive the harsh winter. An estimated 90 per cent of the buildings were either damaged or completely destroyed. Many landslides – possibly several thousand – were also triggered, affecting a large number of communities in surrounding mountain valleys. Landslides still remain the greatest threat to communities during heavy rainfalls, especially in the monsoon.

A project supported by the International Union for the Conservation of Nature (IUCN) attempted to profile the effects of disaster, the aim being to strengthen decision-making tools by identifying the main land-use factors and strategies that affect the vulnerability of communities in the valley.

OBJECTIVES

The aims of the study were to: (a) identify and analyse the damage and loss caused by landslides; (b) examine natural- and human-induced land-use factors related to landslides in the valley; (c) estimate the role of forests as natural barriers to landslides; and (d) examine community land-use strategies that impact the vulnerability of communities.

¹⁰ Summarized from a case study prepared by IUCN Pakistan and which can be downloaded from www.proactnetwork.org

LOCATION

The epicentre of the earthquake was in the Neelum valley towards the north of Muzaffarabad, the capital city of Azad Jammu and Kashmir (AJK). AJK, with an estimated population of 3.5 million, is considered a separate state under indirect control by Pakistan. This is a crowded region with a population density of 264 persons/km². Eighty-eight per cent of the population are rural and depend heavily on natural resources such as forests for fuelwood and construction timber, as well as grazing and water. Agriculture and livestock keeping are key livelihood options and income supplements for a major part of the population. Approximately 42 per cent of AJK has forest cover, while 13 per cent is under cultivation. Most lowland forest is either destroyed or degraded as a result of clearance for domestic use, grazing or commercial logging.

FINDINGS

This study confirms the hypothesis that landslide occurrence is higher on steep slopes, and close to rivers, trails and fault lines, depending to some degree also on the geology. It also showed the positive role of forests in decreasing the risk of landslides. In addition to natural factors, human interference also aggravates such disasters.

Key findings were as follows:

- ★ damage in the lower Neelum Valley was calculated around US\$1 million, excluding damage to the power supply, which alone amounted to US\$3.5 million;
- ★ a majority of the landslides surveyed were due to human-induced factors, especially deforestation and grazing, poor terracing, housing built on exposed slopes and road construction;
- ★ numerous crack zones appeared which now constitute a major risk factor when it rains; and

★ while many survey participants were aware of the need to drain water away from cracks and landslides, few examples of such drainage were observed.

CONCLUSIONS AND LESSONS LEARNED

In many developing countries, the underlying causes of landslides are linked with economic development, poverty and resource degradation. This study demonstrated a strong link between vegetative cover, land ownership and management regime, terracing, road construction and debris flows. There is a clear need for policies to integrate resource management into DRR strategies, to raise awareness and provide incentives for private owners to plant and maintain more vegetation. Plans for new roads need to include improved location, proper grading and locally adapted techniques for slope stabilisation such as vegetative mesh matting combined with soil stabilising plants. The role of protective forests – clearly recognised in some mountainous European countries – should be examined as cost-effective natural barriers to help reduce the likelihood of landslides. The AJK Forest Department is now promoting biological measures for controlling landslides.

6. LANDSLIDES AND AVALANCHES

6.1. OVERVIEW

Landslides are mass movements of soil and debris down a slope, while avalanches are a similar phenomenon involving snow. Both types of hazard can be initiated by rainfall, earthquakes, volcanic eruptions and human activities. About 3.7 million km² of land worldwide is susceptible to landslides, representing a risk to a population of nearly 300 million people (Dilley et al, 2005).

Landslides, including avalanches, killed over 8,000 people in 2006, affected 2.6 million and caused about US\$1.5 billion in damage (EM-DAT, CRED, 2007).

Vegetation cover has an important role to play in landslide prevention, mainly because roots reinforce and stabilise soil layers on steep terrain. Dense, deep-rooted trees and shrubs are most effective in minimising mass soil movements (FAO, 2006; Sidle and Ochiai, 2006). Vegetation cover can especially prevent the occurrence of shallow landslides (< 1-2m deep), while deep-seated landslides (> 5m deep) on steep terrains are less influenced by vegetation cover. Certain types of vegetation can also have an adverse effect on slope stability. Unstable trees, for example, can initiate a landslide under high wind conditions, but such cases are rare.

6.2. CASE STUDY: SLOPE STABILITY: BENEFITS OF FOREST VEGETATION IN CENTRAL JAPAN¹¹

BACKGROUND

A clear understanding of the benefits of woody vegetation and the conditions under which it can and cannot stabilise hill slopes is essential for planning revegetation projects in unstable areas, and managing existing forests in a sustainable manner. What has been lacking is a long-term perspective on the effects of forest cutting and regeneration on slope stability within an area of similar geology, soils, and climate. In this example, landslides are examined over a 40-year period in a relatively small, unstable catchment in central Japan. This case study is unique because the soils, lithologies, rainfall, vegetation pattern and slope conditions are very similar throughout the catchment. Ninety-five per cent of the area has been harvested for timber production at various times within smaller sub-catchments, with accurate records dating back to 1912.

¹¹ Summarized from a case study prepared by Dr Roy Sidle, Disaster Prevention Research Institute, Kyoto University, Japan and which can be downloaded from www.proactnetwork.org

OBJECTIVE

The main objective of the project was to quantitatively assess the effects of different forest stand ages on landslide frequency and sediment production from landslides. Associated with this is the application of knowledge gained to other forest management systems.

LOCATION

This study was conducted within the 8.5km² Sanko catchment, in south-western Nara Prefecture, central Japan. Soils are shallow Cambisols, typically ranging from 0.5-1m in depth. The entire area is owned by Sanko Forestry and has been continuously managed since 1912. Since then, only clear-cut harvesting has been practiced within this catchment, with replanting typically occurring 1-2 years after logging. About 95 per cent of the catchment has been converted to Japanese cedar (sugi), with minor amounts of Japanese cypress (hinoki). The remaining area comprises secondary broadleaf forests, forest roads and log storage areas. Both the sugi and hinoki forests are managed on rotation intervals of about 80 years. The region therefore has a unique mosaic of different ages of regenerating forest stands – representing different periods of clear cutting – that have experienced a wide range of rainfall conditions.

FINDINGS

Total landslide volume per unit area in forests that were harvested from 0-25 years prior to aerial photo identification was 4.5 times higher than similar landslide volumes in clear cuts that were greater than 25 years old. Thus, the effects of clear cutting in these sugi and hinoki forests appear to disappear within 25 years after harvesting, with increasing root strength of the regenerating stands. Assuming that landslides frequencies and sediment supply rates from landslides in forests older than 25 years represent recovered conditions, a ratio of increase can be calculated for the most susceptible period – 1-10

years after clear cutting – for different landslide volume classes.

The largest increase in both landslide frequency and sediment supply rates occurred for landslides smaller than 100m³ (7.5 and 7 fold, respectively), while the smallest increases in the first 10 years after clear cutting were observed for landslides larger than 200m³ (3.4 and 2.5 fold increases, respectively). Thus, it is apparent that trees provided the greatest stability benefits against smaller landslides. Since such landslides are the most numerous worldwide, this is an important benefit of forest vegetation in controlling sediment releases in catchments.

For all landslide size categories combined, the ratio of landslide frequency between forests 1–10 years in age and those 26–40 years in age was 6.3; this ratio was 4.2 for sediment supply rate. The frequency of landslides was also assessed for different slope gradient categories in both recently clear cut (1–10 years previously) forests and older (26–40 years ago) clear cuts. These findings showed large increases in landslide frequency in younger clear cuts for all slope gradient categories, especially on slopes steeper than 30°.

This example clearly shows that forest cover can reduce landslide erosion by a factor of 4-5 compared with sites that lack substantial tree root strength. These benefits appear to be primarily associated with reducing the frequency of smaller landslides. The original stability of the steep land which has been deforested can be regained by re-establishing forest cover and through the gradually build up of soil organic matter to prevent surface erosion and runoff. Once forests are successfully established on such lands, it is then possible to manage them to support local incomes.

Findings also have important implications for sediment hazard reduction in unstable areas where forest cover has been converted to other vegetation types with weaker rooting systems, for example, pasture, agricultural crops or exotic plantations. Such cases are currently prominent

in parts of South-east and East Asia, Africa and Latin America. Such land conversion scenarios have great impact on landslide susceptibility in steep terrain compared with careful and long-term planning of forest harvesting.

CONCLUSIONS AND LESSONS LEARNED

It is clear that forest cover provides the most effective protection against shallow landslides compared with other types of vegetation. Forest cover can be maintained with careful management objectives that allow land owners to derive economic benefits from the forests. The benefits of forest cover related to deep-seated landslides are not so great, except possibly in the tropics. In the present situation, older forest vegetation with mature root systems reduced landslide erosion and sediment delivery to streams by 4-5 fold compared with young forests with little root strength. Reported differences would be even greater for scenarios where forests in similar terrain were converted to agricultural crops or exotic plantations with little root strength. The effects of the latter would in addition persist as long as the converted vegetation was in place, not the 3-20 year window of susceptibility typical of managed forests. Substantial benefits can therefore be achieved by reforestation of steep terrain that has already been converted to cropland or exotic plantations.

6.3. SNOW AVALANCHES

OVERVIEW

Snow avalanches are an abrupt and rapid flow of snow – often mixed with air, ice, water and surface soil – down a mountainside. They are phenomena of high, snow covered mountain areas and locations immediately downhill from them. Typically an avalanche will occur during or after a large snowstorm, the main triggers being a

slope of 25-50°, heavy snow cover, instability in the snow layer, and an external impact such as stepping or jumping on the snow.

While mountain slopes may not be densely populated, lower-lying settlements, roads, bridges, railway networks and other infrastructure and services are vulnerable to avalanches. In this context, each year the winter sports industry brings – temporarily – millions of people into avalanche-prone areas. The number of avalanche-related deaths worldwide, however, is not precisely known since many occur in places with poor communications and press coverage such as the Andes, Himalayas, Urals, Caucasus, Altai and Tien Shan. Adding known deaths per year in Europe, North America, Japan and New Zealand (160) with known casualties on mountaineering expeditions (10-20) to estimates from elsewhere (100-200) gives a total of 270-380 deaths per year on average (Meister, 2002; Eidg. Institutes für Schnee- und Lawinenforschung Weissfluhjoch, n.d.). There are, however, exceptional avalanches that have killed thousands of people – such as the destruction of the town of Yungay, Peru in 1970, where at least 18,000 people were killed following a rockfall/landslide triggered by an avalanche (Wikipedia.org, 2008).

