

The role of ecosystems in disaster risk reduction



UNITED NATIONS
UNIVERSITY

UNU-EHS

Institute for Environment
and Human Security



The role of ecosystems in disaster risk reduction

Edited by Fabrice G. Renaud, Karen Sudmeier-Rieux
and Marisol Estrella



**United Nations
University Press**

TOKYO • NEW YORK • PARIS

© United Nations University, 2013

The views expressed in this publication are those of the authors and do not necessarily reflect the views of the United Nations University.

United Nations University Press
United Nations University, 53-70, Jingumae 5-chome,
Shibuya-ku, Tokyo 150-8925, Japan
Tel: +81-3-5467-1212 Fax: +81-3-3406-7345
E-mail: sales@unu.edu General enquiries: press@unu.edu
<http://www.unu.edu>

United Nations University Office at the United Nations, New York
2 United Nations Plaza, Room DC2-2062, New York, NY 10017, USA
Tel: +1-212-963-6387 Fax: +1-212-371-9454
E-mail: unuony@unu.edu

United Nations University Press is the publishing division of the United Nations University.

Cover design by Maria Paul
Cover photograph by Michael Crozier

Printed in the United States of America for the Americas and Asia
Printed in the United Kingdom for Europe, Africa and the Middle East

ISBN 978-92-808-1221-3
e-ISBN 978-92-808-7190-6

Library of Congress Cataloging-in-Publication Data

The role of ecosystems in disaster risk reduction / edited by Fabrice G. Renaud,
Karen Sudmeier-Rieux and Marisol Estrella.

pages cm

Includes bibliographical references and index.

ISBN 978-9280812213 (pbk.)

1. Hazardous geographic environments. 2. Natural disasters – Environmental aspects. 3. Ecosystem management. 4. Emergency management. 5. Ecological disturbances. I. Renaud, Fabrice G. II. Sudmeier-Rieux, Karen. III. Estrella, Marisol.

GF85.R65 2013

363.34'72—dc23

2013002399

Endorsements

“The application of disaster risk reduction has saved millions of lives and helped communities globally. But the ecosystems on which communities depend upon for their protection, economic well-being and recovery have, until now, been largely ignored in disaster risk reduction. Incorporating ecosystems into disaster risk reduction can save lives, aid recovery and help build a more resilient and secure planet for all. This timely book is an essential tool for policymakers, scientists, economists, sociologists, and practitioners on why and how to integrate ecosystems into disaster risk reduction. Scientific studies have repeatedly confirmed the role of healthy ecosystems in providing resilience against disasters; and they have demonstrated how environmental degradation contributes to more severe disasters including droughts, floods, and storm surges. A key challenge is how to integrate this knowledge into policy and planning. Multi-disciplinary approaches that combine ecology and engineering, science with sociology and economics have to be implemented. This book provides a sobering evaluation of the consequences of ignoring ecosystems in disaster risk reduction. But it also offers a range of well-considered and practical solutions which could be used in many existing regulations, policies and risk reduction activities.”

Deborah Brosnan, Environment and Policy Scientist, University of California, Davis, One Health Institute

“In 2004, the earth shook, the waters rose, and the Indian Ocean tsunami changed the world. Almost a quarter of a million coastal dwellers died that day. Several years later, the earth shook again, this time in Haiti, and a disturbingly similar number of people lost their lives. In both cases,

sustainable, healthy ecosystems could have substantially mitigated these disasters.

Recent disasters in Japan, the US East Coast, and several in SE Asia including Thailand and the Philippines, have led to a simple yet unsolvable question: How can the world's most vulnerable populations reduce the risk posed by natural hazards?

The Role of Ecosystems in Disaster Risk Reduction brings together the world's experts on how the natural environment has evolved tools to buffer against natural hazards in real, sustainable and cost effective ways. From coastal ecosystems that buffer large waves while providing valuable services to Indian Ocean communities to protective services that forests provide in the Swiss Alps, this book is a valuable contribution showing how environmentally and economically sustainable solutions can provide real benefits to exposed populations and resources."

Brian G. McAdoo, College Rector, Professor of Science, Yale-NUS College

"Why do ecosystems matter in disaster risk reduction? This book meets an urgent need. Intuitively we understand that working with and not against nature will help in protecting us from impacts of extreme natural events, but evidence has been lacking regarding the effectiveness and efficiency of such measures, particularly as alternatives to or in combination with engineered solutions. This rich collection of research findings and tested practices takes us around the globe, from coasts to forests, from agricultural landscapes to protected areas, from cities to mountains. It addresses conflicts between socio-economic development and environmental concerns, taken to its extreme in Cape Town where policymakers and planners have had to overcome the legacy of apartheid to find a sustainable trajectory. And it gives readers an array of methods and instruments to help overcome the sector and disciplinary stovepipes that often stand in the way of the holistic approaches needed to meet and reconcile multiple objectives: protecting vulnerable people and assets, halting the erosion of biodiversity and making sustainable use of our natural resource base. Those looking for the state of the art in ecosystem-based disaster risk reduction now know where to go."

Johan Schaar, Co-Director, Vulnerability and Adaptation Initiative, World Resources Institute

"With the human and economic losses of disaster events projected to grow, and with two-thirds of global disaster losses being caused by hydro-meteorological events, this is a very timely compilation of the evidence needed to link up ecosystem management with disaster risk management as mutually reinforcing initiatives. It comes at a time when the post-2015

development paradigm and framework for disaster risk management are on the drawing boards. It will surely go a long way in informing the convergence of policies and benchmarks for ecosystem management as an integral aspect of climate and disaster risk management, to ensure near-term development gains and long-term climate and disaster resilience.

An extremely timely and comprehensive publication, a game-changer in the approach to natural resource management for sustainable development – and for climate and disaster resilience.”

Prashant Singh, Team Leader, Partnerships and Governance, Global Facility for Disaster Reduction and Recovery (GFDRR) at The World Bank

“How do ecosystems relate to disasters? How do ecosystems contribute to disaster risk reduction (DRR)? This book gives us answers to these questions.

It is timely to address DRR-related coastal issues and water resources management, which are inevitable to countries being prone to water-related disasters such as storm surges and tsunamis as well as floods, droughts and erosion. Forestry and vegetation cover are also dealt with in relation to land management and landslides. These are serious problems which many parts of the world are facing in the twenty-first century under the pressure of sustainable development and survivable societies. Future perspectives are also given in concluding chapters.

This book will be of interest to disaster managers and policymakers, eco-hydrologists, coastal and water resources planners, engineers and managers, research scientists and students, international donor agencies, and many professionals from NGOs and the media.”

Kaoru Takara, Disaster Prevention Research Institute, Kyoto University, Japan

Contents

List of figures.	xii
List of tables	xvii
List of boxes	xix
List of contributors.	xxi
Foreword by <i>Margareta Wahlström</i>	xxviii
Acknowledgements	xxx
List of abbreviations.	xxxii
Part I: Why do ecosystems matter in disaster risk reduction?	1
1 The relevance of ecosystems for disaster risk reduction	3
<i>Fabrice G. Renaud, Karen Sudmeier-Rieux and Marisol Estrella</i>	
2 Ecosystem-based disaster risk reduction (Eco-DRR): An overview	26
<i>Marisol Estrella and Nina Saalismaa</i>	

Part II: Ecosystems and coastal disaster risk reduction	55
3 Investigating the performance of coastal ecosystems for hazard mitigation	57
<i>Sam S.L. Hettiarachchi, Saman P. Samarawickrama, Harindra J.S. Fernando, A. Harsha R. Ratnasooriya, N.A. Kithsiri Nandasena and Srimal Bandara</i>	
4 Bioshields: Mangrove ecosystems as resilient natural coastal defences	82
<i>Carmen Lacambra, Daniel A. Friess, Tom Spencer and Iris Möller</i>	
5 Integrating the role of ecosystems in disaster risk and vulnerability assessments: Lessons from the Risk and Vulnerability Assessment Methodology Development Project (RiVAMP) in Negril, Jamaica	109
<i>Pascal Peduzzi, Adonis Velegrakis, Marisol Estrella and Bruno Chatenoux</i>	
6 Increasing the resilience of human and natural communities to coastal hazards: Supporting decisions in New York and Connecticut	140
<i>Michael W. Beck, Ben Gilmer, Zach Ferdaña, George T. Raber, Christine C. Shepard, Imen Meliane, Jeffrey D. Stone, Adam W. Whelchel, Mark Hoover and Sarah Newkirk</i>	
7 A coastal adaptation strategy for the City of Cape Town: An ecosystem-based management approach towards risk reduction	164
<i>Darryl Colenbrander, Penny Price, Gregg Oelofse and Sakhile Tsotsobe</i>	
8 Lessons from local initiatives on ecosystem-based climate change work in Tonga	191
<i>Stavros Mavrogenis and Ilan Kelman</i>	
Part III: Water resources management for disaster risk reduction .	219
9 Good flood, bad flood: Maintaining dynamic river basins for community resilience	221
<i>Pieter van Eijk, Chris Baker, Romana Gaspirc and Ritesh Kumar</i>	

10 Utilizing integrated water resources management approaches to support disaster risk reduction.	248
<i>James Dalton, Radhika Murti and Alvin Chandra</i>	
11 The matter is not if, but when and where: The role of capacity development in disaster risk reduction aiming for a sustainable water supply and sanitation.	270
<i>Madeleine Fogde, Luis Macario and Kirsten Carey</i>	
Part IV: Sustainable land management for disaster risk reduction .	291
12 The role of vegetation cover change in landslide hazard and risk.	293
<i>Maria Papathoma-Koehle and Thomas Glade</i>	
13 Protection forests: A key factor in integrated risk management in the Alps	321
<i>André Wehrli and Luuk Dorren</i>	
14 Forest cover and landslide trends: A case study from Dolakha District in central-eastern Nepal, 1992–2009.	343
<i>Stéphanie Jaquet, Karen Sudmeier-Rieux, Marc-Henri Derron and Michel Jaboyedoff</i>	
Part V: Policy, planning and future perspectives	369
15 Reducing vulnerability: The role of protected areas in mitigating natural disasters	371
<i>Nigel Dudley, Kathy MacKinnon and Sue Stolton</i>	
16 Urban disaster risk reduction and ecosystem services.	389
<i>Lorenzo Guadagno, Yaella Depietri and Urbano Fra Paleo</i>	
17 Applying environmental impact assessments and strategic environmental assessments in disaster management	416
<i>Anil Kumar Gupta and Sreeja S. Nair</i>	
18 Opportunities, challenges and future perspectives for ecosystem-based disaster risk reduction	437
<i>Marisol Estrella, Fabrice G. Renaud and Karen Sudmeier-Rieux</i>	
Index	457

Figures

2.1	Environmental causes and consequences of disasters	29
2.2	Multiple benefits of ecosystems	31
2.3	Eco-DRR in the framework of sustainable development . .	39
3.1	Wave profiles in the central part of the tank	67
3.2	Schematic diagram of the experimental set-up	67
3.3	Simulation of coral reefs in two-dimensional physical modelling.	68
3.4	Representation of high-density (20 per cent porosity) and low-density (50 per cent porosity) structures.	68
3.5	Normalized velocity as a function of normalized height = 10 cm, $\omega = 0.4$ Hz	69
3.6	Normalized velocity as a function of normalized height = 20 cm, $\omega = 0.4$ Hz	69
3.7	Normalized velocity as a function of normalized height = 30 cm, $\omega = 0.4$ Hz	70
3.8	Variation of normalized velocity with the porosity of the structure for solitary waves	70
3.9	Detailed sketch of a solitary wave.	74
3.10	Experimental set-up	74
3.11	The two types of vegetation found in the Sri Lankan coastal belt	75
3.12	Comparison of experimental wave profile with theoretical wave	76
3.13	Spatial progress in surface elevation.	77

3.14	Maximum water surface elevation.	78
4.1	The interconnected ecosystem services provided by mangroves.	83
4.2	Examples of ecosystem services provided by mangroves. . .	98
5.1	Distribution of the coastal ecosystems of Negril, Jamaica, and locations of the 74 beach profiles used in the study . . .	113
5.2	Comparison between model predictions using natural profiles and predictions using equivalent linear profiles, under the same wave and sedimentary conditions	118
5.3	Numerical model results for (a) wave heights and (b) wave-induced currents at Negril	123
5.4	Numerical model predictions for cross-shore wave height and bed shear stress distributions in the presence of shallow coral reefs.	124
5.5	Numerical model predictions for cross-shore bed shear stress distribution in the presence of patchy and dense seagrasses	125
5.6	The means of the lower and upper limits of the beach retreats estimated by the ensemble models	126
5.7	Near-shore bed cover and shoreline changes along Negril's beaches, also showing the location of the 74 beach profiles used	127
5.8	Scatter plots of beach retreat rates against the cross-shore widths of (a) the shallow coral reefs and (b) the seagrass meadows, showing an inverse relationship.	129
5.9	Flooding in the wider Negril area on the basis of a simplified inundation model and digital elevation models. .	130
6.1	Study area along the shores of New York and Connecticut including Long Island Sound and the Atlantic Ocean coasts	142
6.2	Visualizing storm surge and sea level rise in Bridgeport, Connecticut.	147
6.3	Ecological systems around Old Lyme, Connecticut	148
6.4	Social vulnerability: Low, medium and high social vulnerability of census block groups throughout the study area in New York and Connecticut.	149
6.5	Potential economic impacts: Estimated replacement costs (i.e. potential economic losses) of built infrastructure from across the study area based on the HAZUS model	150
6.6	Integrating socioeconomic and ecological data to support land-use planning decisions to meet hazard mitigation and conservation objectives.	151