The role of forests in avalanche protection and/or reduction has long been recognised in Europe's alpine countries. In Switzerland, for example, protection forests have been recognised in the federal forest law since 1876, which specifies three groups of forest functions: protection, social benefit and production. Management of protective forests attracts federal incentive payments (Brassel and Lischke, 2001) which amounted to US\$45 million in 2006 (Baltensweiler and Hallenbarter, 2007). While recognition is given to the fact that forests offer an efficient and inexpensive multiple hazard protection – and because of this forests are managed to help protect against rock fall, landslides, debris flows and avalanches (Swiss Federal Office for the Environment, 2008) – to protect critical infrastructure, protection forests in Switzerland are used in combination with hard structures that prevent the triggering of avalanches.

6.4. CASE STUDY: QUANTIFYING THE PROTECTIVE CAPACITY OF FORESTS AGAINST SNOW AVALANCHES, SWITZERLAND¹²

BACKGROUND

In October 2004 the Swiss Federal Office for the Environment requested the Research Institute for Forest, Snow and Landscape Research to develop a method to quantify the protective capacity of mountain forests against avalanches. Results were to be used to estimate the economic value of mountain forests and would serve as a basis to distribute federal funding to the Cantons (states). The project was part of a much larger attempt by the government to assess the function of mountain forest against all gravitational driven mountain hazards, including rock falls and hydrologically driven movements such as debris flows and shallow landslides.

METHODS

The Swiss government divides mountain forests into those with 'primary' and 'normal' defence functions. For a forest to be classified as 'primary', it must contribute to reducing danger in a location with a potential avalanche release zone that poses a significant threat to people and/or infrastructure. To identify 'primary' protection forests, the project had to resolve three fundamental problems in natural hazard research:

- ★ The 'disposition' problem required that a method be developed to determine the location and size of avalanche release zones, based on slope (25° in non-forested terrain, 30° in forested areas). A GIS-application

was developed to combine forest cover with a digital terrain model, and refined to select smaller zones for avalanche paths with frequent avalanche activity.

- ★ The 'flow' problem required damage potential to be modelled predictively, using advanced finite volume techniques based on the specification of appropriate friction coefficients which determine the avalanche velocity and final run out distance. In Switzerland these parameters are based on back-calculations with observed and documented avalanche events. At the present state of knowledge, the parameters are selected based on terrain, avalanche size (return period) and starting zone elevation.

- ★ The 'validation' problem required that seven test regions were selected to represent Switzerland's different climatic regions, in each of which historical avalanche data were used to test the models. The Cantonal authorities judged the quality of the results by comparing historical observations to model simulations. The quantitative comparisons were restricted to regions with a large and well documented damage potential (housing, roads and railway lines).

Finally, two different calculation scenarios were used in the SilvaProtect project. In a first step, starting zones in forested regions were removed. Inundation areas were calculated with the numerical model. Then, in the next step, the starting zones in forested areas were included in the calculations, i.e. the calculations were performed as if the forest did not exist. The difference between the two scenarios provided an estimate of the protective capacity of the forest.

FINDINGS

One of the primary aims of the SilvaProtect project was to develop a uniform method to determine the protective capacity of mountain forests over a large area: in this case an area greater than 25,000km² was simulated. The initial conditions of the simulations were to

¹² Summarized from a case study prepared by Dr. Perry Bartelt, SLF, Switzerland and which can be downloaded from www.proactnetwork.org

a large extent automatically generated and therefore a uniform procedure was applied to a large, diverse area. The quality of the results was judged by local experts employed by the Cantons, not the programme developers. In general, the simulation results were in good agreement with the observed or historical avalanche data.

While the main goal of this initiative was achieved it also highlighted certain limitations as outlined below.

- ★ Avalanches are complex phenomena that contain a variety of flow forms (dry, wet, powder). The SilvaProtect project assumed dry, flowing avalanches. Another important assumption was that the avalanches did not entrain additional material during their downward descent. For a particular avalanche track such aspects need to be reviewed critically.
- ★ Because a large area was covered, detailed information concerning individual starting zones was lost. Application of the model to smaller areas or for single avalanche tracks would require detailed information of the track climate, terrain and vegetation.
- ★ Defining the correct initiation scenarios is critical. For example, in the SilvaProtect it was assumed that starting zones were released independently. If two neighbouring zones were to release at the same time, the total avalanche mass would travel farther.

CONCLUSIONS AND LESSONS LEARNED

Even though the simulation models used were not designed to function at the scale at which they were finally tested they nevertheless performed better than expected. The main reason was that the model was used to provide an indication of danger so the demand on accuracy was not that high. A more detailed hazard scenario would require additional input of local expertise, in relation to the terrain and climatic conditions, for example. The advantages of a large-scale hazard

analysis such as this are that they are time- and cost-effective and provide uniform results. They are, however, no replacement for detailed studies.

Avalanches are one example of a gravitationally driven natural hazard. It is not clear whether the methods employed in the SilvaProtect study can be applied to other similar hazards. Moreover, the mechanics of avalanche-forest interaction require further study. The methodology used in this example is based on two extreme scenarios: forest or no forest. This is acceptable for large avalanche or extreme events but would require modification if smaller avalanche events were to be considered.

7. FLOODING

7.1. OVERVIEW

There is a useful distinction to be made between fresh water and salt water flooding. Fresh water floods typically occur when rainfall exceeds the absorptive capacity of soils and aquifers in a catchment¹³, and the surplus runoff then also exceeds the storage capacity of downstream rivers and systems. A flood then results when each river bursts its banks and occupies its floodplain. This may be a routine, seasonal occurrence, or an exceptional one. It can be devastating economically, if buildings and farms are located in the floodplain. Agricultural impacts, however, are often temporary – they may even be beneficial as fertile sediment is deposited on fields – since the water is fresh.

Salt water floods occur when sea water is driven inland by a storm surge or tsunami. Soils and ground water aquifers may suffer salt contamination which may take many years to be cleansed.

This section focuses on fresh water floods which, in addition to the above-mentioned processes may also be caused by snowmelt, by

¹³ Catchments are often called 'watersheds' in American usage, but this word is elsewhere reserved to mean the topographic boundary between catchments.

heavy rainfall onto a poorly-drained area or floodplain, by the long-term raising of a water table (i.e. the upper margin of groundwater to the soil surface), or catastrophic flooding as a result of dam failure. Freshwater floods can also arise when high tides and storm surges – and, increasingly, rising sea levels – congest drainage, causing river levels to back up inland. This chapter also focuses largely on the downstream events that relate to flooding, but recognition is given to the fact that there are many opportunities for environmental management in headwater catchments which could also significantly reduce these impacts, some of which are incidentally shared with other hazard prevention systems such as avalanche and landslide prevention.

As more than 80 per cent of the world's population live in productive, but low-lying and inherently flood-prone areas, floods are among the most common and most devastating of all natural hazards. Areas most susceptible include the mid-western USA, Central America, coastal South America, Europe, eastern Africa, northeast India and Bangladesh, China, the Korean peninsula, South-east Asia, Indonesia, and the Philippines. An average of 157 major floods was recorded annually from 1998-2006: 216 occurred in 2007. These killed a large number of people (9,254 annually from 1998-2006, 8,493 in 2007),

injured or otherwise affected many others (123 million annually from 1998-2006, 178 million in 2007), and caused serious economic losses (US\$19 billion annually from 1998-2006 and US\$24 billion in 2007) (Scheuren, J-M, Pers. Comm).

Historically, flood-prone rivers have been extensively managed through hard engineered flood control structures, especially in western countries (Caldecott, 2007). Such structural “solutions” to flood and transport problems have caused the loss of 90 per cent of the original floodplain in the upper reaches of the Rhine river in Europe, and the river is now flowing twice as fast as before (Ramsar Convention, 2005), resulting in a succession of devastating floods in the lower reaches of the Rhine, in Germany, France, Belgium and the Netherlands. Innumerable flood control works were also built along the Mississippi river in the USA, including artificial levees up to 15m high on at least 10,000km of the river’s banks and those of its tributaries, while the main stream has been additionally straightened to now flow for 1,750km through artificial channels. In 1992, a federal government inter-agency study of floodplain management concluded that 60 years of building flood control structures in the Mississippi basin had not had any real effect in reducing deaths and property damage (Federal Interagency Floodplain Management Task Force, 1992). The following year, after most of the river’s catchment had received up to 200 per cent more rain than normal, unusually fast water flows hit the city of St Louis where the Mississippi and Missouri rivers meet, brushing aside the levees that hemmed it in: 487 counties in nine states became flood disaster areas in a few hours.

These experiences have led to an increasing shift towards soft engineering in flood management, including approaches that use natural attenuation features of wetland ecosystems such as floodplains, salt marshes, mudflats, reefs and wooded riparian zones in upstream reaches. Several storm and flood-prone countries have now opted for floodplain restoration and – partial – removal of hard engineering structures.

Flood prevention in the Netherlands has long been through the exclusive construction of dykes and drainage of wetlands but the risks posed by climate change through increases in sea level and extreme river discharges, have now led to a shift in the trade-off costs of continuing indefinitely to raise all dikes. In less heavily developed areas of this country, a large-scale programme of river restoration has now been implemented including broadening floodplains, re-creating water retention areas in natural depressions, and re-opening secondary river channels (Stuip et al, 2002). Similarly, after the 1993 flood in the mid-western USA, the federal government bought 25,000 flood-prone properties, which were converted into wetlands. These wetlands now act as a sponge to prevent flooding. In the monsoon regions of Asia, appropriately designed paddy fields can be similarly used for flood alleviation and to restore ground water resources.

7.2. CASE STUDY: MANAGED RE-ALIGNMENT AND THE RE-ESTABLISHMENT OF SALTMARSH HABITAT, UK¹⁴

BACKGROUND

Coastal communities in the low-lying coastal zone of the shallow North Sea Basin are vulnerable to storm surges, particularly those coinciding with high spring tides. Such surges are often accompanied by high waves which can overtop and breach sea defences. Predicted sea level rises due to climate change will pose additional future threats, as this will raise the base level for future storm surges. Annual rates of sea level rise of 6mm have been predicted in this area until 2030, increasing to 8.5mm between 2030 and 2100.

¹⁴ Summarized from a case study prepared by Daniel Friess, Dr Iris Möller, Dr Tom Spencer, CCRU, Cambridge University, UK and which can be downloaded from www.proactnetwork.org

Accelerated sea level rise also has consequences for intertidal habitats since these may be trapped against sea walls and prevented from expanding inland, while being eaten away by advancing marine ecosystems. Managed realignment describes the repositioning of an existing hard sea defence to a more landward location, allowing accommodation space for the creation of intertidal habitat. The resultant increase in the intertidal zone allows increased flood water storage and wave attenuation. Managed realignment was originally proposed at Freiston Shore due to increased rates of erosion experienced at the base of the sea wall, and higher repair/maintenance costs as a result. This sea defence was a focus of erosion due to its construction too far seaward, compared with the surrounding artificial shoreline. This made the defence a focus of wave attack, both directly and as a result of refraction around the outlying structure.

ECOSYSTEM MODIFICATION

The Freiston Shore re-alignment trial created 66ha of saltmarsh habitat and 15ha of saline lagoon. The Wash Banks coastal defence project – of which this re-alignment site is a part – protects more than 80,000ha of low-lying land, including many villages and the town of Boston, with a population of more than 35,000 people. As part of the re-alignment scheme, the existing sea defence was breached in three places and a new landward lying secondary defence was strengthened. Linear drainage channels were also excavated within the site to facilitate sediment and nutrient delivery into the interior of the re-alignment area. In addition to the full coastal realignment, a smaller (15ha) saline lagoon was created, allowing regulated sluice-controlled exchange of tidal water on the highest spring tides only.

FINDINGS

Managed re-alignment at Freiston Shore can be considered a success, with vegetation establishing more quickly here than at many other re-alignment trials in the UK, with 86 per cent of the site being vegetated by 2006. Research has shown that UK saltmarshes can reduce wave height by almost 61 per cent by increasing bed surface friction, and can reduce total wave energy by an average of 82 per cent. Other studies have shown that swards of saltmarsh grass vegetation can reduce wave heights by 70 per cent and wave energy by over 90 per cent, though this is a highly non-linear process.

CONCLUSIONS AND LESSONS LEARNED

This study illustrates that managed re-alignment can be a viable and successful strategy to adapt to the impact of sea level rise and/or increased wave action on low-lying coasts. By providing additional flood storage capacity and intertidal surfaces that attenuate incident wave energy, flood risk is reduced – at least in the short- to medium-term – after the new intertidal surface has become stabilised and vegetated. Over longer (+50 year) time periods, the increased defence efficiency cannot be guaranteed, as continued landward retreat may be necessary to maintain an intertidal profile that supports saltmarsh vegetation.

Natural Flood Storage and Flood Prevention Facilities

For more than the past 200 years the public water supply for Worcester, western England, has come from a waterworks located on a 4ha site on the banks of the River Severn. The site was within the natural floodplain of the river but an artificial flood defence – consisting of a high concrete wall – had been constructed to protect the facility. When the waterworks was decommissioned, the owners, Severn Trent Water, in partnership with the City Council planning department and the Environment Agency, agreed a scheme to restore the land to a public park.

The flood wall and 17 brick and concrete tanks were removed, the site was recontoured and the active floodplain was restored. The spoil was used to fill the deeper tanks and housing was developed on an adjoining site, not at risk of flooding. A local river, Barbourne Brook, was broken out of its culvert and allowed to flow freely through the park and into the river.

The city of Worcester experienced serious flooding in the following summer, but the new flood management design worked. The park kept the flood level down by providing a much-needed extra 4ha of flood storage capacity and through-flow of flood water, while the new housing facility was not affected.

On the opposite side of the UK, the flood washlands upstream of Lincoln, along with associated defences, have been providing flood protection from the rivers Witham, Brant and Till to approximately 7,000 residential, commercial and industrial properties. During the June 2007 flooding, the washlands were operated successfully to avoid major flooding from these rivers. While the artificial flood defences within Lincoln can safely protect against an event that has a 1-in-10 annual chance of happening, by using the washlands to store water, the risk of flooding is reduced to approximately 1-in-100.

Timing, however, is critical to success. If the washlands are employed too early, their storage capacity can be used up, leaving no capacity for any flow that might follow. If they are used too late, the safe flow through the populated area may be exceeded and flooding will occur. During the summer 2007 floods, the Environment Agency had a team of people forecasting and monitoring the conditions in order to determine the optimum time for operation of the various control structures.

(Source: Pitt Review – Lessons Learned from the 2007 Floods, available at <http://www.cabinetoffice.gov.uk/the-pitt-review.aspx>)

7.3. CASE STUDY: ECOSYSTEM SERVICES OF A FLOODPLAIN WITH A PRESERVED HYDROLOGICAL REGIME, CZECH REPUBLIC¹⁵

BACKGROUND

In the Czech Republic – as in the most of Europe – the majority of floodplains have been transformed to minimise flood pulses to intensify agriculture and protect infrastructures. Following catastrophic flooding in 1997 and 2002, a broader discussion started on how water retention might be increased. In 2005, water management authorities introduced a plan for watershed management, and proposed 205 localities to be reserved for the possible construction of future reservoirs, a predicted shortage of water during summer months being the main reason for this proposal. No floodplain was included among the reservoirs. After severe protests by NGOs and the academic community, the list of reservoirs was abandoned and a series of softer measures were adopted into the watershed management plan.

OBJECTIVES

This study was aimed at quantifying four ecosystem services – flood mitigation, maintenance of biodiversity, carbon sequestration, and production of hay, wood and fish. The quantification sought to demonstrate the value and benefits of natural floodplain segments in a monetary way.

¹⁵ Summarized from a case study prepared by Dr David Pithart, Academy of Sciences, Czech Republic and which can be downloaded from www.proactnetwork.org

LOCATION AND CONDITIONS

The Lužnice floodplain is one of the last floodplains with unaltered hydrological regime in the Czech Republic. The river still meanders and changes its course after major flood events. The study area (470ha) is about 12km in lengths with a 1-2km wide floodplain, located in southern Czech Republic between the Austrian border and the towns of Suchdol and Luzničí. It is flooded for several weeks every year. The long-term (50 years) average river discharge is 5.8m³/s.

The floodplain area consists of a main stream and standing water bodies, meadows – both maintained and abandoned – pastures, and softwood forest dominated by willow (*Salix* spp) and white poplar (*Populus alba*), also with oak (*Quercus robur*) and alder (*Alnus glutinosa*). In winter, the water bodies regularly freeze and become covered by snow. The water level fluctuates in the range of 1.5m. There is no settlement within the floodplain, but some farming is practised.

Carbon sequestration was measured at Mokré louky, a flat depression with an area of 450ha. The area is covered by several metres of peat, which is superimposed on quaternary alluvial sands and clays.

FINDINGS

According to a digital elevation model of the site, the potential retention volume for the 470ha site is 7 million m³. To translate this into a real-time occurrence, the volume of a real flood situation from spring 2006 was used. This volume – 4.7 million cubic metres – gives a retention volume of 10,251m³/ha.

The average cost of artificial water retention in the Czech Republic is US\$23/m³, which results in a value of US\$11,800/ha/yr, using a 5 per cent discount rate. In terms of flood mitigation, peaks of larger floods – which may cause damage downriver – are delayed for two days and reduced by 10-20 per cent if flows at

the inlet and outlet of the 12km long floodplain segment are compared.

In terms of carbon sequestration, sedge grasses in the wet meadows accumulated about 1,988kg and 2,202kg of carbon per hectare during 2006 and 2007 respectively, the difference being caused by different hydrological regimes. During 2006, when several floods events were recorded, a decreasing carbon accumulation was observed in August. During this flood period, sedge grass stands were flooded and plants lost their above-ground biomass. The following year, in contrast, was without floods (20 per cent less precipitation than the previous year), and no decrease was noted in net ecosystem production.

The different water regimes had an important influence on carbon accumulation by the studied ecosystem. The rate of carbon accumulation was also measured directly by harvesting above-ground plant biomass. The amount of carbon in harvested biomass corresponded well with eddy covariance measurements. At a wet meadows site, 2,095 tonnes of carbon was sequestered per hectare per annum (7.5 tonnes of CO₂). With a marketable price of US\$20/tonne, this service results in a value of US\$144/ha/yr.

Monetary Values of Ecosystem Services in the Lužnice floodplain

Service	Value/ ha (US\$)
Flood mitigation (water retention)	11,788
Biodiversity refugium	15,000
Carbon sequestration	144
Fish production	37 (528)
Hay production	78 (200)
Wood production	21 (166)
TOTAL	27,068

The monetary value of the ecosystem services of the Lužnice floodplain is summarised in the table above, with an overall service value in excess of US\$27,000/ha. Numbers in brackets refer to the value of the service related to 1ha of specific land cover – water surface, meadows and forest cover. Services provided as a refuge for biodiversity and flood mitigation are one order of magnitude higher than carbon sequestration and two orders of magnitude higher than production services.

While the above demonstrates a range of values attached to this natural floodplain and its services, a precise hydrological study based on hydraulic modelling is required in order to quantify full mitigation potential of this landscape. Preliminary results of water chemistry monitoring clearly show that there is an uptake of phosphorus and nitrogen during the flow of water through the floodplain, but additional study is also required. Likewise, related phenomena such as thermoregulation and the deposition of non-detrimental suspended solids should be evaluated as an ecosystem service.

CONCLUSIONS AND LESSONS LEARNED

This study highlights a number of ecosystem services of significant value, which can also be expressed also in financial terms. The value of non-production services of this floodplain is much higher than production services. The overall value of ecosystem services is in line with those observed elsewhere. This particular floodplain is undoubtedly close to its optimum level in terms of providing balanced ecosystem services. Similar studies should be undertaken on more modified floodplains to compare difference of ecosystem service values. Such results can help strengthen arguments for reverse conversions of floodplain segments as an alternative or supplementary measure to hard engineering constructions such as reservoirs.