6.7	Average effect size of marsh vegetation (Hedges' <i>d</i>) on (a) wave attenuation and (b) shoreline stabilization as measured by increases in accretion/marsh surface elevation change or decreases in lateral erosion	152
7.1	The distribution of the resident population across the City of Cape Town, 2001	165
7.2	Map of Cape Town illustrating the spatial legacy of apartheid planning still evident in post-apartheid South African cities	166
7.3	Strip development of residential properties along the coast	168
7.4	Informal settlement in the Cape Flats, Cape Town	169
7.5	Open swathes of undeveloped land in the Cape Flats area	170
7.6	Camps Bay, a typical example of a highly developed and affluent coastal area in the South Peninsula	171
7.7	A screen-shot of the GIS Inundation Model depicting three temporary inundation scenarios, overlaid with the city's service infrastructure	173
7.8	Examples of highly vulnerable areas in Cape Town	175
7.9	Private property in Milnerton at risk from storm surge events and coastal erosion	176
7.10	Ad hoc and unregulated approaches to coastal erosion and storm surge defence	177
7.11	Dune cordons in Table View indicating the narrow belt into which they have been restricted	178
7.12	The coastal set-back overlaid with the GIS Inundation Model	181
7.13	Infrastructure damaged by storm surge events at Monwabisi on the Cape Flats	183
7.14	A derelict water slide at the Macassar recreational facility, Cape Flats	184
8.1	Map of Tongatapu showing Kolovai, Sopo and Popua	196
8.2	The mangrove plantations in the Kolovai project area	197
8.3	Rubbish in the Kolovai project area	198
8.4	The Kolovai seawall	200
8.5	New ecosystem behind the seawall	200
8.6	Area not protected by the seawall	201
8.7	Coastal erosion in the Sopo area	203
8.8	Mangroves and non-eroded coast in the Sopo area	203
8.9	Remnants of Popua's mangrove swamp that protected the coastline	204
8.10	Saturated ground in Popua	205
8.11	House on stilts in Popua	205

8.12	The Ha'apai group, Tonga.	206
8.13	Dying trees on Hihifo beach, Lifuka, with sandbags visible.	207
9.1	GIS maps illustrating the dynamic wetland regimes in the Mahanadi Delta, Orissa	231
9.2	Rice farming in the Mahanadi Delta (India), 2012.	232
9.3	Measured and projected flooding extent in the Niger Delta, 1982–2010, under different scenarios	236
9.4	Decrease in flooding extent in the Niger Delta, 1920–2010.	237
9.5	Fishermen in the Inner Niger Delta (Mali), June 2008.	237
9.6	Small-scale agriculture in the Inner Niger Delta (Mali), June 2008.	238
9.7	The “Room for the River” concept: Restoring former floodplains and using agricultural land for water retention, while protecting human settlements	241
11.1	Map of Sofala province in Mozambique.	272
11.2	Natural disasters in Mozambique, 1956–2008	274
11.3	Number of cholera cases per month in Sofala province, 1999–2003	274
11.4	Illustration of a communication strategy to establish a local web of information-sharing.	277
11.5	Local theatre performance as part of World Water Day celebrations in Búzi, 2003.	280
11.6	Solar pumps in Búzi district, 2007.	283
11.7	Administrative chief João Jonas and provincial technician Bernadette Manga in front of the emergency water supply in Chupanga, 2007	285
11.8	A clean, well-maintained emergency latrine in Chupanga, 2007	286
11.9	Safe resettlement area in Guara Guara with UDDT toilets, 2003.	287
12.1	Schematic representation of various options for vegetation change in a given catchment/region	294
12.2	Examples of the consequences of landslide occurrence for different event magnitudes.	297
12.3	Destabilized slopes on the unforested part of the hills, East Cape, North Island, New Zealand	299
12.4	Extensive mud and debris deposits behind a fence following extensive landsliding in the catchment, East Cape, North Island, New Zealand	301
13.1	Avalanche protection forest in Andermatt, Switzerland	322
13.2	The protection forest system with its three main components.	325

13.3	Photo of a local road in Austria threatened by rock fall with three commonly used protective measures in the Alps	327
13.4	Example of target profiles from the NaiS guidelines	332
13.5	Checklist from the NaiS guidelines for comparing the current protection forest stand structure and its projected development in 10 and 50 years.	334
13.6	The protective effect of the forest expressed as the reduction in the number of passing rocks	336
14.1	Physiographical map of Nepal	345
14.2	Trends in Nepal's forest cover, 1964–2004	347
14.3	Methodology scheme for forest cover, degradation and community forest trends.	350
14.4	Map showing Dolakha District, the forest cover study area and the community forest study area	351
14.5	Community forests studied in Dolakha District: Gairimudi, Namdu and Suspa VDCs.	353
14.6	Schematic trends in the study area, 1992 and 2009.	355
14.7	Forest cover linked to slope angle for study area	356
14.8	Landslide and forest cover trends, 1992–2009, for the study area	357
14.9	Location of the two examples	359
14.10	Case A: Degradation along the rivers in Bimeshwar municipality, 1992 and 2009	360
14.11	Case B: Impact of a road on landslide occurrence	361
16.1	Interactions between the social and ecological systems in urban areas in the production of urban risk and disasters. .	396
17.1	Paradigm shifts in disaster management.	417
17.2	Basic components of an EIA study in India	423
17.3	Sample SEA framework for agricultural policy	425
17.4	Inputs of EIA and SEA to DRR.	426
17.5	EIA applications in DRR phases	427
17.6	Integration of environmental and natural disaster management at district level.	432

Tables

1.1	Deadliest events worldwide for the period 1980–2011	4
1.2	Casualties linked to two major meteorological events over the island of Hispaniola in 2004.	13
1.3	Social, economic and governance indicators for Haiti and the Dominican Republic	14
2.1	Hazard mitigation functions of ecosystems	34
2.2	Examples of the estimated economic value of ecosystem services for natural hazard mitigation.	36
3.1	Test conditions	75
4.1	Summary of the disaster statistics presented in the text	88
4.2	Characteristics of mangroves reported to increase their effectiveness in coastal protection.	93
5.1	Main geo-environmental information used/converted in GIS.	116
5.2	Community-level indicators used in the workshop discussions.	121
6.1	Stakeholders participating in the process.	156
7.1	Quantifying the risk.	174
8.1	Key messages emerging from ecosystem-based approaches in Tonga.	209
10.1	Integrated water resources management and the Hyogo Framework for Action.	254
10.2	Mobilizing practical IWRM approaches to water-related disaster risk reduction: Principles of the approach	260

12.1	The influence of woody vegetation on slope stability.	302
12.2	The ability of forests to control natural hazards.	308
14.1	Surface of different areas of Dolakha District, Nepal, in 2009 based on most recent data sources.	352
14.2	Land-use change in the study area (10 VDCs), 1992–2009 ..	354
14.3	Results: Community forests and forest cover changes in the study area, 1992–2009	356
14.4	Landslide areas in 1992 and 2009	358
14.5	Landslide areas in 1992 covered by forests in the study area in 2009.	358
14.6	Effects of forests on slopes.	362
15.1	Examples of the role of protected areas in preventing or mitigating against natural disasters.	376
15.2	Results from studies on the effectiveness of protected areas in maintaining vegetation cover.	383
16.1	Some notable disasters in cities and metropolitan areas . . .	392
16.2	Policy measures dealing with various natural hazards and their relationship with the local ecosystem in various geographical areas.	406

Boxes

1.1	Use of terms	18
2.1	Definition of ecosystem.	28
2.2	Definition of ecosystem services	31
2.3	“Making Space for Water”: A government strategy for flood and coastal erosion risk management in the UK	32
2.4	Community-based forest rehabilitation for slope stability, Bolivia	33
2.5	Restoring wetlands for flood mitigation and local development, China.	37
2.6	Preserving wetlands for flood protection, New Orleans, USA.	41
2.7	Resilience to drought through agro-ecological restoration of drylands, Burkina Faso and Niger.	43
5.1	Main activities of RiVAMP	115
6.1	Coastal Resilience: Conceptual framework	143
9.1	Definition of terms	222
9.2	Case Study 1: From beneficial floods to flood vulnerability in the Mahanadi Delta, India.	230
9.3	Case Study 2: Infrastructure developments and community resilience in the Inner Niger Delta	235
9.4	Case Study 3: Flood risk reduction by providing Room for the River	241
10.1	The Tacaná watersheds programme: Risk reduction through IWRM.	262

13.1	Differing definitions and delimitations of protection forests across the alpine space	328
15.1	Protecting and restoring forests for avalanche and landslide control.....	373
15.2	Wetland protection for regulating floods	375
15.3	Protecting natural forests for flood control	379
15.4	Investing in mangroves	380
16.1	Urban flood reduction in New York, USA.....	398
16.2	Chicago, USA: Green Permit Program.....	399
16.3	Stuttgart, Germany: Combating the heat island effect and poor air quality with green aeration corridors.....	399
16.4	Reforestation in the Rokko Mountain Range, Japan	401
16.5	Flood reduction in Boston's Charles River Basin, USA	402
16.6	Urban flood risk in Mozambique.....	404
16.7	The Netherlands: "Room for the River".....	405
17.1	Classification of disasters based on origin of hazards.....	418
17.2	EIA of mining projects	422
17.3	Humanitarian response and EIA.....	429

Contributors

Chris Baker is head of the Wetlands and Water Resources Management programme at Wetlands International.

Srimal Bandara is a graduate of the University of Moratuwa, Sri Lanka, and presently employed by the Sri Lanka Ports Authority.

Michael W. Beck is lead scientist for the Global Marine Team of The Nature Conservancy and an adjunct faculty member at the University of California, Santa Cruz, USA. He has been a visiting Pew Marine Fellow at the United Nations University Institute for Environment and Human Security.

Kirsten Carey is a Master's student on the Programme in Globalization, Environment and Social Change, Department of Human Geography, Stockholm University, Sweden.

Alvin Chandra is an Environment Officer at the Environment

Protection Authority, Tasmania, Australia, and Vice-President of the Erasmus Mundus Students and Alumni Association, Oceania Regional Chapter. He also co-leads the Disaster Risk Reduction Group for the Commission on Ecosystem Management of the International Union for Conservation of Nature.

Bruno Chatenoux is a civil engineer and geologist involved as a geographic information system expert with the Global Change and Vulnerability Unit at the United Nations Environment Programme, GRID-Geneva.

Darryl Colenbrander obtained an MSc in Integrated Coastal Management through the Oceanographic Research Institute and the University of KwaZulu-Natal, South Africa. Since 2008 he has been employed by the City of Cape Town as the Environmental Resource Management Department's Coastal

Coordinator, where his current focal point is the development of city-wide strategic coastal planning and regulatory mechanisms.

James Dalton is the Coordinator of Global Initiatives in the Water Programme of the International Union for Conservation of Nature (IUCN). He is based at the IUCN headquarters in Gland, Switzerland.

Yaella Depietri is a PhD student at the Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona, Spain, and at the United Nations University Institute for Environment and Human Security (UNU-EHS) in Bonn, Germany.

Marc-Henri Derron is a lecturer at the Centre for Research on Terrestrial Environment at the University of Lausanne, Switzerland. He holds a PhD in environmental geology and has worked for six years in the Geohazards group of the Geological Survey of Norway. His present research focuses on active remote sensing for geohazards assessment, landslide investigation, monitoring and early warning.

Luuk Dorren specializes in natural hazards and protection forests. He has a PhD in physical geography. Since 2008, he has been working for the Swiss Federal Office for the Environment, co-leading the hazard and risk assessment of the national road network. In addition, he teaches mountain risk engineering at the University of Natural Resources and Life Sciences, Vienna, Austria.

Nigel Dudley is Industry Fellow, School of Geography, Planning and Environmental Management at the

University of Queensland, Australia, and works with Equilibrium Research in the UK. His work focuses principally on the integration of protected areas into wider environmental management strategies.

Marisol Estrella is Programme Coordinator for the Disaster Risk Reduction Unit of the United Nations Environment Programme Post-Conflict and Disaster Management Branch based in Geneva, Switzerland.

Zach Ferdaña is the Senior Marine Conservation Planner for the Global Marine Team of The Nature Conservancy.

Harindra J.S. Fernando is currently the Wayne and Diana Murdy Endowed Professor of Engineering and Geosciences at the University of Notre Dame, USA. During 1984–2009, he was affiliated with the Department of Mechanical and Aerospace Engineering at Arizona State University, USA. In 1994 he was appointed the founding Director of the Center for Environmental Fluid Dynamics at Arizona State University, a position he held till 2009 while holding a co-appointment with the School of Sustainability, Arizona State University.

Madeleine Fogde is Senior Programme Manager for the Swedish International Agricultural Network Initiative and the Integrated Sustainable Sanitation Programme at Stockholm Environment Institute, Sweden.

Urbano Fra Paleo is Associate Professor of Human Geography at

the University of Santiago de Compostela, Spain, and a Visiting Professor at the University for Peace, Costa Rica. He is a member of the Scientific Committee of the Integrated Risk Governance Project and has been a Research Associate at the University of Denver, USA, and a Fellow of the American Geographical Society Library. He is editor of *Building Safer Communities: Governance, Spatial Planning and Responses to Natural Hazards* (IOS Press, 2009).

Daniel A. Friess is an Assistant Professor in the Department of Geography, National University of Singapore. His research interests concern physical-ecological linkages in mangrove forests and how they influence ecosystem stability in the face of threats such as sea level rise.

Romana Gaspirc is a Technical Officer within the Wetlands and Water Resources Management programme at Wetlands International.

Ben Gilmer is a geographer for the Global Marine Team of The Nature Conservancy.

Thomas Glade is leading the Working Group on Geomorphic Systems and Risk Research and Head of the Department of Geography and Regional Research at the University of Vienna, Austria. His research interests cover geomorphic processes, human impacts on the environment, and natural hazard and risk analysis, including studies on vulnerability.

Lorenzo Guadagno is a Knowledge Management Officer at the Ecosystems and Livelihoods Adaptation Network, Gland,

Switzerland. He has been working with the Secretariat of the International Strategy for Disaster Reduction and the International Union for Conservation of Nature and is a member of its Commission on Ecosystem Management.

Anil Kumar Gupta is Associate Professor at the Government of India's National Institute of Disaster Management and Director of the Indo-German Programme on Environmental Knowledge for Disaster Risk Management. His areas include legal and policy framework, risk and vulnerability analysis, environmental impact assessment, human resource planning and mainstreaming disaster risk reduction.

Sam S.L. Hettiarachchi is Professor of Civil Engineering of the University of Moratuwa, Sri Lanka, and serves as Chairman of the Working Group on Risk Assessment and Reduction of the UNESCO/Intergovernmental Oceanographic Commission Intergovernmental Coordination Group for the establishment of the Indian Ocean Tsunami Warning System.

Mark Hoover is currently a Research Associate at Yale University, USA. His contributions to this book were undertaken while he was a Research Associate at the Center for Land Use Education and Research at the University of Connecticut, USA.

Michel Jaboyedoff is a geologist with degrees in physics and a PhD degree in clay mineralogy. Since 2005, he has been a full professor at the University of Lausanne, Switzerland,

focusing his research on natural hazards and related risks. He is involved in several risk management projects around the world (Argentina, Canada, Nepal, Norway, Switzerland) and is part of several European FP7 Projects and Swiss National Science Foundation Projects.

Stéphanie Jaquet has a Master's degree from the University of Lausanne, Switzerland, in environmental geosciences, with a focus on the analysis, monitoring and representation of natural hazards during which she specialized in landslide risk management and community forestry in Nepal. Currently she is a Project Officer at the Global Risk Forum in Davos, Switzerland.

Ilan Kelman is a Senior Research Fellow at the Center for International Climate and Environmental Research – Oslo, Norway. His main research interests are island sustainability and disaster diplomacy.

Ritesh Kumar is a Conservation Programme Manager at Wetlands International South Asia and a member of the Scientific and Technical Review Panel of the Ramsar Convention.

Carmen Lacambra is the Director of Environmental Services at Grupo Laera, a ThinkTank Consultancy Team based in Bogotá, Colombia, and with projects in Central and South America. Most of the projects Carmen has been involved in focus on climate change adaptation strategies and disaster management plans for several cities in the region

and for different sectors of the economy, as well as the incorporation of natural ecosystems in planning, adaptation and disaster risk management initiatives.

Luis Macario has an MSc in rural development from Eduardo Mondlane University, Mozambique. He is currently working as a water and sanitation specialist for the Water and Sanitation Program of the World Bank in Mozambique.

Kathy MacKinnon is a Vice-Chair of the World Commission on Protected Areas of the International Union for Conservation of Nature, with responsibility for the Convention on Biological Diversity and Climate Change. Previously she was Lead Biodiversity Specialist at the World Bank, where she worked on biodiversity conservation and ecosystem-based approaches to climate change.

Stavros Mavrogenis is a researcher at the European Centre for Environmental Research and Training, Panteion University of Athens, Greece. His main field of interest is climate change adaptation law and policy for Small Island Developing States (SIDS), disaster risk reduction in the Global South and disaster diplomacy.

Imen Meliane is the International Marine Policy Director for The Nature Conservancy.

Iris Möller is Deputy Director, Cambridge Coastal Research Unit, Department of Geography, and College Lecturer in Physical Geography, Fitzwilliam College, University of Cambridge, UK. Her

research focuses on quantifying the coastal landform dynamics and the sea defence service provided by coastal environments over a range of time-scales and in varying environmental settings.

Radhika Murti is the Programme Coordinator for Disaster Risk Reduction at the International Union for Conservation of Nature. Her work focuses on the development and implementation of global initiatives on ecosystem-based disaster risk reduction.

Sreeja S. Nair is Assistant Professor at the Government of India's National Institute of Disaster Management (NIDM) and Coordinator of the Indo-German Programme on Environmental Knowledge for Disaster Risk Management. She is in charge of the Geoinformatics facility at NIDM. She coordinates research projects on risk and vulnerability analysis, disaster databases, and climate change.

N.A. Kithsiri Nandasena is a graduate of the University of Mortauwa, Sri Lanka, and currently reading for a PhD degree at the University of Saitama, Japan.

Sarah Newkirk is California Coastal Program Director for The Nature Conservancy and previously was the New York Coastal Program Director.

Gregg Oelofse is the Head of Environmental Policy and Strategy at the City of Cape Town, South Africa. He has a Master's degree in Conservation Biology and has been working as an environmental professional for 18 years. His interests include integrated coastal management, ecosystem services,

adaptation, urban biodiversity conservation and environmental fiscal reform mechanisms.

Maria Papathoma-Koehle is a postdoctoral researcher in the Department of Geography and Regional Research at the University of Vienna, Austria. Her research focuses on physical vulnerability to alpine hazards.

Pascal Peduzzi is an environmental scientist. He is head of the Global Change and Vulnerability Unit at the United Nations Environment Programme, GRID-Geneva.

Penny Price is Climate Adaptation lead for the Western Cape Government, South Africa, Chair of the Provincial Strategic Outcome 7 Working Group on Climate Adaptation, and a member of South Africa's National Climate Adaptation Technical Group.

George T. Raber is an Associate Professor in the Department of Geography and Geology at the University of Southern Mississippi, USA.

A. Harsha R. Ratnasooriya is a Senior Lecturer in Civil Engineering at the University of Moratuwa, Sri Lanka. He has been engaged in research into bioshields against coastal hazards.

Fabrice G. Renaud is Head of the Environmental Vulnerability and Ecosystem Services section of the United Nations University Institute for Environment and Human Security (UNU-EHS), Bonn, Germany. He is responsible for carrying out research and developing concepts and projects

dealing with the environmental dimension of vulnerability, with the resilience of social-ecological systems to external shocks, with water pollution, and with land degradation processes, particularly in the context of climate change.

Nina Saalismaa is an independent environmental consultant specializing in ecosystem-based disaster risk reduction.

Saman P. Samarawickrama is Professor of Civil Engineering at the University of Moratuwa, Sri Lanka. His research covers a wide portfolio in coastal and harbour engineering.

Christine C. Shepard is a marine scientist with the Global Marine Team of The Nature Conservancy.

Tom Spencer is Director, Cambridge Coastal Research Unit, Department of Geography, and Reader in Coastal Ecology and Geomorphology, University of Cambridge, UK. He is author (with H.A. Viles) of *Coastal Problems: Geomorphology, Ecology and Society at the Coast* (Edward Arnold, 1995) and (with O. Slaymaker) of *Physical Geography and Global Environmental Change* (Longman, 1998). In 2005 he edited (with C.A. Fletcher) *Flooding and Environmental Challenges for Venice and Its Lagoon: State of Knowledge* (Cambridge University Press).

Sue Stolton is a partner in Equilibrium Research, UK, and a member of the World Commission on Protected Areas of the International Union for Conservation of Nature. Her work focuses on protected areas and broad-scale approaches to conservation.

Jeffrey D. Stone is a project manager and senior geospatial analyst for the Science Services Program at the Association of State Floodplain Managers.

Karen Sudmeier-Rieux holds a PhD from the Center for Research on Terrestrial Environment at the University of Lausanne, Switzerland, where she is currently a researcher and a consultant on issues related to the environment and disaster risk reduction. She is thematic lead on disaster risk reduction for the International Union for Conservation of Nature (IUCN) Commission on Ecosystem Management and has published a number of IUCN publications and articles on ecosystems, livelihoods and disaster risk reduction.

Sakhile Tsotsobe is Coastal Coordinator in the City of Cape Town's Sport, Recreation and Amenities Department, responsible for developing and managing coastal management programmes related to the use of beach amenities. He is part of a team that develops adaptation strategies for climate change and sea level rise risk. He previously worked as a biological oceanographer at South Africa's Department of Environmental Affairs.

Pieter van Eijk is a Senior Technical Officer within the Wetlands and Livelihoods programme at Wetlands International.

Adonis Velegrakis is Professor in the Department of Marine Sciences, School of Environment, University of the Aegean, Greece. He has an MSc and a PhD in Oceanography

and an LLM in Environmental Law and Law of the Sea. His areas of expertise include beach erosion and vulnerability to climatic changes and extreme events, marine and coastal environmental impact assessments and coastal morphodynamics.

André Wehrli is an expert in protection forests and natural hazards. He holds a PhD in natural sciences from the Swiss Federal Institute of Technology in Zurich

and has been working for the Swiss Federal Office for the Environment since 2005. In addition, he works as a freelance consultant on disaster risk reduction for Swiss Humanitarian Aid.

Adam W. Whelchel is Director of Science for the Connecticut Chapter of The Nature Conservancy. He is project manager for the New York and Connecticut Coastal Resilience Program.

Foreword: Why do ecosystems matter in disaster reduction?

Margareta Wahlström, Special Representative of the Secretary-General for Disaster Risk Reduction and Head of the UN Office for Disaster Risk Reduction

The current global framework for disaster risk reduction, the Hyogo Framework for Action, was agreed in Kobe, Japan, in January 2005 as the world struggled to come to terms with the loss of life and devastation caused by the Asian tsunami of a few weeks earlier. Sustainable ecosystems and environmental management were placed top of the list under the Hyogo Framework's Priority for Action No. 4 on reducing underlying risk factors, and a few months later Hurricane Katrina engulfed New Orleans in a disaster that was both predictable and predicted. As is often the case following major disaster events, there was much focus on what should have been done to strengthen the city's physical infrastructure, such as improving the levee and drainage systems or building protection walls.

There is, of course, a very important but less appreciated "resilience gap" that faced New Orleans and the many small towns and villages that bore the brunt of the Asian tsunami, and that was the deterioration of their natural defences. In other words, there was a general failure to appreciate why ecosystems matter in disaster risk reduction and how they help to build a community's resilience to disaster events. In the case of New Orleans, economic development prior to Katrina had taken place at the expense of losing 4,800 km² of wetlands in the Mississippi Delta, which took thousands of years to accumulate and helped to dissipate the energy of storm surges in centuries past.

If one considers that floods disrupt the lives of over 100 million people every year, then it seems obvious that ecosystems have a role to play in

limiting the impacts on our built environment and that we cannot simply pretend we can avoid harm by constructing more dykes, dams, spillways and other built structures. The proper use and preservation of natural and constructed wetlands not only help withstand storm surges but also reduce the volumes of rainwater runoff in urban areas. A key benefit of wetlands and environmental buffers is to act as flood retention basins and reduce flooding in built-up areas. One statistic worth pondering in relation to the value of well-managed ecosystems is that 1.3 million trees can catch 7 billion m³ of rainwater per year, which amounts to a major reduction in stormwater drainage.

This is a welcome and timely publication that will make a major contribution towards shaping the successor to the Hyogo Framework for Action, which expires in 2015. It is also a forceful and eloquent reminder that environmental management is an essential part of best practice in disaster risk reduction.

Acknowledgements

We are extremely grateful to the following experts who have volunteered their time and knowledge to peer-review the chapters in this book. Alphabetically, our sincere thanks go to Sálvano Briceño (Science Committee, Integrated Research on Disaster Risk, Switzerland), George Buoma (Environmental Policy Advisor, USA), Jane Gibbs (Coast and Flood Policy, New South Wales Government, Australia), Bruce Glavovic (Resource & Environmental Planning Programme, Massey University, New Zealand), Frank Graf (Institute for Snow and Avalanche Research – WSL/SLF, Switzerland), Dennis Hamro-Drotz (UNEP Post-conflict and Disaster Management Branch, Switzerland), Marcus Kaplan (German Development Institute, Germany), Brian G. McAdoo (Department of Earth Science and Geography, Vassar College, USA, and Yale-NUS College, Singapore), Jeffrey A. McNeely (Cornell University, USA), Padma Narsey Lal (Ecosystem Sciences, Commonwealth Scientific and Industrial Research Organisation, Australia), Hassan Partow (UNEP Post-conflict and Disaster Management Branch, Switzerland), Jyotiraj Patra (Risk, Resources, Resilience and Global Sustainability – R3GS, India), Jonathan Randall (Environmental and Social Performance, Millennium Challenge Corporation, USA), Torsten Schlurmann (Franzius-Institute for Hydraulic, Waterways and Coastal Engineering, Leibniz Universität Hannover, Germany), Rajib Shaw (Graduate School of Global Environmental Studies, Kyoto University, Japan), David C. Smith (Institute of Sustainable Development, University of the West Indies, Jamaica), Keshar Man Sthapit (HELVETAS Swiss Intercooperation, Afghanistan), Alexia

Stokes (Institut National de Recherche Agronomique, France), Joerg Szarzynski (United Nations University Institute for Environment and Human Security, Germany), Paul Venton (International Development Consultant: Disasters, Climate Change and Environment, USA), Torsten Welle (United Nations University Institute for Environment and Human Security, Germany) and Bettina Wolfgramm (Centre for Development and Environment, University of Bern, Switzerland, and University of Central Asia, Bishkek, Kyrgyzstan). We are also grateful to Philipp Koch and Hannes Etter from the United Nations University Institute for Environment and Human Security for their support during the preparation of this book.