8. FIRE

8.1. OVERVIEW

All but the most constantly wet ecosystems have some experience of fire. While some North American coniferous forests burn every few years, other ecosystems burn so frequently that their species show precise adaptations to fire, such as bark that insulates or ablates, or plants whose vegetative parts remain underground. Seeds of certain species will not germinate unless they are exposed to hot fire, so apart from its potentially destructive nature, fire does have an important role in creating and maintaining biodiversity

“Wildfire” in the current context is interpreted as a hot, dangerous and potentially destructive outbreak of fire that can erupt when accumulated biomass has been ignited after a period of prolonged drought, and is then exposed to strong winds. Such fires can cause near-irreparable harm to ecosystems, overwhelming their adaptive defences. They can also result in human death (48 annually from 1998-2006 and 150 in 2007 alone), injury or other effects (52,240 annually from 1998-2006 and nearly 1.8 million people in 2007) and serious economic losses (US\$1.9 billion annually from 1998-2006 and US\$4.6 billion in 2007) (Scheuren, J-M, Pers. Comm).

Although wildfires can be induced by natural events such as lightning strikes, they are often human-induced as a result of forest or land clearance for agriculture. As climate change is increasing the intensity and frequency of drought in many areas, the number of wildfires is also on an upward trend in certain areas. Regions with distinct dry and wet seasons have potentially more fires than others. Under these climates, vegetation growth during the wet season can increase the fuel load while flammable conditions during the dry season can lead to more frequent and intense fires. In addition to seasonal patterns in precipitation, temperature and wind speed are also important factors that need to be taken into account. Hot conditions and intense winds may promote both a high frequency and intensity of fire by favouring an abundance of dry fuel by actively spreading a fire (MEA, 2005).

The risk of major wildfires can, however, be decreased by reducing or modifying the fuel load. Such a reduction is achieved by conducting controlled or “prescribed” fires, by removing vegetation that might ignite and/or by creating firebreaks¹⁶. Prescribed fires are used to burn areas under relatively safe conditions, such as early in the dry season or in calm or cloudy

¹⁶ In fire-prone areas such as California a 30m defensible space of partly-cleared vegetation around private houses is now required by law

weather. Such burning regimes can also help maintain or improve native plant and animal habitat, control the spread of noxious and invasive weeds and restore productivity of grazing lands. Appropriate fire management regimes can also reduce the overall number and extent of wildfires and thereby reduce the emissions of greenhouse gases they would otherwise have caused.

8.2. CASE STUDY: WEST ARNHAM FIRE MANAGEMENT AGREEMENT, AUSTRALIA ¹⁷

BACKGROUND

Fighting extensive wildfires in unmanaged lands is both difficult and expensive. In parts of Australia's Northern Territory, fire regimes have changed markedly over the last century, with an increased incidence of destructive late dry season fires, in contrast with the intricate cooler burning regimes thought to have been used under traditional Aboriginal management. Fire-sensitive elements within the landscape – most notably monsoon rainforest patches and sandstone heathland plants – are among the vegetation groups being negatively impacted by these late fires.

In an attempt to control and reverse current trends, improved fire management is being implemented through an innovative public-private partnership, a programme that also offsets some of the greenhouse gas emissions from a liquefied natural gas plant located elsewhere in the country.

Currently around 10 per cent of the project area's landscapes are affected by early dry season fires, while 30-60 per cent are affected by late dry season wildfires. Field studies and remote sensing data show that early dry season fires emit less

greenhouse gases per area affected than the more intense, late dry season fires. If the proportion of early dry season fires can be increased to around 15-20 per cent to create fire breaks and patchy mosaics of burnt land – and if this then reduces the extent of later and more intense wildfires to 15-20 per cent of the landscape – then savings of around 100,000 tonnes of CO₂ can be expected per annum. To put this in context, in 2004, fire in northern Australia's savannahs released an estimated 218 million tonnes of CO₂, equivalent to 38 per cent of Australia's total greenhouse gas emissions.

LOCATION

This programme is being implemented across an area of 28,000km² of Western Arnhem Land in the Northern Territory. Aboriginal Land Trusts hold most of this region as inalienable tenure: many parts of the region are managed in ways reflecting the more than 40,000 years of continuous occupation by these peoples.

The West Arnhem Fire Management Agreement is a partnership between several stakeholders, namely Darwin Liquefied Natural Gas Pty Ltd., the Northern Territory Government, Aboriginal Traditional Owners and indigenous representative organisations, the Northern Land Council, the Northern Territory Bushfires Council and Tropical Savannas CRC. The range of interests and expertise represented in the Agreement included private and public parties of a greenhouse gas offsetting agreement, implementers of fire management practices, a project developer and manager of the fire regimes working together with aboriginal ranger groups, a research and management group, and a monitoring and a reporting service on greenhouse gas emissions.

OBJECTIVES

The main purpose of this initiative is to reduce the amount of smoke and greenhouse gas emitted through reducing the number and

¹⁷ Summarized from a case study prepared by Tropical Savannas CRC, Australia, and which can be downloaded from www.proactnetwork.org

frequency of late dry season fires. Reducing emissions in this way will offset greenhouse gas emissions from the gas plant mentioned above. At the same time, many of the project's benefits are reflected through the protection of the cultural and natural values of the plateau and in the social and economic stimulus it provides for indigenous communities. Introducing more patchy and diverse fire regimes, for example, is expected to benefit biodiversity as evidence indicates that the current late dry season fires are degrading key habitats for many species.

METHODS

Strategic fire management practices are applied from early in the dry season to reduce the size and extent of unmanaged wildfires. Early burning involves a mixture of on-the-ground patch fires set by people physically on the ground as well as larger scale fire breaks lit along tracks, rivers and creeks from helicopters. This breaks up the landscape and makes it more difficult for wildfires to spread across the fire breaks later in the year. With strategic breaks in place it becomes more feasible to burn later into the year if required. Limiting wildfires will in turn reduce the emission of greenhouse gases from that landscape.

CONCLUSIONS AND LESSONS LEARNED

Strategic fire management, as shown here, can generate multiple benefits. Environmental benefits include reduction of greenhouse gas emissions and protection of ecosystems, while economic benefits include increased employment and economic participation of aboriginal communities, and the avoided economic costs of destructive wildfires and associated loss of biomass and ecosystem services. Finally, social benefits include enhancement of traditional indigenous culture related to fire and increased participation of aboriginal communities.

As part of the agreement described above, Darwin Liquefied Natural Gas will provide around US\$1 million every year for the next 17 years to the Aboriginal Traditional Owners of Western Arnhem Land to implement a burning strategy to offset 100,000 tonnes of CO₂ each year. This project does not generate any income from carbon trading but is a fee for a service arrangement in which indigenous people are paid for fire management to produce greenhouse gas offsets.

This approach has significant potential for application in other fire-prone regions of north Australia – and perhaps elsewhere. Field studies and remote sensing data have shown that early dry season fires emit less greenhouse gases per area affected than the more intense, late dry season fires. This is mainly because the earlier fires are not as intense and burn less of the grassy fuel, do not burn the entire grass layer, usually stay in the grass layer without invading the forest canopy, and can usually be stopped easily. If the types of fire that burn across northern Australia can be changed then less smoke and greenhouse gases will be emitted.

9. DROUGHT AND DESERTIFICATION

9.1. OVERVIEW

A drought is a prolonged period of abnormally low rainfall, leading to a shortage of water (ISDR, 2007). Drought and food insecurity caused an estimated 460,000 premature deaths in 1997–2006, affected 1.1 billion people and caused over US\$30 billion in economic losses (EM-DAT, CRED, 2007). But droughts typically build slowly through time, over months and years, and are therefore perhaps the least clear-cut of all natural hazards. Moreover, a drought can only be defined relative to the climate history of the location, and to the patterns of land use and water dependency that have become established as adaptations to that climate history. Thirsty crops, towns and industries established during years when rainfall or other water sources might have been available become vulnerable if dry years then occur.

Almost 40 per cent of the world's land area and 70 per cent of the global human population are exposed to some level of drought (Dilley et al, 2005). The most drought-prone areas in the world are the south-western USA, Central America, north-eastern Brazil, the Sahel, the Horn of Africa, southern and central Africa, Madagascar, southern Spain and Portugal, central Asia, north-

west India, north-east China, South-east Asia, central Indonesia and southern Australia (Dilley et al, 2005). Many of these relatively dry areas are becoming drier as a result of climate change: Spain, the south-western USA and Australia in particular are now enduring prolonged droughts. These facts, combined with the absolute need for water by people, livestock and crops, all combine to mean that drought is the single natural hazard with greatest impact on human livelihoods – especially when considered together with its companion, desertification.

Desertification is strongly associated with already dry areas and is widespread around the fringes of natural deserts such as the Sahel where the Sahara is spreading south at a rate of around 25km a decade. Desertification is also severe in Afghanistan, Kazakhstan and elsewhere in Central Asia, as well as in western China, the Indian states of Rajasthan and Chhattisgarh, and in Mongolia. Some 10 per cent of the island of Madagascar has been desertified, while Nigeria is losing about 3,500km² of land annually to desert encroachment.

If drought and desertification are seen as parts of a vicious cycle that also involve damage to vegetation cover, desiccation and wind erosion, solutions must lie in breaking that cycle. Options

include the planting of trees and shrubs as shelterbelts, greenbelts, hedges and living fences to break the force of wind and shade the soil, binding it together with roots, trapping water and restoring organic materials to it. Farming systems that mimic natural ecosystems and closely match local conditions instead of ignoring them, are well suited to these conditions, but need to be encouraged further. Valuable practices include using drought- and salt-resistant crops, rotation of crops and grazing with fallow periods, agroforestry (growing trees and other crops together with the main crop, or in pasture areas) and mulching (using crop residues, leaves, or porous rocks) to cover soil to reduce erosion and evaporation.

Village Defences against Hazards

Villagers in Dan Saga, Niger, almost lost their land to desertification until they decided to plant and protect young trees. In time the trees began to halt the sands from spreading and now form an integral part of their farming system, providing fodder for livestock. In such a fashion Niger may have gained 200 million trees in two decades.

The challenge in this case – and most often in such circumstances – is to find ways to mobilise enough people to take such measures over a long-enough period to make a difference. This often comes down to finding the right incentive structure to encourage people to plant and tend trees, which is usually about providing security of tenure.

(Source: Pearce, F. 29 March 2008. Can't see the desert for the trees. New Scientist 2649.)