Abbreviations

ADV	Acoustic Doppler Velocity
AsgiSA	Accelerated and Shared Growth Initiative for South Africa
CAMP	coastal area management plan
CARICOM	Caribbean Community
CbA	community-based adaptation
CBA	cost–benefit analysis
CBD	Convention on Biological Diversity
CCA	climate change adaptation
CCSR	Center for Climate Systems Research
CCT	City of Cape Town
CDB	Caribbean Development Bank
CEA	country environmental analysis
CENOE	Centro Nacional Operativo de Emergência [National Emergency Operations Centre], Mozambique
CF	community forest
CFUG	Community Forest User Group
CRED	Centre for Research on the Epidemiology of Disasters
CRiSTAL	Community-based Risk Screening Tool – Adaptation and Livelihoods
Defra	Department for Environment, Food and Rural Affairs, UK
DIA	disaster impact assessment
DMP	Disaster Management Plan
DoF	Department of Forests, Nepal
DRM	disaster risk management
DRR	disaster risk reduction
EbA	ecosystem-based adaptation

Eco-DRR	ecosystem-based disaster risk reduction
EIA	environmental impact assessment
EM-DAT	Emergency Events Database
FECOFUN	Federation of Community Forest Users, Nepal
FEMA	Federal Emergency Management Agency, USA
GCM	Global Circulation Model
GDP	gross domestic product
GIS	Geographic Information System
GRRT	Green Recovery and Reconstruction Toolkit
HAZUS-MH	Hazards U.S. – Multi-Hazards tool
HFA	Hyogo Framework for Action
ICZM	integrated coastal zone management
INGC	Instituto Nacional de Gestão das Calamidades [National Disaster Management Institute], Mozambique
IPCC	Intergovernmental Panel on Climate Change
ISDR	International Strategy for Disaster Reduction
IUCN	International Union for Conservation of Nature
IWRM	integrated water resources management
LiDAR	Light Detection and Ranging
MEOW	Maximum Envelopes of Water
MERET	Managing Environmental Resources to Enable Transitions to More Sustainable Livelihoods
MESCAL	Mangrove Ecosystems for Climate Change Adaptation and Livelihoods
MSL	mean sea level
MSV	Many Strong Voices
NDMA	National Disaster Management Authority, Pakistan
NEP	National Estuary Program, USA
NGO	non-governmental organization
NOAA-CSC	National Oceanic and Atmospheric Administration's Coastal Services Center
NWP	Nairobi Work Programme
OECD	Organisation for Economic Co-operation and Development
PAARSS	Projecto de Abastecimento de Água Rural e Saneamento em Sofala [Programme for Rural Water Supply and Sanitation]
PARPA	Plano de Acção para a Redução da Pobreza Absoluta [National Poverty Reduction Strategy]
PEDRR	Partnership for Environment and Disaster Risk Reduction
PIOJ	Planning Institute of Jamaica
PROFOR	Programa de Repoblamiento Forestal
REA	rapid environmental impact assessment
RiVAMP	Risk and Vulnerability Assessment Methodology Development Project
SBSTA	Subsidiary Body for Scientific and Technological Advice
SEA	strategic environmental assessment
SIDS	Small Island Developing States
SLOSH	Sea, Lake and Overland Surges from Hurricanes

SLR	sea level rise
SLRTF	Sea Level Rise Task Force
SOVI	Social Vulnerability Index
SREX	Special Report on Managing the Risks of Extreme Events and Disasters
TEEB	The Economics of Ecosystems and Biodiversity
UDDT	urine-diverting dry toilet
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations International Strategy for Disaster Reduction
UNU-EHS	United Nations University Institute for Environment and Human Security
UWI	University of the West Indies
VDC	Village Development Committee
WFP	World Food Programme
WSSD	World Summit on Sustainable Development

Part IV

Sustainable land management for disaster risk reduction

12

The role of vegetation cover change in landslide hazard and risk

Maria Papathoma-Koehle and Thomas Glade

Introduction

Landslides cause economic losses as well as considerable loss of life worldwide. They are commonly triggered either by hydro-meteorological events or by earthquakes. However, preconditioning factors such as topography, geology, soils, hydrological conditions, landslide history and vegetation cover determine the response of a landslide-prone catchment to a specific trigger. In this chapter, the focus is on the role of vegetation within the preconditioning factors and how a change might influence the consequent landslide risk. Also, aspects of climate change are addressed.

According to the Intergovernmental Panel on Climate Change (IPCC) Working Group I (2007), the type, frequency and intensity of extreme events such as heatwaves, droughts and floods are expected to change as a result of climate variations. Moreover, in a recent IPCC report (2012) it is suggested that there is high confidence that changes in heavy precipitation will affect landslides in some regions. Moreover, landslide occurrence in terms of magnitude, intensity, temporal pattern and spatial extent might be affected by this change. For example, increasing precipitation frequency and intensity as well as changes in soil temperature leading to a changed soil moisture regime can reduce slope stability (UNU, 2006). At large scales, higher temperature and mild winters will cause permafrost melting and saturation of soils, which might affect slope stability and eventually the occurrence of landslides (Bärring and Persson, 2006). Bo et al. (2008) also point out that climate change will affect

the stability of slopes owing to changes in vegetation and in ground and surface water levels and they list the types of slopes that are most vulnerable to such change. Indeed, not all landslide types are expected to have the same reaction to these climatic changes. According to Geertsema et al. (2007), landslide types such as debris slides, debris flows and rock fall respond rapidly to these hydro-meteorological variations, whereas other types, such as earth slides and flows, have a delayed response. Responses are also heavily dependent on the magnitude of the triggering event.

Not only might climate change directly affect landslide occurrence but it can also influence the preconditioning factors of landslide initiation. For example, vegetation transformation driven by climate change might lead to changed slope stability and consequent landslide occurrence. However, such changes occur at different scales. Whereas direct interventions such as deforestation are occurring in rather smaller regions over short periods, climate change is affecting larger regions and principally at longer time scales. Thus, changes in vegetation cover as the result of climate change may be two-fold (see Figure 12.1): (1) climate change might slowly but constantly develop vegetation cover (for example, a slow shift in the tree line), and (2) extreme events might result in rapid changes (for example, fires remove forests or wind destroys forest cover). In addition to climatic stresses, anthropogenic forces often result in dramatic vegetation changes. Such forces might be related to (3) the logging of

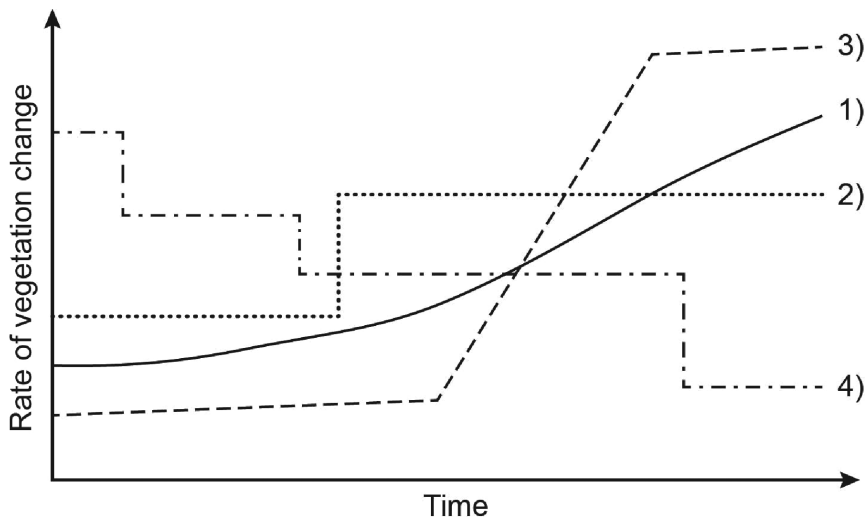


Figure 12.1 Schematic representation of various options for vegetation change in a given catchment/region with (1) continuous climate change; (2) extreme hydro-meteorological events; (3) forest logging; and (4) changes in agricultural practices

forests in large areas or (4) changes in agricultural practices owing to policy decisions or farmers' economic motives.

Numerous studies have investigated the role of vegetation in relation to the occurrence of hazardous phenomena such as landslides, rock falls and debris flows (Alcántara-Ayala et al., 2006; Bathurst et al., 2009; Dörren et al., 2004, 2006; Gerrard and Gardner, 2002; Glade, 2003a; Greenway, 1987; Kuriakose et al., 2006; Masuya et al., 2009; Schmidt et al., 2001; Steinacher et al., 2009; Sudmeier-Rieux et al., 2011; Wasowski et al., 2007; Woltjer et al., 2008). They all regard vegetation as an important factor that influences slope stability.

Changes in vegetation as a result of climate change or anthropogenic factors may affect landslide occurrence but they may also play an important role in increasing or decreasing the physical vulnerability of individual elements at risk. Since vulnerability is of major importance to risk assessments and risk reduction strategies, as emphasized in the Hyogo Framework for Action 2005–2015, its role has to be closely examined and taken into consideration by decision-makers. Vulnerability is affected by people moving into previously forested areas with consequent impacts on landscapes because of the construction of critical infrastructure, the building of urban areas, a change in land use in regions cleared of forests, etc. Thus, the elements at risk and vulnerability are increasing concurrently with a reduction in vegetation cover. In addition, removal of “protection forests” in already developed regions might increase the vulnerability of existing critical infrastructure or houses (see below on protection forests).

Hence, the effects of climate change should not be overestimated. It is very difficult to assess the impact of climate change on slope stability owing to a lack of data on historical landslide activity and to other factors that also affect slope stability (Alcántara-Ayala et al., 2006). These other factors range from anthropogenic slope modifications, such as leveling, to a changed hydrological regime through drainage and also water supply to the slopes. According to Winter et al. (2010), these factors might have a positive or a negative influence on slope stability that even exceeds that of climatic changes. For example, Wasowski et al. (2007) concluded for their investigated catchment in Italy that changed slope stability is related not to climate change but to land-use change. Nevertheless, all authors dealing with the effects of climate change on natural hazards point out that it is urgent for decision-makers to consider climate change and put mitigation and adaptation strategies high on their agenda.

This chapter examines the ways in which changes in vegetation cover can affect the spatio-temporal pattern of landslide occurrences, its related consequences and the implications that these changes might have in decision-making and disaster management. We review the trends in

vegetation change resulting from climate change and anthropogenic factors and the possible consequences for landslide occurrence and overall landslide risk. We present recent strategies of using land cover and vegetation for landslide risk reduction and emphasize the possible gaps and needs for future research.

Landslide hazard, vulnerability and risk

Landslides can be defined as the downslope movement of soil, rock or debris as the result of gravitational forces, which can be triggered by heavy rainfall, rapid snow melting, slope undercutting, etc. (see, for example, Crozier, 1999; Glade and Crozier, 2005b). The term “landslide” is used in this chapter for shallow landslides (defined by BRP, BWB and BUWAL, 1997, as less than 2 metres deep), debris flow (solid material with a high water content) and rock fall (loose stones and boulders) according to the internationally widely accepted definitions of Cruden and Varnes (1996) and Dikau et al. (1996). These types of landslides are mainly affected by vegetation cover and human activity, in contrast to deep-seated landslides, which are less likely to be stabilized by vegetation cover and are more affected by geological and hydrological conditions. The impact of landslides on buildings and infrastructure ranges from zero (if no buildings are exposed) or minimum (if landslide magnitude is minor and only negligible damage can be expected) to maximum (collapse or burial of buildings and infrastructure, loss of life and loss of agricultural land; refer to Glade and Crozier, 2005b, for more details). As far as debris flows and soil flows are concerned, not only do they influence the stability of buildings, but also, during low-magnitude events, material can enter buildings through doors or windows and damage building interiors (Holub and Fuchs, 2009). In contrast, large-magnitude events damage or even destroy the building structure such as walls (see Figure 12.2). On the other hand, rock falls usually affect individual buildings rather than large areas and they may also damage building interiors. Although, in Europe, large-magnitude landslides have a low probability of claiming lives, the concentration of assets on steep slopes, high standards of living and high population densities have rendered European households vulnerable to even small-magnitude landslide events (Blöchl and Braun, 2005).

The majority of studies concerning landslide hazards focus on hazard assessments (mapping and zoning), landslide modelling and landslide risk management. Although hazard assessments are very important for disaster risk reduction, understanding the vulnerability of the built environment, the natural environment and society is equally important.

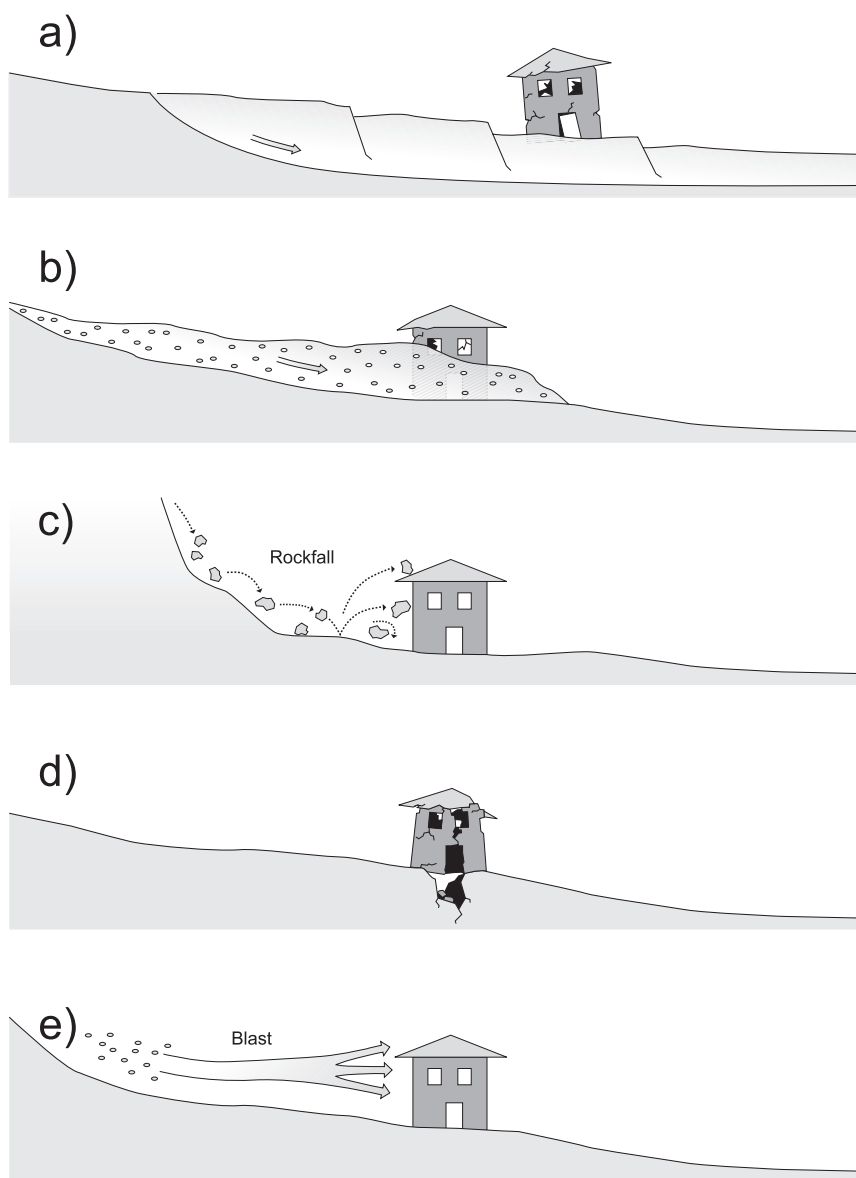


Figure 12.2 Examples of the consequences of landslide occurrence for different event magnitudes: (a) shallow translational or rotational landslide; (b) debris flow; (c) rock fall; (d) subsidence and (e) rock avalanche
Source: Based on Glade and Crozier (2005b).

Vulnerability assessment of elements at risk of landslide-related phenomena is a relatively new field of research (Glade, 2003b; Hufschmidt and Glade, 2010; Zhihong et al., 2010), which additionally brings together scientists from different disciplines (Fuchs, 2009). Because there is no common definition of vulnerability across all disciplines (the social sciences, the natural sciences, engineering), each group of scientists provides its own definition, clearly demonstrating the lack of common language and hindering vulnerability research from moving forwards (Brooks, 2003). In the social sciences, vulnerability is related only to the social context, whereas engineers and natural scientists try to define thresholds in order to determine acceptable risk and at what point risk reduction measures should be taken (Bohle and Glade, 2007).

As far as physical vulnerability is concerned, the most common definition used by natural scientists and engineers is the one proposed by the Office of the United Nations Disaster Relief Coordinator (UNDRO, 1984: 3): “Vulnerability is the degree of loss to a given element, or set of elements, within the area affected by a hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss).” On this basis, the majority of vulnerability assessment methods for landslides either estimate the associated vulnerability (Glade, 2003b) or concentrate on creating vulnerability curves that connect the intensity of a process to the degree of economic loss of buildings (Bohle and Glade, 2007). In a review of methods for assessing vulnerability to alpine hazards, Papathoma-Köhle et al. (2011b) suggest that nearly half of the methods apply vulnerability curves. However, that means that in most cases only one characteristic of the element at risk (usually the building type) and of the phenomenon (intensity expressed as, for example, the thickness of the deposit in the case of debris flow) is taken into consideration. However, there are studies referring to other vulnerability indicators, such as demographics and vegetation cover near buildings (for example, Bell and Glade, 2004; Kappes et al., 2012; Papathoma-Köhle et al., 2007).

Papathoma-Köhle et al. (2007) introduced a framework to undertake an assessment of the vulnerability of buildings to landslides, based on the development of an “elements at risk database”. It takes into consideration the characteristics and use of buildings, their importance for the local economy and the demographic characteristics of the inhabitants (population density, age, etc.). In a modification of this methodology for multi-hazards, the type of vegetation surrounding a building is also taken into consideration (Papathoma-Köhle et al., 2011a; Kappes et al., 2012) in assessing its overall physical vulnerability. Four categories of vegetation surrounding buildings are presented: no trees, few trees, closed tree line and buildings located within the forest. However, the role of different

vegetation types in protecting an element at risk has yet to be further explored.

The role of vegetation cover in landslide risk

Vegetation can reduce the probability of a landslide through the reduction of the soil pore-water pressure and can reduce the possibility of soil erosion through reinforcement of soil properties through the root system. In Figure 12.3, the destabilized slopes on the unforested part of the hills in East Cape, North Island, New Zealand, are shown. Alternatively, vegetation can increase the hazard by overloading the slope with weight and by weakening the regolith strength through movement of the roots, for example during strong wind storms (Popescu, 2002; Sidle et al., 1985; Steinacher et al., 2009). Another observed effect is that the vegetation cover indeed stabilizes the slope through root reinforcement; however, if the slope fails, the root weight could actually increase the size of the



Figure 12.3 Destabilized slopes on the unforested part of the hills, East Cape, North Island, New Zealand

Photo: Michael Crozier.

landslide. In the case of shallow landslides, rock fall or debris flows, vegetation can also reduce the vulnerability of elements at risk. Here, vegetation not only prevents the initiation of the landslide process but also acts as a protective barrier. In this section, the role of vegetation in landslide hazard, the vulnerability of the elements at risk and, finally, landslide risk are discussed through some examples for shallow landslides, debris flows and rock fall.

Different land uses and corresponding vegetation cover can have a significant influence on slope stability. During a rainstorm event in 2004 in the East Cape region of North Island, New Zealand, large areas were affected by landslides. As other studies have shown, the region has undergone significant land-use changes over the past century owing to the conversion of hillsides into farm pastures (for example, DeRose et al., 1995). Areas affected by landslides recover very slowly, often never returning to pre-landslide conditions (Smale et al., 1997). The landslide process often starts as shallow translational soil slides, which develop within the channels into mud and debris flows. As soon as the displacement of the regolith has been initiated, the transported materials turn into very liquefied matter. Once the drainage line or channel has been reached, these flow types can travel for very long distances, from tens to hundreds of metres downslope, causing damage to buildings and infrastructure that lie in their way. In contrast, forested slopes remain stable (Figure 12.3). Obviously, the magnitude of this triggering event was not large enough to destabilize the areas covered by forests to a similar extent. In the case of this specific event, the forest functioned as a protection against regolith destabilization and subsequent landsliding. However, this does not imply that the forested region and the exposed elements at risk located further downstream in the valleys are completely safe. It can be expected that, with an increasing triggering magnitude, even forested areas and elements at risk near the destabilized slopes will be affected. For events with a magnitude lower than or similar to that of 2004, forest cover can clearly be regarded as a protection against shallow landslides and consequent mud and debris flows.

Also in terms of landslide risk, the consequences are heavily dependent on the vegetation cover in the source areas of the catchment. In the case of 2004, regions below the forests were safe and did not experience any significant damage from landslides. In contrast, exposed elements at risk located in the non-forested regions experienced significant damage ranging from extensive mud cover (see Figure 12.4) to completely damaged houses and infrastructure. Therefore, management of vegetation cover can extensively influence landslide occurrence and consequent landslide risk.

In other regions outside New Zealand, a considerable number of studies have investigated the role of vegetation (in most cases forests) in



Figure 12.4 Extensive mud and debris deposits behind a fence following extensive landsliding in the catchment, East Cape, North Island, New Zealand
Photo: Michael Crozier.

slope stability and landslide occurrence. Peduzzi (2010) investigated the role of vegetation in slope stability in North Pakistan and concludes that the “presence of denser vegetation has a mitigation effect on landslide susceptibility” (Peduzzi, 2010: 633). He supports this argument with the results of landslide modelling with and without considering vegetation density, determined through the Normalized Difference Vegetation Index. The susceptibility of the area to landslides rose by 15.1 per cent when the presence of vegetation was not taken into consideration (Peduzzi, 2010). On the other hand, Popescu (2002) suggests that, although vegetation often reduces the occurrence of landslides through water content reduction and root anchoring, it may also have the opposite effect. He lists some negative effects of vegetation on slope stability, such as the fact that trees may destabilize slopes owing to their weight and their exposure to wind forces. Additionally, Popescu suggests that the roots of trees and plants can penetrate and expand the joints of rock, thus destabilizing the slope. However, he emphasizes that these effects are minor and that the positive effects of the vegetation on slope stability are the dominant ones.

Table 12.1 The influence of woody vegetation on slope stability

Mechanisms	Influences on types of landslides	
	Shallow, rapid	Deep-seated
<i>Hydrological mechanisms</i>		
Interception of rainfall and snow by canopies of vegetation, promoting evaporation and reducing water available for infiltration	B	B
Root systems extract water from the soil for physiological purposes (via transpiration), leading to lower soil moisture levels	B	B
Roots, stems and organic litter increase ground surface roughness and soil's infiltration capacity	MA	MA
Depletion of soil moisture may cause desiccation cracks, resulting in higher infiltration capacity of water to a deeper failure plane	MA	MA
<i>Mechanical mechanisms</i>		
Individual strong woody roots anchor the lower soil mantle into the more stable substrate	B	MB
Strong roots tie across planes of weakness along the flanks of potential landslides	B	B
Roots provide a membrane of reinforcement to the soil mantle, increasing soil shear strength	B	B
Roots of woody vegetation anchor into firm strata, providing support to the upslope soil mantle through buttressing and arching	B	MB
The weight of trees (surcharge) increases the normal and downhill force components	MA/MB	MA/MB
Wind transmits dynamic forces to the soil mantle via the tree bole	A	MA

Source: Marston (2010).

Note: A = mechanism adverse to stability; MA = marginally adverse mechanism; MB = marginally beneficial mechanism; B = beneficial mechanism.

The role of woody vegetation (trees and plants with hard stems) in slope stability is discussed extensively by Marston (2010). The mechanisms that influence slope stability are divided into two categories: hydrological and mechanical (see Table 12.1, which is modified from Greenway, 1987, and Sidle and Ochiai, 2006).

As far as rock fall is concerned, Corominas et al. (2005) suggest that falling rocks often lose their kinetic energy as the result of the presence of trees and never make it to the lowest part of the slope. However, Bigot et al. (2009) suggest that forests can offer protection to buildings only if

the forest structure is adapted to this function. They also consider forests to be not only aesthetically more appealing in comparison with other protective measures such as nets and dams, but also cheaper to maintain. Numerous research studies have been carried out, and there is still ongoing investigation in order to determine the effect of protection forests on rock falls (Dorren et al., 2004, 2006; Masuya et al., 2009; Woltjer et al., 2008; see also below on protection forests).

The effect of vegetation on debris flow initiation and propagation has often been investigated in the past (Pabst and Spies, 2001). Kuriakose et al. (2006) quantify the effect of vegetation on the initiation of debris flow by using numerical simulation. The results revealed that, although during high-intensity rainfall the mitigating role of vegetation might be reduced, vegetation remains crucial to slope stability. Kuriakose et al. also point out that the mechanical effect (that is, root cohesion) rather than the hydrological effect of vegetation seems to play the most important role.

Rickli and Graf (2009) investigate the differences in shallow landslide occurrence between open land and areas covered with forests. By looking at six different landslide areas in Switzerland, they conclude that landslide density in open land is clearly higher than landslide density in forested areas. As far as landslide dimensions are concerned, there are no significant differences, with the exception that landslide depth is greater in forested terrain. Finally, Rickli and Graf (2009) suggest that shallow landslides in forested terrain are triggered in areas with steeper slope inclination.

Furthermore, the role of vegetation in maintaining slope stability has been investigated globally by numerous scientists in several case studies. Despite these efforts, there is still the need for more research on the role of vegetation in relation to the occurrence of rock fall. The vast majority of studies conclude that the role of vegetation in slope stability is positive but its significance varies depending on specific local characteristics such as topography, lithology and hydrology.

Change in vegetation cover and its effect on slope stability

Changes in vegetation cover can result from climate change and from anthropogenic activity (for example, deforestation, land-use change, logging, arson).

Climate change

With respect to climate change, plants may respond in three ways: persistence, migration and extinction (Theurillat and Guisan, 2001).

According to Theurillat and Guisan, possible changes in vegetation in the Alps owing to climate change may include altitudinal shifts of vegetation, changes in its composition and changes in the growth and productivity of grasslands. More specifically, as far as Switzerland is concerned, an increase of 3.3°C in mean air temperature would cause an upward altitudinal shift of 600 metres, which would reduce the area of alpine vegetation belt by 63 per cent (Theurillat and Guisan, 2001). However, the response of tree species in the Alps may vary. For example, a rise in temperature might increase the radial growth of the larch pine (*Larix decidua*), but at the same time it will reduce the radial growth of the Scots pine (*Pinus sylvestris*) because of the lack of water (Theurillat and Guisan, 2001).

In a wider study of the Euro-Mediterranean area, it is suggested that vegetation in Southern and Eastern Europe as well as in North Africa will be most affected by climate change. In more detail, in coastal northern Africa and Spain, grass will be replaced by temperate trees, whereas in non-coastal northern Africa there might be a transition to bare ground conditions as a result of severe drought (Anav and Mariotti, 2011). According to the same study, in Eastern Europe boreal vegetation and grass will be replaced by temperate deciduous trees owing to higher temperatures and increased rainfall.

In the United States, the impact of climate change on vegetation has already been observed, although it varies throughout the country. Modelling of vegetation change under different climatic scenarios for the United States has shown that, for moderate climate change scenarios, vegetation density will increase, but that, under more severe climate change scenarios, there will be a decrease in vegetation density. Especially in the eastern United States, catastrophic fires may cause a transition from forest to savanna (Bachelet et al., 2001). In addition, existing land-use practices (for example, timber harvesting, vegetation conversion, fire, road construction, residential development, mining activities) may accelerate or counteract the response of vegetation to climate change (Sidle et al., 1985; Wasowski et al., 2007). For this reason, land-use planning that takes into account climate change effects on vegetation is crucial (Theurillat and Guisan, 2001).