Some successful initiatives can be highlighted in combating drought and desertification. In 1915, Morocco started to stabilise coastal dunes with vegetation to protect towns like Tangiers and Agadir. The programme planted over 34,000ha of trees over a 60-year period. In 1965, Niger implemented a 2,500ha greenbelt around Niamey, while in Mauritania, greenbelts have been established at over 100 sites to protect large urban settlements – including Nouakchott, the capital city – urban areas with cultivated zones including oasis and rainfed agriculture areas, and punctual protection of smaller sites. The

Kenyan Green Belt Movement has, since the 1970s, encouraged the planting of over 30 million trees against desertification as well for the trees' multiple environmental services (Greenbelt Movement, 2008).

9.2. CASE STUDY: PERMACULTURE IN THE JORDAN VALLEY¹⁸

BACKGROUND

The Jordan Valley Permaculture (JVP) project is a pilot project to rehabilitate 4ha of otherwise non-productive farmland, under high salinity and drought conditions, using the integrated methodologies of permaculture.

The main environmental concerns for the Jordan Valley area, which led to this project were the increasing shortage of freshwater resources for human uses – especially for growing food – and the decreasing quality of freshwater resources due to the high salinity of water and other pollutants, and the decreasing quality of farm system production. More than 100 local people were directly involved in the initiative. Indirect beneficiaries comprised approximately 30,000 people. The site is now being used as a training centre for a regional water management programme for all agricultural communities within the Jordan Valley.

OBJECTIVE

The goal of JVP is to demonstrate the potential for improving human and environmental conditions in the Jordan Valley using low-cost, low-technological approaches. Thus the project aims to: rehabilitate otherwise unproductive farmland through an integrated environmental

¹⁸ Summarized from a case study prepared by Permaculture Research Institute of Australia, and which can be downloaded from www.proactnetwork.org

management model based on permaculture; improve the quantity and quality of agricultural production; improve the livelihood and living conditions of the local people, and; study the impacts of permaculture on the soil, the quality of plant and animal production, the farm system and the local environment.

METHODS

An environmental monitoring programme was implemented to assess the impacts of permaculture practices on the farm and natural resources. The programme included periodic soil, water and plant sampling and analysis. Selected soil properties were recorded before cultivation and after one year of establishment. Crop yields and water use was also monitored, and compared with others in the area. The pilot farm was planted for agricultural production using the principles of permaculture, which depends on the application of specific agricultural patterns and practices that aim for sustainable use of soil, water, plants and animals by design. It is an integrated system for the environmental management of agricultural process, natural resources, local communities and the environment.

FINDINGS

Crop yields per unit of water consumption were generally high in the pilot area, since water needs were reduced by about 40 per cent due to water harvesting and storage by swales (contour ditches), the shading of fruit trees and vegetables by legume trees and the use of plant residues as a natural mulch to insulate the soil and create humus. In addition, crops such as portulaca and sweet potato were planted to act as living mulches throughout the fruit tree systems. The re-use of wastewater from a pool created for geese, and the use of drip irrigation also contributed greatly to water conservation on the farm.

Soil salinity declined during the project even though the farm depends on water of about 4decisiemens per metre salinity for irrigation.

Swales resulted in the collection and storage of rainwater that leached salts from the soil. The use of natural mulching prevented water evaporation and salt accumulation on the soil surface. Mulch also worked as a buffer to reduce the long-term effects for salts on soils and plants. The soil organic matter content increased through the continuous practice of using natural mulching from plant residue and composting of animal manure. The use of natural mulching resulted in a decrease of soil pH, although the soils in the area are normally very alkaline.

CONCLUSIONS AND LESSONS LEARNED

The results show that techniques like swales, natural mulching, rainfall harvesting and legume cultivation have a clear role in improving soil properties, increasing soil organic matter content and reducing soil salinity and water use. This example represents a pilot model for sustainable management of natural resources especially soil, water and plants under extreme drought and salinity conditions. The local community has since adopted the project and now implement permaculture practices in their household gardens.

9.3. CASE STUDY: SAND STORMS¹⁹

Dry sand storms – provoked by drought, desert-like conditions, degraded landscapes and turbulent atmospheric conditions – have the potential to overwhelm farms, settlements and infrastructure, promoting the spread of mobile sand dunes and desertification even further. In a DRR and CCA context, sand storms are near-instantaneous events (e.g. whirlwinds) as well as symptoms of underlying and more continuous processes.

19 Literature review prepared by ProAct Network

Worldwide, an estimated US\$48 billion in economic losses is currently attributed to sandstorms every year. Desert margins are the main source of damaging dry storms, which are historically most common in the great plains of the USA, the former USSR, Morocco, the Arabian Gulf, Australia, the Sahel, China, Mongolia, and Mexico (Youlin et al, 2001). Sand storms cause further concern in areas such as Japan where dust particles carry pollutants from China.

Sand storms cannot be controlled directly, but their tendency to develop as well as their impact can be reduced through measures that include: taking land out of crop cultivation for revegetation with forest and grasses, establishing protective oasis and farmland shelterbelts and windbreaks, maintaining soil structure by keeping crop residues on the land after harvest, and planting seedling trees and shrubs to stabilise advancing dunes.

Breaking the Force

A major effect of a windbreak is to reduce the incidence of low frequency, high magnitude damage events such as sandblasting. A windbreak of tall, dense vegetation can significantly reduce wind speeds for an extended distance beyond it, so a succession of such defences in parallel will re-inforce each others' influence. In addition, trees can also be used to shade buildings and reduce direct exposure to the sun. In coastal areas vegetation helps to stabilise dunes. All these factors imply a vital role for the creative use of tree planting to inhibit the development and impact of dry storms.

(Source: Cleugh, 1998)

Parts of northern China – including Beijing – face destructive dust storms, which have generally increased in both frequency and intensity in recent decades. The root cause of this problem has been traced to worsening desertification as vegetation cover has been removed in many sensitive areas due to population pressure and agricultural practices. Strong seasonal winds generate dry storms that remove millions of tonnes of topsoil. According to China's State Environmental Protection Agency the sandstorm-affected area has now extended beyond three million km².

Thick dust storms overtook Beijing eight times in the spring of 2006, with a storm occurring on 17 April being the worst experienced for five years. The storm, which blew in from Inner Mongolia, was accompanied by winds that delivered an estimated 400,000 tonnes of dust to the city, reducing visibility to less than 100m. In Inner Mongolia, more than 1,170ha of wheat were damaged and 11,000 livestock killed by the storms, causing an economic loss of about US\$1.25 million. This, however, should be seen in the context of economic losses in China as a whole from dry storms, which now amount to some US\$6.5 billion each year (Li Z, 2006). In an attempt to stop dust-forming winds, in 2001 China launched an extensive programme of reforestation with the aim to establish a 4,500km long protective forest – the “Green Wall of China”. While this, and related activities are a positive start, there is a great need also to raise awareness and investment for revegetating storm source areas in Mongolia and elsewhere if there is to be a comprehensive solution to the problem.

In Canada, at least 161 million tonnes of soil is lost each year because of wind erosion: Annual on-farm costs of wind erosion in the Prairie provinces alone are about US\$249 million. During the “Dust Bowl” period of the 1930s, some areas lost their entire topsoil. In response, the Prairie Farm Rehabilitation Administration was established in 1935. Improved agricultural practices, such as planting of barriers and buffers, and zero/minimum tillage were implemented. Field shelterbelts were established, consisting of rows of trees planted on agricultural land to protect crops and soil, to catch and distribute snow, and to improve the microclimate for crops. These reduce wind speeds for a distance of 20-30 times their own height and increase crop yields considerably. Field shelterbelts also offer habitat for wildlife, and provide products such as wood and fruit.

10. CONCLUSIONS AND RECOMMENDATIONS

The main conclusions and recommendations of this review are as follows.

ENVIRONMENTAL MANAGEMENT AND ECO-ENGINEERING HAVE MULTIPLE BENEFITS FOR CLIMATE CHANGE ADAPTATION AND DISASTER RISK REDUCTION

Few would dispute that the Earth's climate is changing and changing more speedily than some had anticipated, resulting in additional climate-related natural hazards that will impact societies around the globe. Traditional forms of hard defences will not be able to cope with the growing threats: in any case, many have been found to be inappropriate and are now being reversed.

Recommendations

Give greater recognition to the cost-effectiveness of eco-engineering approaches – including the social, economic and environment-related services attached with this – in national accounting.

Utilise lessons from this report in negotiations for a post-2012 climate agreement, including the formulation of an inclusive and equitable climate change adaptation scheme.

Engage in policy development at the national and international levels to take full advantage of the climate change adaptation and mitigation potential of environmental management.

Provide added incentives for environmental management measures that also have the potential to both reduce disaster risk, help adapt to climate change and capture CO₂.

LACK OF AWARENESS RESULTS IN UNDER-USED POTENTIAL

The approaches, requirements and benefits of natural buffers and other eco-engineering measures are poorly known among decision-makers, planners and practitioners. It is important and timely to sensitise policy-makers and donors of the measurable adaptation and mitigation effects of well-managed ecosystems.

Recommendations

Natural buffers and other soft protection measures offer new hope and opportunities. These are not necessarily new technologies, but technologies and approaches that may need to be adjusted to local needs. What is needed is enhancement of technology transfer efforts and

stakeholder awareness-raising, so that a medley of best practices and lessons learned can be tailored and applied to specific situations.

Environmental management offers an opportunity to increase the links and national/local level connections between DRR and climate change adaptation agendas, with potential for additional social and economic benefits.

Develop practical guidance on advancing climate change adaptation through ecosystem and environmental management.

MULTIPLE BENEFITS

Eco-engineering has various advantages compared to hard protection measures. Natural buffers and environmental management for example:

- ★ provide additional benefits through environmental goods and services – providing a basis for local livelihoods and acting as carbon sinks through CO₂ sequestration;
- ★ enhance community ownership of DRR solutions;
- ★ are cost-efficient, having often a lower cost of establishment, implementation and maintenance than hard-engineering systems; and
- ★ are dynamic and able to adapt to changing conditions.

Recommendations

Greater recognition needs to be given to the cost-effectiveness of eco-engineering approaches, including the social, economic and environment-related services attached with this. Some benefits, however, are not easy to quantify. Natural buffers and environmental management in relation to DRR can enable and enhance the participation of local communities in adapting to and preparing for disasters. Such methods should be used as an opportunity to increase bottom-up approaches

in DRR. The value of such approaches is often overlooked in national accounting.