Deforestation

According to the Food and Agriculture Organization of the United Nations (FAO, 2010), deforestation is decreasing worldwide, although the rate of deforestation is still alarmingly high. Every year in the last decade, 13 million hectares of forest were converted to agriculture or were lost from natural causes. Furthermore, the deforestation rate varies

significantly from country to country. For example, countries such as Brazil or Indonesia managed to reduce the rate of forest loss, whereas in Australia the rate increased as a result of forest fires (FAO, 2010). Moreover, forest areas managed for the protection of soil and water increased by 59 million hectares worldwide, mainly because of extensive forest planting in China (FAO, 2010).

Despite these general trends, deforestation is of major importance on hilly or mountainous slopes with regard to landslide occurrence. Although there are numerous, detailed studies on the effects of deforestation on slopes and adjacent landslide occurrence (for example, Gerrard and Gardner, 2002; Wang, 2004), no overall and global information is currently available on this topic.

Forest fires

Forest fires are often the result of a combination of factors, which may include ignition agents, fuel condition, topography, climate, wind velocity and direction, precipitation and humidity. Many studies suggest that an increase in forest fires should be expected as a result of climate change (for example, Flannigan et al., 2000). In particular, studies show that there has been an increase in forest fires in North America and Europe. Intensive forest fires strip slopes of vegetation, which could also have a significant impact on the occurrence of landslides (Cannon et al., 1998, 2001; Gabet, 2003). According to Rice (1977) the immediate effect of wild fires is similar to the effect of clear-cuts and may not immediately affect landslide occurrence. At a later stage, however, the remaining roots of the old vegetation will disappear, the macro-pores in the regolith will increase and the landslide hazard may increase. Moreover, Johansen et al. (2001) suggest that, following a fire, the amount of mineral soil exposed may increase by 60–70 per cent. By applying rainfall simulation and comparing the results with rainfall simulation on unburned plots, they conclude that burned plots produced 25 per cent more sediment yield than the unburned plots.

Cannon et al. (2003) suggest that burned plots of land are very susceptible to debris flow events. Following a fire, the soil is dry and incapable of absorbing rainwater. As a consequence there is increased overland flow. The increased runoff may lead not only to extensive soil erosion but also to the transport and deposition of this material in the lower areas of the catchment, for example by channelized debris flows (Cannon et al., 2003). The effect of vegetation change on slope stability may be greater from logging, which is short lived (5–20 years, the period between residual

root decay and subsequent regeneration), compared with forest fires (Sidle et al., 1985).

Land-use change

In order to assess the impact of land-use change on landslide occurrence, many scientists have developed models that consider land-use scenarios in order to assess this impact. For example, Vanacker et al. (2003) modelled the impact of land-use change on landslide occurrence in the Andes, and Van Beek (2002) and Van Beek and Van Asch (2004) have developed several scenarios of land-use change in order to assess changes in landslide-susceptible areas in the Mediterranean.

In Mediterranean environments in Europe, the abandonment of cultivated agricultural land is increasing as a result of globalization, mechanization and intensification (Van Beek, 2002). Van Beek and Van Asch (2004) use a physically based model in order to assess the spatial and temporal landslide activity for two scenarios of land-use change involving land abandonment. The results demonstrate that landslide activity is likely to decrease and consequently the areal extent of landslides will hardly change. These results might have implications for perceived hazard levels and for the landslide hazard zonation of the area. Vanacker et al. (2003) modelled landslide susceptibility with a model that suggested that land-use change would continue in the same way that it had over the preceding 37 years in the Ecuadorian Andes. The modelling results clearly indicate that the conversion of secondary forest to grassland or cropland is likely to increase shallow landslide activity.

Meusbürger and Alewell (2008) investigated the ways that land-use and climate changes are influencing the occurrence of landslides by investigating spatial landslide distributions in the Urseren Valley in Switzerland between 1959 and 2004. In this period, the area affected by landslides increased by 92 per cent. This can be explained only by the increase in extreme rainfall events and by land-use change. Specifically, goat pastures and spring pastures had disappeared and remote and less productive areas had been abandoned, being replaced by uncontrolled grazing within confined areas. Moreover, the abandonment of traditional farming practices, in combination with the mechanization of local agriculture, might have contributed to increased soil erosion and consequently to the occurrence of landslides. On the other hand, areas colonized by shrubs show low landslide density (Meusbürger and Alewell, 2008).

Glade (2003a) focuses on geomorphic responses to anthropogenic land-use and land-cover changes in New Zealand. By analysing sedimentation rates in swamp, lake, coastal and marine environments, Glade

(2003a) concludes that the deforestation that took place after the arrival of the European settlers was connected with increased landslide activity, which was reflected in the sedimentation rates in these environments.

Common to all these studies is the strong interlinkage between landslide occurrence and changes in vegetation cover. Indeed, the link can work both ways. As argued above, forest cover can protect regions against landsliding for lower-magnitude triggering events but may also expand the landslide regions for large triggering events despite root reinforcement of the ground. Nevertheless, the focus of this chapter so far has been on the role of vegetation in preventing the initiation of landslides; the possible change in landslide risk and relevant disaster reduction strategies have yet to be addressed in detail.

Disaster reduction strategies

Vegetation has often been used by planners for hazard reduction and to protect exposed elements against various hazard types such as tsunamis (Forbes and Broadhead, 2007; Ohira et al., 2012; Tanaka et al., 2006) and snow avalanches (Brang et al., 2006; Clouet and Berger, 2010; Schönenberger et al., 2005). In many cases, restoration of vegetation coverage can serve as a cost-effective mitigation measure (Peduzzi, 2010). For example, in the case of tropical cyclones in Viet Nam, planting and protecting mangrove forests as a protection measure not only proved to be seven times cheaper than dyke maintenance but also offered secondary benefits to society such as exploitation of mangrove products by locals in order to increase their income (IFRC, 2002).

In the case of landslides, Popescu (2002) suggests that, although in the post-war period landslides were seen as “engineering problems” that would require “engineered solutions” such as the construction of walls and fences or the use of nets for rock fall, in recent decades there has been a clear shift towards non-structural solutions and environmental consideration. This shift is related to a number of reasons. Not only are civil engineering solutions such as slope flattening, tied-back retaining walls or sheet piles very expensive but they may not justify direct short-term economic investments (Bo et al., 2008). On the other hand, measures such as reforestation schemes to manage landslide hazards may have additional benefits to society, for example employment in forestry and the export of forest products (Phillips and Marden, 2005). As a side-effect, forests might also be used for recreational purposes. Most recently, the aesthetic aspect of landscapes, including forested landscapes, has been expressed as an important added value to society (Taboroff, 2003).

Within disaster reduction strategies, spatial landslide hazard analysis is of major importance for landslide risk assessments. The types of methods range from heuristic assessments to statistical and physically based modelling. Here, the type and spatial distribution of vegetation are some of the main factors determining, respectively, landslide distribution and hazards. Consequently, vegetation is commonly taken into account in spatial landslide hazard analysis and in the delimitation of landslide hazard zones (Van Beek and Van Ash, 2004; Wilkinson et al., 2002).

Besides its consideration within spatial analysis, vegetation is also used to assist risk reduction strategies worldwide (for example in France – Berger and Rey, 2004) in order to enhance slope stability (O’Loughlin, 1984). In particular, protection forests have regularly been used for slope stabilization in many countries in the world for many decades and even centuries (Stoffel et al., 2005). Here, the steep landslide-prone terrain is of particular importance. According to the FAO (2010), approximately 330 million hectares of forest (about 8 per cent of the world’s forests) have as their objective the conservation of soil and water, avalanche control, sand dune stabilization, desertification control or coastal protection. The protective functions of the forest are summarized by Sakals et al. (2006) under the following two categories: retaining material in upslope conditions; containing, confining and resisting material during transport and deposition.

Of course, a forest’s ability to protect an area from landslides depends also on its position in relation to the hazard. Clouet and Berger (2010) summarize the ability of forests to control different hazards in the departure and deposition zones (Table 12.2).

Berger and Rey (2004) recognize the role of forests in protecting against natural hazards in mountainous areas; however, they suggest that their role also depends on the position of the forest, the type of vegetation, its age and the spatial scale of the hazard. They stress that the protection of the forest can be active (when it is located in the hazard

Table 12.2 The ability of forests to control natural hazards

Natural hazard	Location	Forest control implemented
Avalanches	Departure zone	Yes
	Transit and stopping zone	No
Rock falls	Departure zone	Yes
	Transit and stopping zone	Yes
Landslides	Departure zone	No
	Transit and stopping zone	No

Source: Clouet and Berger (2010).

departure zone) or passive (when it is located in the departure and stopping zones). Yet the role of forests is rarely taken into account in risk mapping (Berger and Rey, 2004). Clouet and Berger (2010) suggest that the age of the forest can significantly decrease its protective efficiency. Although they recognize that forest management is very important, they suggest that silvicultural interventions may be very expensive. For this reason, Clouet and Berger (2010) have developed an analysis tool based on Geographic Information Systems that can assist in the prioritization and identification of areas within the forest where intervention is needed.

Berger and Rey (2004) stress that there is a need for a common guide as a tool for decision-making in the management of forests that offer protection against natural hazards in countries such as Austria, France and Switzerland. They present an example from France and make recommendations for better forest management for controlling natural hazards in mountainous areas. They discuss the methodological steps for protective forest delimitation. In France, the delimitation of protective forest areas is used in risk prevention plans. In 2006, a set of guidelines for protection forest maintenance was published (Wehrli et al., 2007).

In Austria, the role of the protective forests was understood as early as 1870 when the lack of forests in torrential catchments and the poor state of existing mountainous forests were considered to have contributed to the catastrophic consequences of floods (Austrian Federal Forests, 2009). Since then, protective forests have been used to mitigate the impact of natural hazards such as avalanches and landslides and, according to the Austrian Forest Act, are divided into three categories (FMAFEWM, 2009):

- site-protection forests: they protect themselves;
- protective forests: they provide protection from natural hazards or they enhance and maintain positive environmental effects such as climate or water balance;
- object-protection forests: they protect human settlements and agricultural areas.

Based on information provided by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft), at least 29 per cent of Austrian forests are protection forests and there are at least 83 current protection forest projects in the country. According to the Ministry, the ideal protection forest is a typical mixed forest with several types of old trees. As far as tree types are concerned, larch (*Larix decidua*) is ideal for use against rock fall, whereas spruce (*Picea*) forests are good against snow avalanches owing to their density. The Austrian authorities recognize that protection forests are a cheap alternative to structural protection measures but they also stress that sustainable forest management is

required (Austrian Federal Forests, 2009). The necessary actions for the protection and management of protection forests in Austria are implemented through the "Protection Forest Platforms" of every federal state (FMAFEWM, 2009).

Finally, since the early 1980s there have been measures for the management of protection forests in Switzerland. A large amount of money is invested every year for their protection and management.

Phillips and Marden (2005) review the use of protection forests in New Zealand, where the importance of erosion control was already understood in the early 1940s. The first reforestation project using a variety of tree species started in 1948 and continued in 1953 with the purchase of eroded land by the government for the establishment of dual-purpose exotic forest, for protection against erosion and for timber production. In 1968 the East Coast Project (1968–1987) was approved so that unforested parts of the critical headwaters could be planted with protection forests. In 1988, the project was reviewed following Cyclone Bola, which caused widespread landslides in the country (Marden and Rowan, 1993). Following this event, it was obvious that mature native forest and pine forest offered significant protection (Hicks, 1991). In 1992, the East Coast Project was replaced by the East Coast Forestry Project, which aimed to plant 200,000 hectares in 28 years (Phillips and Marden, 2005).

In Australia, the Australian Geomechanics Society suggested that changes in vegetation can clearly increase the landslide risk and, for this reason, it includes retention of natural vegetation wherever practicable in the guidelines for hillside construction (AGS, 2000). In other countries, such as South Korea, Taiwan and Japan, forests are also used for erosion control and landslide risk reduction (Phillips and Marden, 2005). In South Korea, although erosion control projects started as early as 1907 and the forest area now occupies almost 65 per cent of the entire country, the majority of the forests consist of very young trees as a result of forest management (Phillips and Marden, 2005).

However, although vegetation can be, and often is, used as a non-structural protection measure against landslides, Peduzzi (2010) stresses that, depending on the slope, increasing vegetation density may not be the only solution since other factors contribute to landslide susceptibility, such as slope characteristics. For example, a common practice for slope stabilization is "bio-engineering", a combination of techniques to protect slopes against erosion, reduce the probability of planar sliding and improve surface drainage (Florineth et al., 2002). Bio-engineering uses vegetation in combination with other methods in order to stabilize a slope and reduce landslide hazard. According to Singh (2010: 385), bio-engineering is "the successful use of vegetation (both live and dead plants as well as use of raw materials derived from plants like jute and coir)

together with engineering structures to increase slope stability. These include the use of vegetation and horticultural practices, coir and jute netting, asphalt mulch solution, retards, wattling etc. in combination with slope modification and improved agronomic practices.” According to Singh, the most economical and simple method for slope stabilization is vegetation turfing. Florineth et al. (2002) suggest that the plants used in bio-engineering are selected on the basis of pioneer plant character, a dense and deep rooting system, potential and adventitious rooting system and fast and simple propagation.

In most cases, vegetation has been used mainly to enhance slope stabilization and avoid the occurrence of landslides rather than for mitigating the vulnerability of individual elements at risk. A review of studies concerning alpine hazards has shown that there are a limited number of vulnerability assessment methodologies dealing with the physical vulnerability of elements at risk of landslides (Papathoma-Köhle et al., 2011b). The review highlights that most methods do not take into account the presence of vegetation (for example forests, single trees, hedges) surrounding the exposed elements at risk (especially buildings). However, there are exceptions, such as the methods presented by Papathoma-Köhle et al. (2011a) and Kappes et al. (2012), who have included the presence of trees surrounding buildings in a database of physical vulnerability indicators for elements at risk.

It is evident that landslide occurrence and consequently landslide risk owing to climate change and anthropogenic factors will change significantly in the future. It is expected that vegetation change will have an effect on slope stability, contributing to an increase in landslide risk. The following recommendations might be beneficial for societies dealing with landslide hazard and risk in the face of climate and vegetation change:

1. Decision-making and planning for mitigation and adaptation should be based on an integrated observation and information system. Thus, systematic monitoring and robust modelling of landslide occurrence and also changes in the factors that affect slope stability (for example vegetation change) are very important (Watson and Haeberli, 2004). For this reason, a further refinement of models linking climate, slope hydrology, vegetation cover and stability is essential (as started by Brooks et al., 2004). Robust monitoring will contribute to determining the sensitivity of different landslide types to changing boundary conditions such as climate change (Glade and Crozier, 2005a).
2. Legislation should strengthen and expand existing restrictions on development in landslide-prone terrain, taking into consideration possible changes resulting from climate change (Bo et al., 2008). For example, in Seattle in the United States, municipal codes forbid the removal or clearing of vegetation or trees within landslide-prone areas

or any action detrimental to the habitat (Kazmierczak and Carter, 2010). In exceptional cases where vegetation removal has to take place, a reforestation plan should be ensured (Kazmierczak and Carter, 2010).

3. More research on the effects of vegetation on the different landslide types should be carried out. Currently, there is some research on the functions of different vegetation types in slope stability, but it is not commonly detailed by landslide type (for example, debris flows, shallow translational landslides, deep-seated rotational landslides).
4. The consequences of vegetation changes for landslide occurrence, and thus the landslide risk, have to be further explored. Here, the physical vulnerability of elements at risk, such as buildings and infrastructure, might be reduced by the presence of vegetation. Notwithstanding studies on rock fall, there is sparse research on how landslide risk reduction can be achieved and which characteristics of the vegetation could enhance its protective role. This could be done by extensive investigation of past event damage reports but also by establishing post-event damage recording protocols (Glade and Crozier, 2005a; Hübl et al., 2002).
5. There should be a shift from civil engineering measures to sustainable silvicultural actions that might also benefit the local economy and community, given that the maintenance costs are not as high as for engineering measures.
6. Climate change should be further taken into consideration in land-use planning, for example by allocating land susceptible to increased landslide activity because of climate change in a way that lowers hazard exposure. Examples of good practice are using land for open public space and sports fields rather than for housing development. In some cases, site abandonment may also be an option (Lee and Jones, 2004).
7. Climate change should be considered in the design of measures for slope stabilization and erosion control. For example, the specification of structural measures should allow for climate uncertainty or variability in the design parameters (Lee and Jones, 2004).
8. Finally, landslide risk assessments should take into account changes in climate and vegetation cover – in addition to socioeconomic changes (for example, the extension of urbanized regions or the development of new critical infrastructure such as transport networks and power lines).

Conclusions

The role of vegetation in landslide occurrence has been investigated for many decades. However, its influence on elements at risk (houses, critical infrastructure), their vulnerability and overall landslide risk is still an

open question. This is even more so considering the short- and long-term effects of climate change. Climate and environmental change are expected to modify vegetation patterns, in particular in sensitive mountain areas. Land-cover changes in combination with increased precipitation may increase the probability of landslide occurrence. More research is needed in order to fully understand the relationship between vegetation and geomorphology (Marston, 2010), especially in landslide research. Although most studies suggest that the existence of vegetation increases slope stability and reduces the occurrence of landslides, many scientists point out that this is not always the case (Marston, 2010; Rickli and Graf, 2009). There are not sufficient studies quantifying the effects of vegetation change on landslide occurrence in both time and space and defining the thresholds of forests or other vegetation types for stabilizing and destabilizing slopes.

Moreover, the change in both landslide magnitude and intensity is still a challenging field of research. The use of protection forests is a common practice in many countries (for example in Austria, China, France, Japan, New Zealand and Switzerland). In most cases, vegetation cover and land use are taken into account in landslide hazard assessments and hazard zonations. However, the protective role of vegetation as far as reducing the physical vulnerability of buildings and infrastructure is concerned is usually not considered. More research is needed focusing on the role of the vegetation surrounding an element at risk and how this element reacts when it is affected by a particular landslide such as a rock fall or debris flow. Last but not least, vegetation and land-use changes caused by climate change should be taken into consideration in decision-making and planning processes.

REFERENCES

- AGS [Australian Geomechanics Society] (2000) *Landslide Risk Management Concepts and Guidelines*. Sub-Committee on Landslide Risk Management. Available at <<http://australiangeomechanics.org/admin/wp-content/uploads/2010/11/LRM2000-Concepts.pdf>> (accessed 26 October 2012).
- Alcántara-Ayala, I., O. Esteban-Chávez and J.F. Parrot (2006) "Landsliding Related to Land-cover Change: A Diachronic Analysis of Hillslope Instability Distribution in the Sierra Norte, Puebla, Mexico". *Catena* 65: 152–165.
- Anav, A. and A. Mariotti (2011) "Sensitivity of Natural Vegetation to Climate Change in the Euro-Mediterranean Area". *Climate Research* 46: 277–292.
- Austrian Federal Forests (2009) "Presseaussendung: Bundesforste-Schutzwälder: Grüner Wall gegen Lawinen, Muren und Steinschlag". Österreichische Bundesforste, <[http://www.bundesforste.at/index.php?id=54&no_cache=1&tx_ttnews\[tt_news\]=398](http://www.bundesforste.at/index.php?id=54&no_cache=1&tx_ttnews[tt_news]=398)> (accessed 26 October 2012).

- Bachelet, D. et al. (2001) "Climate Change Effects on Vegetation Distribution and Carbon Budget in the United States". *Ecosystems* 4: 164–185.
- Bärring, L. and G. Persson (2006) "Influence of Climate Change on Natural Hazards in Europe: Natural and Technological Hazards and Risks Affecting the Spatial Development of European Regions". *Geological Survey of Finland, Special Paper* 42: 93–107.
- Bathurst, J.J., C.I. Bovolo and F. Cisneros (2009) "Modelling the Effect of Forest Cover on Shallow Landslides at the River Basin Scale". *Ecological Engineering* 36: 317–327.
- Bell, R. and T. Glade (2004) "Quantitative Risk Analysis for Landslides: Examples from Bildudalur, NW-Iceland". *Natural Hazards and Earth System Sciences* 4(1): 117–131.
- Berger, F. and F. Rey (2004) "Mountain Protection Forests against Natural Hazards and Risks: New French Developments by Integrating Forests in Risk Zoning". *Natural Hazards* 33(3): 395–404.
- Bigot, C., L.K.A. Dorren and F. Berger (2009) "Quantifying the Protective Function of a Forest against Rockfall for Past, Present and Future Scenarios Using Two Modelling Approaches". *Natural Hazards* 49: 99–111.
- Blöchl, A. and B. Braun (2005) "Economic Assessment of Landslide Risks in the Swabian Alb, Germany: Research Framework and First Results of Homeowners and Experts Surveys". *Natural Hazards and Earth System Science* 5: 389–396.
- Bo, M.W., M. Fabius and K. Fabius (2008) "Impact of Global Warming on Stability of Natural Slopes". In J. Locat, D. Perret, D. Turmel, D. Demers and S. Leroueil (eds), *Proceedings of the 4th Canadian Conference on Geohazards: From Causes to Management*. Quebec: Presse de l'Université Laval.
- Bohle, H.-G. and T. Glade (2007) "Vulnerabilitätskonzepte in Sozial- und Naturwissenschaften". In C. Felgentreff and T. Glade (eds), *Naturrisiken und Sozialkatastrophen*. Heidelberg: Spektrum Akademischer Verlag, pp. 99–119.
- Brang, P. et al. (2006) "Management of Protection Forests in the European Alps: An Overview". *Forest, Snow and Landscape Research* 80(1): 23–44.
- Brooks, N. (2003) "Vulnerability Risk and Adaptation: A Conceptual Framework". Tyndall Centre for Climate Change Research, Working Paper 38.
- Brooks, S.M., M.J. Crozier, T. Glade and M.G. Anderson (2004) "Towards Establishing Climatic Thresholds for Slope Instability: Use of a Physically-based Combined Soil Hydrology–Slope Stability Model". *Pure and Applied Geophysics* 161: 881–905.
- BRP [Bundesamt für Raumplanung], BWB [Bundesamt für Wasserwirtschaft] and BUWAL [Bundesamt für Umwelt, Wald und Landschaft] (1997) "Berücksichtigung der Massenbewegungsgefahren bei raumwirksamen Tätigkeiten: Empfehlung", <<http://www.planat.ch/de/infomaterial-detailansicht/datum/2011/06/29/beruecksichtigung-der-massenbewegungsgefahren-bei-raumwirksamen-taetigkeiten/>> (accessed 26 October 2012).
- Cannon, S.H., R.M. Kirkham and M. Parise (2001) "Wildfire-related Debris-flow Initiation Processes, Storm King Mountain, Colorado". *Geomorphology* 39(3–4): 171–188.

- Cannon, S.H., P.S. Powers and W.Z. Savage (1998) "Fire-related Hyperconcentrated Debris Flows on Storm King Mountain, Glenwood Springs, Colorado, USA". *Environmental Geology* 35: 2–3.
- Cannon, S.H. et al. (2003) "Debris-Flow Response of Basins Burned by the 2002 Coal Seam and Missionary Ridge Fires, Colorado". In D.D. Boyer, P.M. Santi and W.P. Rogers (eds), *Engineering Geology in Colorado: Contributions, Trends, and Case Histories*. Association of Engineering Geologists Special Publication 14, Colorado Geological Survey Special Publication 55, CD-ROM.
- Clouet, N and F. Berger (2010) "New GIS Developments in Mountain Protection Forests Zoning against Snow Avalanches and Rockfalls". In *Proceedings of the International Symposium Interpraevent 2010*, 26–30 April 2010, Taipei, Taiwan, pp. 382–390.
- Corominas, J. et al. (2005) "Quantitative Assessment of the Residual Risk in a Rockfall Protected Area". *Landslides* 2: 343–357.
- Crozier, M.J. (1999) "Slope Instability: Landslides". In D. Alexander and R.W. Fairbridge (eds), *Encyclopedia of Environmental Science*. Dordrecht: Kluwer, pp. 561–562.
- Cruden, D.M. and D.J. Varnes (1996) "Landslide Types and Processes". In A.K. Turner and R.L. Schuster (eds), *Landslides: Investigation and Mitigation*. Special Report. Washington, DC: National Academy Press, pp. 36–75.
- DeRose, R.C. et al. (1995) "Effect of Landslide Erosion on Taranaki Hill Pasture Production and Composition". *New Zealand Journal of Agricultural Research* 38: 457–471.
- Dikau, R. et al. (eds) (1996) *Landslide Recognition: Identification, Movement and Causes*. Chichester: John Wiley & Sons.
- Dorren, L.K.A., F. Berger and U.S. Putters (2006) "Real-size Experiments and 3-D Simulation of Rockfall on Forested and Non-forested Slopes". *Natural Hazards and Earth System Sciences* 6: 145–153.
- Dorren, L.K.A. et al. (2004) "Combining Field and Modelling Techniques to Assess Rockfall Dynamics on a Protection Forest Hillslope in the European Alps". *Geomorphology* 57(3–4): 151–167.
- FAO [Food and Agriculture Organization of the United Nations] (2010) *Global Forest Resources Assessment 2010: Main Report*. FAO Forestry Paper 163. Rome: FAO.
- Flannigan, M.D., B.J. Stocks and B.M. Wotton (2000) "Climate Change and Forest Fires". *The Science of the Total Environment* 262: 221–229.
- Florineth F., H.P. Rauch and H. Staffler (2002) "Stabilization of Landslides with Bio-engineering Measures in South Tyrol/Italy and Thankot/Nepal". In *Proceedings of the International Congress INTERPRAEVENT 2002 in the Pacific Rim, 14–18 October 2002, Matsumoto, Japan*. Congress publication, Vol. 2, pp. 827–837.
- FMAFEWM [Federal Ministry of Agriculture, Forestry, Environment and Water Management, Austria] (2009) "Der österreichische Wald". Available at <http://www.lebensministerium.at/publikationen/forst/der_oesterreichische_wald.html> (accessed 26 October 2012).