Many environmental management measures also have the potential to both reduce disaster risk (adaptation) and to capture CO₂ (mitigation).

CLIMATE FUNDING POTENTIAL

In order to facilitate implementation of DRR projects combining adaptation with mitigation, there is a need to explore financing opportunities through climate change funding. MitAd and AdMit mechanisms can provide win-win opportunities that promote mitigation while also enhancing much-needed adaptation.

Recommendation

An in-depth assessment needs to be conducted on potential financial mechanisms from climate funds, including the potential engagement of the private sector for environmental management as an approach to climate change adaptation.

BROADEN STAKEHOLDER ENGAGEMENT

There is a need for interdisciplinary dialogue for engineers, natural scientists, disaster managers and decision-makers, through which integrated solutions may be sought. It is equally important to involve community members who ultimately maintain and care for the DRR systems.

Recommendation

The establishment of communities of practice on natural buffers in DRR should be enhanced. This will foster a network of professionals who build capacity, engage stakeholders in a dialogue and assist in technology transfer on issues relating to DRR.

PRACTICAL ACTIONS NEED TO BE TAKEN IN RELATION TO PLANNING AND MANAGEMENT

Healthy ecosystems and well planned environmental management have the greatest capacity to mitigate at least certain categories and scales of natural hazards. Ecosystems, such as coastal forests, need to be appropriately managed to provide a substantial buffering effect. Many cases demonstrate that when natural barriers – such as coastal vegetation and sand dunes – are removed or degraded, these areas become highly vulnerable to natural hazards. Reconstruction after a disaster places high pressure on important ecosystems, such as mangrove forests. Meeting short-term interests through coastal deforestation, for example, renders communities more vulnerable to subsequent hazards.

Recommendation

Development interventions by international and national agencies need to enhance the defensive capacities of ecosystems rather than degrade them. This should include appropriate elements of awareness raising and introducing viable alternative prevention and reconstruction options, such as using environmentally appropriate construction materials. Implementation of pilot projects should also be supported in some of the most vulnerable areas. Post-disaster reconstruction needs to be ecosystem-sensitive.

RESEARCH AND MONITORING NEEDS

There are still many gaps in our knowledge as to how to manage certain ecosystems in an appropriate and sustainable manner. More precision is also required with respect to the limits of environmental management measures in risk management.

Recommendations

There is a clear need for additional research into both ecosystem management, the broader potential use of ecosystem goods and services and, in particular, further evidence of quantitative data in relation to ecosystems and their role in disaster risk prevention and reduction. Long-term monitoring – currently almost non-existent – on natural buffers is also required, including integration of DRR monitoring into ecosystem projects. The geographic coverage of research should also be broadened in order to understand better local specificities.

In order to make relevant information more readily available and applicable, a clearing mechanism needs to be established for environmental management practices for DRR and climate change adaptation, providing information on technologies, costs, performance, availability, implementation requirements and so forth

ENVIRONMENTAL MANAGEMENT IS NOT AN ALL-ENCOMPASSING SOLUTION

Natural buffers cannot protect against all hazards, or offer complete protection. Instead, they must be used in integration with other risk management components, such as early warning systems and awareness raising. Often the most appropriate solution may be combining hard and soft defences so that way that environmental management is used on wide areas for multiple benefits while critical infrastructure is protected with small-scale hard protection structures.

Recommendation

The establishment and sound management of natural buffers should become a standard component of DRR strategies. Soft defence systems should be used with adequate awareness of their benefits – DRR capacities as well as other environmental services – and limits.

GLOSSARY

Adaptation. In the context of climate change, adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2007b). Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation:

- **Anticipatory adaptation** – Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.
- **Autonomous adaptation** – Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.
- **Planned adaptation** – Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

Adaptation Fund. A mechanism established to finance concrete adaptation projects and programmes in developing countries that are Parties to the Kyoto Protocol (UNFCCC, n.d.). The Fund is to be financed with a share of proceeds from clean development mechanism (CDM) project activities and receive funds from other sources.

Annex I Parties. The industrialised countries listed in Annex I to the United Nations Climate Change Convention, which were committed to return their greenhouse-gas emissions to 1990 levels by the year 2000 (UNFCCC, n.d.). They have also accepted emissions targets for the period 2008-2012 as per the Kyoto Protocol. They include the 24 original OECD members, the European Union, and 14 countries with economies in transition.

Carbon market. A popular but misleading term for a trading system through which countries may buy or sell units of greenhouse-gas emissions in an effort to meet their national limits on emissions, either under the Kyoto Protocol or under other agreements, such as that among member states of the European Union (UNFCCC, n.d.). The term comes from the fact that carbon dioxide is the predominant greenhouse gas and other gases are measured in units called ‘carbon-dioxide equivalents’.

Carbon sequestration. The process of removing carbon from the atmosphere and depositing it in a reservoir (UNFCCC, n.d.).

Certified Emission Reductions (CER). A Kyoto Protocol unit equal to 1 metric tonne of CO₂-equivalent. CERs are issued for emission reductions from CDM project activities. Two special types of CERs called temporary certified emission reduction (tCERs) and long-term certified emission reductions (lCERs) are issued for emission removals from afforestation and reforestation CDM projects (UNFCCC, n.d.).

Clean Development Mechanism (CDM). A mechanism under the Kyoto Protocol through which developed countries may finance greenhouse-gas emission reduction or removal projects in developing countries, and receive credits for doing so which they may apply towards meeting mandatory limits on their own emissions (UNFCCC, n.d.).

Desertification. Land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (UNCCD, 1994).

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 (ISDR, 2008). A disaster is a

function of the risk process. It results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk.

Disaster mitigation. Structural and non-structural measures undertaken to limit the adverse impact of natural hazards, environmental degradation and technological hazards (ISDR, 2008).

Disaster 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 (ISDR, 2008).

Disaster prevention. Activities to provide outright avoidance of the adverse impact of hazards and means to minimize related environmental, technological and biological disasters (ISDR, 2008). Depending on social and technical feasibility and cost/benefit considerations, investing in preventive measures is justified in areas frequently affected by disasters. In the context of public awareness and education, related to disaster risk reduction changing attitudes and behaviour contribute to promoting a 'culture of prevention'.

Disaster response (relief). The provision of assistance or intervention during or immediately after a disaster to meet the life preservation and basic subsistence needs of those people affected (ISDR, 2008). It can be of an immediate, short-term, or protracted duration.

Disaster recovery. Decisions and actions taken after a disaster with a view to restoring or improving the pre-disaster living conditions of the stricken community, while encouraging and facilitating necessary adjustments to reduce disaster risk (ISDR, 2008). Recovery (rehabilitation and reconstruction) affords an opportunity to develop and apply disaster risk reduction measures.

Disaster risk. The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions (ISDR, 2008). Conventionally risk is expressed by the notation: Risk = Hazards x Vulnerability. Some disciplines also include the concept of exposure to refer particularly to the physical aspects of vulnerability. Beyond expressing a possibility of physical harm, it is crucial to recognize that risks are inherent or can be created or exist within social systems. It is important to consider the social contexts in which risks occur and that people therefore do not necessarily share the same perceptions of risk and their underlying causes.

Disaster risk reduction. The conceptual framework of elements considered with the possibilities to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of hazards, within the broad context of sustainable development (ISDR, 2008). The disaster risk reduction framework is composed of the following fields of action:

- Risk awareness and assessment, including hazard analysis and vulnerability/capacity analysis;
- Knowledge development, including education, training, research and information;
- Public commitment and institutional frameworks, including organisational, policy, legislation and community action;
- Application of measures including environmental management, land-use and urban planning, protection of critical facilities, application of science and technology, partnership and networking, and financial instruments;

- Early warning systems, including forecasting, dissemination of warnings, preparedness measures and reaction capacities.

Drought. A naturally-occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems (UNCCD, 1994).

Ecological engineering (eco-engineering). A long-term, ecological strategy to manage a site with regard to natural or man-made hazards (Norris et al, 2008; Mitsch and Jørgensen, 2004). The proactive design of sustainable ecosystems which integrate human society with its natural environment, for the benefit of both. It involves the creation and restoration of ecosystems.

Ecosystem. An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit (MEA, 2005). Humans are an integral part of ecosystems. Ecosystems vary enormously in size; a temporary pond in a tree hollow and an ocean basin can both be ecosystems.

Ecosystem services. Ecosystem services are the benefits people obtain from ecosystems (MEA, 2005). These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits.

Environmental management. Management and the managed use of the environment, both natural and man-made.

Floodplain. A land area adjacent to rivers and streams that is subject to recurring inundation.

Greenhouse gases (GHGs). These are the gases released by human activity that are responsible for climate change and global warming (Capoor and

Ambrosi, 2007). The six gases listed in Annex A of the Kyoto Protocol are carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), as well as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆).

Hard engineering. In the context of disaster risk reduction, the use of man-made structures, such as concrete breakwalls or steel sheet piling to stabilize shorelines (Caulk et al, 2000).

Kyoto Mechanisms. Three procedures established under the Kyoto Protocol to increase the flexibility and reduce the costs of making greenhouse-gas emissions cuts; they are the Clean Development Mechanism, Emissions Trading and Joint Implementation (UNFCCC, n.d.).

Kyoto Protocol. An international agreement standing on its own, and requiring separate ratification by governments, but linked to the UNFCCC (UNFCCC, n.d.). The Kyoto Protocol, among other things, sets binding targets for the reduction of greenhouse-gas emissions by industrialized countries.

Mitigation. In the context of climate change, human intervention to reduce the sources or enhance the sinks of greenhouse gases (UNFCCC, n.d.). Examples include using fossil fuels more efficiently for industrial processes or electricity generation, switching to solar energy or wind power, improving the insulation of buildings, and expanding forests and other «sinks» to remove greater amounts of carbon dioxide from the atmosphere.

National Adaptation Programme of Action (NAPA) A UNFCCC supported process for Least Developed Countries (LDCs) to identify priority activities that respond to their urgent and immediate needs with regard to adaptation to climate change (UNFCCC, n.d.).

Natural hazard. Natural processes or phenomena occurring in the biosphere that may constitute a damaging event (ISDR, 2008). Natural hazards can be classified by

origin namely: geological, hydrometeorological or biological. Hazardous events can vary in magnitude or intensity, frequency, duration, area of extent, speed of onset, spatial dispersion and temporal spacing.

Offsets. Offsets designate the emission reductions from project-based activities that can be used to meet compliance – or corporate citizenship – objectives vis-à-vis greenhouse gas mitigation (Capoor and Ambrosi, 2007).

Soft engineering. In the context of disaster risk reduction, the use of ecological principles and practices to achieve stabilisation and safety (Caulk et al, 2000). Soft engineering is achieved by using vegetation and other materials and improving ecological features.

Structural / non-structural measures. Structural measures refer to any physical construction to reduce or avoid possible impacts of hazards, which include engineering measures and construction of hazard-resistant and protective structures and infrastructure (ISDR, 2008). As physical measures, both hard and soft engineering can be referred to as ‘structural’. Non-structural measures refer to policies, awareness, knowledge development, public commitment, and methods and operating practices, including participatory mechanisms and the provision of information, which can reduce risk and related impacts.

Verified Emission Reduction (VER). A unit of greenhouse gas emission reductions that has been verified by an independent auditor (Capoor and Ambrosi, 2007). This designates emission reductions units that are traded on the voluntary market.

Voluntary carbon offset. Individuals and organisations may choose to reduce their greenhouse gas emissions although not bound to do so under the Kyoto Protocol by buying carbon credits. Credits for such purposes are generally required in small quantities. Buyers generally purchase credits from smaller projects that are not interesting for a Kyoto compliance buyer. Although the project is smaller and does not

go through the Clean Development Mechanism project cycle, it must be validated and verified by an independent party.

Vulnerability. The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards (ISDR, 2008). In the context of climate change, the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (UNFCCC, n.d.).

Washlands. An area of the floodplain that is allowed to flood or is deliberately flooded by a river or stream for flood management purposes, with potential to form a wetland habitat (Morris et al, 2003).

Wetlands. Areas of marsh, fen, peatland and water, both natural and artificial, temporarily or permanently waterlogged (Ramsar Convention, 2005). The water may be static or flowing, fresh or brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres.

BIBLIOGRAPHY

Alongi, D.M. 2008. Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science* 76:1 1-13.

Baltensweiler, A. and Hallenbarter, D. 2007. Mit Modellen dem Schutzwald auf der Spur. Jahresbericht der Eidg. Forschungsanstalt WSL 2006: 10-11. ISSN 1424-2699: http://www.waldwissen.net/themen/naturgefahren/schutzwald/wsl_schutzwald_modell_EN (Accessed 21 May 2008).

Barbier, E.B., Koch, E.W., Silliman, B.R., Hacker, S.D., Wolanski, E., Primavera, J., Granek, E.F., Polasky, S., Aswani, S., Cramer, L.A., Stoms, D.M., Kennedy, C.J., Bael, D., Kappel, C.V., Perillo, G.M.E., and Reed, D.J. 2008. Coastal Ecosystem-Based Management with Nonlinear Ecological Functions and Values. *Science* 319:5861, 321 – 323.

Baxter, R. 2001. Wildfires! EC professionals needed. *Erosion Control* 8:2. http://www.forester.net/ec_0103_wildfires.html (accessed 02 June 2008).

Bebi, P. Personal Communication. WSL - Institute for Snow and Avalanche Research SLF, Research Unit Ecosystem Boundaries, Forest and Treeline Ecotone Group, Flüelastrasse 11, CH-7260 Davos.

Bourne, J. 2000. Louisiana's vanishing wetlands: Going, going. . . . *Science*, 289: 5486.

Brander, R.W., Kench, P.S. and Hart, D. 2004. Spatial and temporal variations in wave characteristics across a reef platform, Warraber Island, Torres Strait Australia. *Marine Geology* 207: 169-184.

Brassel, P. and Lischke, H. (eds) 2001. Swiss National Forest Inventory: Methods and Models of the Second Assessment. Swiss Federal Research Institute WSL.

Caldecott, J.O. 2007. *Water: Life in Every Drop*. Virgin Books (London).

Caldecott, J.O. and Karim, A. 2008. Final Report of the Identification Mission for EC support in the area of Environment and Disaster Management in Bangladesh. European Commission (Dhaka).

Capoor, K. and Ambrosi, P. 2007. State and Trends of the Carbon Market 2007. The World Bank. Also: http://en.wikipedia.org/wiki/Emissions_trading#cite_note-28 (accessed 3 June 2008).

Caulk, A.D., Gannon, J. E., Shaw, J. R. and Hartig, J. H. (eds). 2000. Best Management Practices for Soft Engineering of Shorelines. Greater Detroit American Heritage River Initiative.

Cleugh, H.A. 1998. Effects of windbreaks on airflow, microclimates and crop yields. *Agroforestry Systems*, 41(1): 55-84.

Cochard, R., Ranamukhaarachchi S.L., Shivakoti, G.P., Shipin, O.V., Edwards, P.J., and Seeland, K.T. 2008. The 2004 tsunami in Aceh and Southern Thailand: A review on coastal ecosystems, wave hazards and vulnerability. *Perspectives in Plant Ecology, Evolution and Systematics* 10: 3-40.

Dahdouh-Guebas, F., Jayatissa, L.P., Di Nitto, D., Bosire, J.O., Lo Seen, D. and Koedam, H. 2005. How Efficient Were Mangroves as a Defence Against the Recent Tsunami? *Current Biology* 15, 12.

Danielsen, F., Sorensen, M.K., Olwig, M.F., Selvam, V., Parish, F., Burgess, N.D., Hiraishi, T., Karunagaran, V.M., Rasmussen, M.S., Hansen, L.B., Quarto, A. and Suryadiputra, N. 2005. The Asian Tsunami: A Protective Role for Coastal Vegetation. *Science*, 310: 643.

Dilley, M., Chen, R.S., Deichmann, U., Lerner-Lam, A. L., Arnold, M., Agwe, J., Buys, P., Kjekstad, O., Lyon, B. and Yetman, G. 2005. Natural Disaster Hotspots: A Global Risk Analysis. Disaster Risk Management Series No 5. The World Bank.

EC. 2006. Regional Environmental Profile of Asia. Prepared by Julian Caldecott and Richard Pagett for the European Commission. Agrer and European Commission (Brussels).

Eidg. Institutes für Schnee- und Lawinenforschung Weissfluhjoch / Davos (1970/71 to 1988/89): Schnee und

- Lawinen in den Schweizer Alpen Winter 1970/71 bis Winter 1988/89, Winterberichte des Eidg. Institutes für Schnee- und Lawinenforschung Weissfluhjoch (Davos).
- EM-DAT, CRED, University of Louvain, Belgium. In: IFRC 2007. World Disasters Report 2007: Focus on Discrimination.
- Eong, O.J. 2005. Tsunami Damage on Mangroves in Peninsular Malaysia. In: The Importance of Mangrove and Other Coastal Ecosystems in Mitigating Tsunami Disasters. Symposium held in Kuala Lumpur, Malaysia, 23 August 2005.
- Ewel et al, 1998; Ewel, K.C., Twilley, R.R., and Eong Ong, J. 1998. Different Kinds of Mangrove Forest Provide Different Goods and Services. *Global Ecology and Biogeography Letters* 7:83-44.
- FAO. 2006. Coastal protection in the aftermath of the Indian Ocean tsunami: what role for forests and trees? 28-31 August 2006. <http://www.fao.org/forestry/coastalprotection/en/> (accessed 29 April 2008).
- FAO. 2006. Global Forest Resources Assessment 2005 – Progress towards sustainable forest management. FAO, Rome, Italy.
- Federal Interagency Floodplain Management Task Force. 1992. Floodplain Management in the United States: An Assessment Report, Volume 2: Full Report. L. R. Johnston Associates, Washington DC, USA.
- Forbes, K. and Broadhead, J. 2007. The role of coastal forests in the mitigation of tsunami impacts. RAP publication 2007/1. FAO, Rome, Italy.
- Greenbelt Movement. 2008. <http://greenbeltmovement.org/index.php> (accessed 2 May 2008).
- Hadi, S., Latief, H., and Muliddin. 2003. Analysis of Surface Wave Attenuation in Mangrove Forests. *Proc. ITB Eng. Science* 35: 2, 89-108.
- Hamilton, L.S. and Snedaker, S.C. 1984. Handbook for Mangrove Area Management. Environment and Policy Institute, East-West Centre (Honolulu, Hawaii, USA).
- Harvey, F. 27 April 2007. The carbon market. *Financial Times*.
- Hiraishi, T. and Harada, K. 2003. Greenbelt Tsunami Prevention in South-Pacific Region. Report for the Port and Airport Research Institute. Vol 42. No. 2. June 2003. Japan.
- Huq, S. and Ayers, J. 2007. Critical List: The 100 most vulnerable nations to climate change. *Sustainable Development Opinion*. Dec 2007. IIED.
- IFRC. 2002. World Disasters Report 2002 – Focus on reducing risk. IFRC, Geneva, Switzerland.
- Ingold, T.S. 1982. Reinforced Earth.
- International Tsunami Information Centre. <http://ioc3.unesco.org/itic/> (accessed 02 May 2008).
- IPCC. 2007a. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change.
- IPCC. 2007b. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change.
- ISDR. 2005. Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. United Nations secretariat of the International Strategy for Disaster Reduction.
- ISDR. 2007. Words into Action: A Guide for Implementing the Hyogo Framework. Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. United Nations secretariat of the International Strategy for Disaster Reduction.
- ISDR. 2007. Drought Risk Reduction Framework and Practices: Contributing to the Implementation of the Hyogo Framework for Action. United Nations secretariat of the International Strategy for Disaster Reduction.
- ISDR. 2008. Disaster statistics. <http://www.unisdr.org/disaster-statistics/introduction.htm> (accessed 20 May 2008).

- ISDR 2008. Terminology on disaster risk reduction. <http://www.unisdr.org/eng/library/lib-terminology-eng.htm> (accessed 05 June 2008).
- Iverson, L.R. and Prasad, A.M. 2007. Using landscape analysis to assess and model tsunami damage in Aceh province, Sumatra. *Landscape Ecology* 22:323–331.
- Kathiresan, K. and Rajendran, N. 2005. Coastal mangrove Forests Mitigated Tsunami. *Estuarine, Coastal and Shelf Science* 65: 601-606
- Kerr, A.M., Baird, A.H., and Campbell, S.T. 2007 Comments on “Coastal mangrove forests mitigated tsunami” by K. Kathiresan and N. Rajendran [*Estuar. Coast. Shelf Sci.* 65 (2005) 601e606]. *Estuarine, Coastal and Shelf Science* 67: 539-541.
- Klein, R.J.T., S. Huq, F. Denton, T.E. Downing, R.G. Richels, J.B. Robinson, F.L. Toth. 2007. Inter-relationships between adaptation and mitigation. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 745-777.
- Latief, H. and Hadi, S. 2008. The Role of Forests and Trees in Protecting Coastal Areas Against Tsunami. Regional technical workshop “Coastal protection in the aftermath of the Indian Ocean tsunami: what role for forests and trees?” Khao Lak, Thailand : 28 - 31 August 2006.
- Li Z. 23 May 2006. Sandstorms affect air quality in Northern China, Beijing. *Worldwatch Institute News Updates*. <http://www.worldwatch.org/node/3934> (accessed 29 April 2008)
- Macintosh, D.J. and Ashton, E.C. 2005. Principles for a code of conduct for the management and sustainable use of mangrove ecosystems. World Bank, ISME, cenTER Aarhus. Work in Progress for Public Discussion. Version: 10 March 2005.
- Massel, S.R., Furukawa, K., and Brinkman, R.M. 1999. Surface wave propagation in mangrove forests. *Fluid Dynamics Research* 24: 219-249.
- Mazda, Y., Magi, M., Kogo, M. and Hong, P.N. 1997. Mangroves as a coastal protection from waves in the Tong King Delta, Vietnam. *Mangroves and Salt Marshes* 1: 127-135.
- Mazda, Y. Wolanski, E. and Ridd, P.V. 2006. *The Role of Physical Processes in Mangrove Environments Manual for the preservation and utilisation of mangrove ecosystems.*
- MEA. 2005. *Ecosystems and Human Well-Being: Current State and Trends: Findings of the Condition and Trends Working Group. Millennium Ecosystem Assessment.*
- Meister, R. 2002. *Lawinen: Warnung, Rettung, Prävention. IKAR-CISA: International Commission for Alpine Rescue.*
- Mitsch, W. J. and Jørgensen, S.E. 2004. *Ecological engineering and ecosystem restoration.*
- Moench, M., Mechler, R. and Stapleton, S. 2007. *Guidance note on the Costs and Benefits of Disaster Risk Reduction. Prepared for ISDR High level Platform on Disaster Risk Reduction. 4-7 June 2007.*
- Morris, J., Hess, T. M., Gowing, D. J., Leeds-Harrison, P. B., Bannister, N., Vivash, R. M. N. and Wade, M. 2003. *Integrated Washland Management for Flood Defence and Biodiversity. 38th DEFRA Flood and Coastal Management Conference.*
- Nicholls, R. J. 2005. Storm surges in coastal areas. In: Arnold. M., Chen, R.S., Deichmann, U., Dilley, M., Lerner-Lam, A. L., Pullen, R.E. and Trohanis, Z. 2005. *Natural Disaster Hotspots Case Studies. Disaster Risk Management Series No 6. The World Bank.*
- Norris, J. E., Stokes, A., Mickovski, S. B., Cammeraat, E., van Beek, R., Nicoll, B. C. and Achim, A. (eds). 2008. *Slope Stability and Erosion Control: Ecotechnological Solutions.*
- Othman, M.A. 1994. Value of mangroves in coastal protection. *Hydrobiologia* 285: 277-282, 1994.
- Oxfam. 2007a. *Climate Alarm: Disasters increase as climate change bites. Oxfam Briefing Paper 108 (Oxfam, London).*

- Oxfam. 2007b. Up in smoke? Asia and the Pacific. The threat from climate change to human development and the environment. The fifth report from the Working Group on Climate Change and Development (Oxfam, London).
- Oxfam International. 2007. Adapting to climate change: what's needed in poor countries and who should pay. Oxfam Briefing Paper 104.
- Pye-Smith, C. and Feyerabend, G.B. 1994. *The Wealth of Communities: Stories of Success in Local Environmental Management*. Earthscan (London, UK).
- Quartel, S., Kroon, A., Augustinus, P.G.E.F., Van Santen, P. and Tri, N.H. 2007. Wave attenuation in coastal mangroves in the Red River Delta, Vietnam. *Journal of Asian Earth Sciences* 29: 576–584.
- Ramsar Convention on Wetlands. 2005. *Wetland Values and Functions*. Ramsar Bureau, Gland, Switzerland.
- Salazar-Vallejo, S.I. 2002. Huracanes y Biodiversidad Costera Tropical. *Revista de Biología Tropical* 50:2 415–428.
- Sanchez-Azofeifa, G. A., Pfaff, A., Robalino, J. A. and Boomhower, J.P. 2007. Costa Rica's Payment for Environmental Services Program: Intention, Implementation, and Impact. *Conservation Biology* 21:5.
- Scheuren, J-M., personal communication, EM-DAT, WHO Collaborating Centre for Research on the Epidemiology of Disasters (CRED), School of Public Health, Université catholique de Louvain, 30.94 Clos Chapelle-aux-Champs, 1200 Brussels, Belgium.
- Sheppard, C., Dixon, D.J., Gourlay, M., Sheppard, A., and Payet, R. 2005. Coral mortality increases wave energy reaching shoers protected by reef flats: Examples from the Seychelles. *Estuarine, Coastal and Shelf Science* 64: 223–234.
- Sidle, R.C. Kyoto University, Disaster Prevention Research Institute, Japan. Personal Communication 23-06-2008.
- Sidle, R.C. and Ochiai, H. 2006. *Landslides: Processes, Prediction, and Land Use*. Am. Geophysical Union, Water Resour. Monogr. No. 18.
- Siripong, A., Yumuang, S. and Swangphol, N. 2005. The 26 December 2004 Tsunami: Impacts on Mangroves along some Thai Coasts. In: *The Importance of Mangrove and Other Coastal Ecosystems in Mitigating Tsunami Disasters*. Symposium held in Kuala Lumpur, Malaysia, 23 August 2005.
- Stern N.H. 2006. *The economics of climate change: Stern review on the economics of climate change*. HM Treasury, UK.
- Smith, R. 2000. *The Potential Market for Sisal and Henequen Geotextiles*. In: *Common Fund for Commodities – Alternative Applications for Sisal and Henequen – Technical paper No. 14*. Proceedings of a Seminar held by FAO and CFC. <http://www.fao.org/DOCREP/004/Y1873E/y1873e08.htm#TopOfPage> (accessed 23 May 2008).
- Stone, G. W. and McBride R. A. 1998. Louisiana barrier islands and their importance in wetland protection: Forecasting shoreline change and subsequent response of wave climate. *Journal of Coastal Research* 14: 900–915.
- Stuip, M.A.M, Baker, C.J. and Oosterberg, W. 2002. *The socio-economics of wetlands*. Wetlands International and RIZA. Quoted in: De Groot, R.S., Stuip, M.A.M., Finlayson, C.M. and Davidson, N. 2006. *Valuing wetlands: guidance for valuing the benefits derived from wetland ecosystem services*. Ramsar Technical Report No. 3/CBD Technical Series No. 27. Ramsar Convention Secretariat and Secretariat of the Convention on Biological Diversity.
- 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.
- Swiss Federal Office for the Environment. *Protection forests*. Available in French: <http://www.bafu.admin.ch/naturgefahren/01920/index.html?lang=fr> (accessed 09 May 2008).

Tanaka, N., Sasaki, Y., Mowjood, M. I. M., Jinadasa, K. B. S. N. and Homchuen, S. 2007. Coastal vegetation structures and their functions in tsunami protection: experience of the recent Indian Ocean tsunami. *Landscape and Ecological Engineering*. 3: 33–45.

Telegraph News. 2008. <http://www.telegraph.co.uk/news/1961980/Myanmar-cyclone-death-toll-will-hit-200,000,-say-British.html> (accessed 4 June 2008).

UNCCD. 1994. United Nations Convention to Combat desertification, Article 1.

UNDP. 2007. Human Development Report 2007/2008: Fighting Climate Change – Human Solidarity in a Divided World. United Nations Development Programme (New York).

UNEP-WCMC. 2006. In the front line: shoreline protection and other ecosystem services from mangroves and coral reefs. UNEP-WCMC, Cambridge, UK.

UNFCCC. 2006. Application of environmentally sound technologies for adaptation to climate change. Technical paper. FCCC/TP/2006/2.

UNFCCC. 2007a. Climate Change: Impacts, Adaptation and Vulnerabilities in Developing Countries.

UNFCCC. 2007b. Investment and Financial Flows to Address Climate Change.

UNFCCC (n.d.). Glossary of climate change acronyms. http://unfccc.int/essential_background/glossary/items/3666.php#M (accessed 5 June 2008).

Yohe, G.W., R.D. Lasco, Q.K. Ahmad, N.W. Arnell, S.J. Cohen, C. Hope, A.C. Janetos and R.T. Perez. 2007. Perspectives on climate change and sustainability. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK.

Youlin, Y., Squires, V. and Li, Q. 2001. Global alarm: Dust and sandstorms from the world's drylands. UNCCD.

Wikipedia.org. 2008. <http://en.wikipedia.org/wiki/Avalanche> (accessed 3 June 2008).

Woodley, J.D. 1992. The incidence of hurricanes on the north coast of Jamaica since 1870: are the classic reef descriptions atypical? *Hydrobiologia* 247: 133-138.

Woodley, J.D., Chornesky, E.A., Clifford, P.A., Jackson, J.B.C., Kaufman, L.S., Knowlton, N., Lang, J.C., Pearson, M.P., Porter, J.W., Rooney, M.C., Rylaarsdam, K.W., Tunnicliffe, V.J., Wahle, C.M., Wulff, J.L., Curtis, A.S.G., Dallmeyer, M.D., Jupp, B.P., Koehl, M.A.R., Neigel, J., and Sides, E.M. 1981. Hurricane Allen's Impact on Jamaican Coral Reefs. *Science* 214: 749-755.

ProAct
network



ProAct Network Secretariat
Chemin des Couleuvres 8B
CH-1295 Tannay
Switzerland

Telephone: +41 22 960 8060
Fax: +41 22 960 8069

Email: info@proactnetwork.org
Web page: www.proactnetwork.org