- Forbes, K. and J. Broadhead (2007) "The Role of Coastal Forests in the Mitigation of Tsunami Impacts". Food and Agriculture Organization of the United Nations.
- Fuchs, S. (2009) "Susceptibility versus Resilience to Mountain Hazards in Austria: Paradigms of Vulnerability Revisited". *Natural Hazard and Earth System Sciences* 9: 337–352.
- Gabet, E. (2003) "Post-fire Thin Debris Flows: Sediment Transport and Numerical Modelling". *Earth Surface Processes and Landforms* 28: 1341–1348.
- Geertsema, M., V.N. Egginton, J.W. Schwab and J.J. Clague (2007) "Landslides and Historic Climate in Northern British Columbia". In R. McInnes, J. Jakeways, M. Fairbank and R. Methie (eds), *Landslides and Climate Change: Challenges and Solutions*. London: Taylor & Francis, pp. 9–16.
- Gerrard, J. and R. Gardner (2002) "Relationships between Landsliding and Land Use in the Likhu Khola Drainage Basin, Middle Hills, Nepal". *Mountain Research and Development* 22(1): 48–55.
- Glade, T. (2003a) "Landslide Occurrence as a Response to Land Use Change: A Review of Evidence from New Zealand". *Catena* 51: 297–314.
- Glade, T. (2003b) "Vulnerability Assessment in Landslide Risk Analysis". *Die Erde* 134(2): 121–138.
- Glade, T. and M.J. Crozier (2005a) "Landslide Hazard and Risk: Concluding Comment and Perspectives". In T. Glade, M.G. Anderson and M.J. Crozier (eds), *Landslide Hazard and Risk*. Chichester: Wiley, pp. 767–774.
- Glade, T. and M.J. Crozier (2005b) "The Nature of Landslide Hazard Impact". In T. Glade, M.G. Anderson and M.J. Crozier (eds), *Landslide Hazard and Risk*. Chichester: Wiley, pp. 43–74.
- Greenway, D.R. (1987) "Vegetation and Slope Stability". In M.G. Anderson and K.S. Richards (eds), *Slope Stability: Geotechnical Engineering and Geomorphology*. Chichester: Wiley, pp. 187–230.
- Hicks, D.L. (1991) "Erosion under Pasture, Pine Plantations, Scrub and Indigenous Forest: A Comparison from Cyclone Bola". *New Zealand Forestry* 36(3): 21–22.
- Holub, M. and S. Fuchs (2009) "Mitigating Mountain Hazards in Austria: Legislation, Risk Transfer, and Awareness Building". *Natural Hazard and Earth Systems Science* 9: 523–537.
- Hübl, J., H. Kienholz and A. Loipersberger (eds) (2002) "DOMODIS – Documentation of Mountain Disasters: State of Discussion in the European Mountain Areas". Journal Series 1, Manual 1, International Research Society INTERPRAEVENT, Klagenfurt, Austria.
- Hufschmidt, G. and T. Glade (2010) "Vulnerability Analysis in Geomorphic Risk Assessment". In I. Alcántara-Ayala and S. Goudie (eds), *Geomorphological Hazards and Disaster Prevention*. Cambridge: Cambridge University Press, pp. 233–243.
- IFRC [International Federation of Red Cross and Red Crescent Societies] (2002) "Mangrove Planting Saves Lives in Vietnam". Press release, June, <<http://www.grida.no/publications/et/ep3/page/2610.aspx>> (accessed 26 October 2012).
- IPCC [Intergovernmental Panel on Climate Change] (2007) *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the

- Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge UK, and New York, NY, USA: Cambridge University Press.
- IPCC (2012) "Summary for Policymakers". In *Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge, UK, and New York, NY, USA: Cambridge University Press, pp. 1–19.
- Johansen, M.P., T.E. Hakonson and D.D. Breshears (2001) "Post-fire Runoff and Erosion from Rainfall Simulation: Contrasting Forests with Shrublands and Grasslands". *Hydrological Processes* 15: 2953–2965.
- Kappes, M., M. Papathoma-Köhle and M. Keiler (2012) "Assessing Physical Vulnerability for Multi-hazards Using an Indicator-based Methodology". *Applied Geography* 32(2): 577–590.
- Kazmierczak, A. and J. Carter (2010) *Adaptation to Climate Change Using Green and Blue Infrastructure: A Database of Case Studies*. Manchester: University of Manchester Press.
- Kuriakose, S.L. et al. (2006) "Effect of Vegetation on Debris Flow Initiation: Conceptualization and Parameterization of a Dynamic Model for Debris Flow Initiation in Tikovil River Basin, Kerala, India, Using PCRASTER". In *2nd International Symposium on Geo-information for Disaster Management (Gi4DM) – Remote Sensing and GIS Techniques for Monitoring and Prediction of Disasters*, 25–26 September 2006, Goa, India.
- Lee, E.M. and D.K.C. Jones (2004) *Landslide Risk Assessment*. London: Thomas Telford.
- Marden, M. and D. Rowan (1993) "Protective Value of Vegetation on Tertiary Terrain before and during Cyclone Bola, East Coast, North Island, New Zealand". *New Zealand Journal of Forestry Science* 23(3): 255–263.
- Marston, R.A. (2010) "Geomorphology and Vegetation on Hillslopes: Interactions, Dependencies and Feedback Loops". *Geomorphology* 116: 206–217.
- Masuya H. et al. (2009) "Basic Rockfall Simulation with Consideration of Vegetation and Application to Protection Measure". *Natural Hazards and Earth System Sciences* 9: 1835–1843.
- Meusburger, K. and K. Alewell (2008) "Impacts of Anthropogenic and Environmental Factors on the Occurrence of Shallow Landslides in an Alpine Catchment (Urseren Valley, Switzerland)". *Natural Hazards and Earth System Sciences* 8: 509–520.
- Ohira, W., K. Honda K. and K. Harada (2012) "Reduction of Tsunami Inundation by Coastal Forests in Yogyakarta, Indonesia: A Numerical Study". *Natural Hazards and Earth System Sciences* 12: 85–95.
- O'Loughlin, C.L. (1984) "Effectiveness of Introduced Forest Vegetation for Protection against Landslides and Erosion in New Zealand's Steeplands". In C.L. O'Loughlin and A.J. Pearce (eds), *Symposium on Effects of Forest Land Use on*

- Erosion and Slope Stability*. Honolulu, Hawaii: New Zealand Forest Service, pp. 275–280.
- Pabst, R.J. and T.A. Spies (2001) “Ten Years of Vegetation Succession on a Debris-flow Deposit in Oregon”. *Journal of the American Water Resources Association* 37(6): 1693–1708.
- Papathoma-Köhle, M. et al. (2007) “Elements at Risk as a Framework for Assessing the Vulnerability of Communities to Landslides”. *Natural Hazards and Earth System Sciences* 7: 765–777.
- Papathoma-Köhle, M., M. Kappes and M. Keiler (2011a) “An Indicator-based Methodology for Vulnerability Assessment in Alpine Areas”. *Geophysical Research Abstracts*, Vol. 13, EGU2011-4942, EGU General Assembly.
- Papathoma-Köhle, M., et al. (2011b) “Physical Vulnerability Assessment for Alpine Hazards: State of the Art and Future Needs”. *Natural Hazards* 58(2): 645–680.
- Peduzzi, P. (2010) “Landslides and Vegetation Cover in the 2005 North Pakistan Earthquake: A GIS and Statistical Quantitative Approach”. *Natural Hazards and Earth System Sciences* 10: 623–640.
- Phillips, C.J. and M. Marden (2005) “Reforestation Schemes to Manage Regional Landslide Risk”. In T. Glade, M.G. Anderson and M.J. Crozier (eds), *Landslide Hazard and Risk*. Chichester: Wiley & Sons., pp. 517–546.
- Popescu, M.E. (2002) “Landslide Causal Factors and Landslide Remedial Options”. Keynote Lecture, Proceedings 3rd International Conference on Landslides, Slope Stability and Safety of Infra-Structures, Singapore, pp. 61–81. Available at Online Geoengineering Library, <<http://www.geoengineer.org/Lanslides-Popescu.pdf>> (accessed 25 October 2012).
- Rice, R.M. (1977) “Forest Management to Minimize Landslide Risk”. In *Guidelines for Watershed Management*. FAO Conservation Guide No. 1. Rome: Food and Agriculture Organization of the United Nations, pp. 271–287.
- Rickli, C. and F. Graf (2009) “Effects of Forests on Shallow Landslides: Case Studies in Switzerland”. *Forest, Snow and Landscape Research* 82(1): 33–44.
- Sakals, M.E. et al. (2006) “The Role of Forests in Reducing Hydrogeomorphic Hazards”. *Forest, Snow and Landscape Research* 80(1): 11–22.
- Schmidt, K.M. et al. (2001) “The Variability of Root Cohesion as an Influence on Shallow Landslide Susceptibility in the Oregon Coast Range”. *Canadian Geotechnical Journal* 38(5): 995–1024.
- Schönenberger, W., A. Noack and P. Thee (2005) “Effect of Timber Removal from Windthrow Slopes on the Risk of Snow Avalanches and Rockfall”. *Forest Ecology and Management* 213(1–3): 197–208.
- Sidle, R.C. and H. Ochiai (2006) *Landslides: Processes, Prediction, and Land Use*. Water Resources Monograph Series, Vol. 18. Washington, DC: American Geophysical Union.
- Sidle, R.C., A. Pearce and C.L. O’Loughlin (1985) *Hillslope Stability and Land Use*. Water Resources Monograph Series Vol. 11. Washington, DC: American Geophysical Union.
- Singh, A.K. (2010) “Bioengineering Techniques of Slope Stabilization and Landslide Mitigation”. *Disaster Prevention and Management* 19(3): 384–397.

- Smale, M.C., M. McLeod and P.N. Smale (1997) "Vegetation and Soil Recovery on Shallow Landslide Scars in Tertiary Hill Country, East Cape Region, New Zealand". *New Zealand Journal of Ecology* 21(1): 31–41.
- Steinacher, R. et al. (2009) "The Influence of Deforestation on Slope Instability". *Austrian Journal of Earth Sciences* 102(2): 90–99.
- Stoffel, M.D. et al. (2005) "Analyzing Rockfall Activity (1600–2002) in a Protection Forest: A Case Study Using Dendrogeomorphology". *Geomorphology* 68(3–4): 224–241.
- Sudmeier-Rieux, R. et al. (2011) "The 2005 Pakistan Earthquake Revisited: Methods for Integrated Landslide Assessment". *Mountain Research and Development* 31(2): 112–121.
- Taboroff, J. (2003) "Natural Disasters and Urban Cultural Heritage: A Reassessment". In A. Kreimer, M. Arnold and A. Carlin (eds), *Building Safer Cities: The Future of Disaster Risk*, Vol. 3. Washington, DC: World Bank, pp. 233–272.
- Tanaka, N. et al. (2006) "Coastal Vegetation Structures and Their Functions in Tsunami Protection: Experience of the Recent Indian Ocean Tsunami". *Landscape and Ecological Engineering* 3(1): 33–45.
- Theurillat, J.-P. and A. Guisan (2001) "Potential Impact of Climate Change on Vegetation in the European Alps: A Review". *Climatic Change* 50: 77–109.
- UNDRO [Office of the United Nations Disaster Relief Coordinator] (1984) *Disaster Prevention and Mitigation: A Compendium of Current Knowledge. Vol. 11: Preparedness Aspects*. New York: United Nations.
- UNU [United Nations University] (2006) "Landslides". News Release, MR/E01/06, 17 January.
- Van Beek, L.P.H. and T.W.J. Van Asch (2004) "Regional Assessment of the Effects of Land-Use Change on Landslide Hazard by Means of Physically Based Modelling". *Natural Hazards* 31: 289–304.
- Van Beek, R. (2002) *Assessment of the Influence of Changes in Land Use and Climate on Landslide Activity in a Mediterranean Environment*. Netherlands Geographical Studies NGS 294, Utrecht.
- Vanacker, V. et al. (2003) "Linking Hydrological, Infinite Slope Stability and Land-use Change Models through GIS for Assessing the Impact of Deforestation on Slope Stability in High Andean Watersheds". *Geomorphology* 52: 299–315.
- Wang, Y. (2004) "Environmental Degradation and Environmental Threats in China". *Environmental Monitoring and Assessment* 90(1): 161–169.
- Wasowski, J., D. Casarano and C. Lamanna (2007) "Is the Current Landslide Activity in the Daunia Region (Italy) Controlled by Climate or Land Use Change?" In R. McInnes, J. Jakeways, H. Fairbank and E. Mathie (eds), *Landslides and Climate Change – Challenges and Solutions. Proceedings of the International Conference on Landslides and Climate Change, Ventnor, Isle of Wight, UK, 21–24 May 2007*. London: Taylor & Francis, pp. 41–49.
- Watson R.T. and W. Haeberli (2004) "Environmental Threats, Mitigation Strategies and High-mountain Areas". *Ambio Special Report* 13: 2–10.
- Wehrli, A. et al. (2007) "Schutzwald management in den Alpen: Eine Übersicht". *Schweizerische Zeitschrift für Forstwesen* 158(6): 142–156.

- Wilkinson, P.L. et al. (2002) "Landslide Hazard and Bioengineering: Towards Providing Improved Decision Support through Integrated Numerical Model Development". *Environmental Modelling & Software* 17(4): 333–344.
- Winter, M.G. et al. (2010) "Introduction to Land-use and Climate Change Impacts on Landslides". *Quarterly Journal of Engineering Geology and Hydrogeology* 43: 367–370.
- Woltjer M. et al. (2008) "Coupling a 3D Patch Model and a Rockfall Module to Assess Rockfall Protection in Mountain Forests". *Journal for Environmental Management* 87(3): 373–388.
- Zhihong, L. et al. (2010) "Quantitative Vulnerability Estimation for Scenario-based Landslide Hazards". *Landslides* 7: 125–134.

Index

A

Accelerated and Shared Growth Initiative
for South Africa (AsgiSA), 179,
188n17

Acoustic Doppler Velocity (ADV), 66–67

adaptation, defined, 18

agroforestry systems, 374

Antarctica, 372

anthropogenic

activity, 303, 418

climate change, 191

factors, 295–96

forces, 294

influences, 114

land-use and land-cover changes, 306

pressures, 100, 257

processes, 255

removal of seagrasses, 136n7

slope modifications, 295

Argentina, 33, 376, 378–79, 446

AsgiSA. *See* Accelerated and Shared
Growth Initiative for South Africa
(AsgiSA)

B

Bali Action Plan, 15

barrier islands, 29, 34, 41, 376–77

barriers

avalanche, 323, 326

beaches and coastal, 89

against extreme waves, 62

against hazards, 64

natural or fabricated, 85

natural protective, 32

non-porous natural, 34

against overtopping, 61

tree trunks and root plates act as, 326

against wind erosion and sand storms, 10,
35

biodiversity

burning to decrease wildfire hazards and,
42

coastal ecological corridors and, 181

conservation and coastal hazard

mitigation, 148–49, 151

conservation and disaster mitigation, 380

conservation and reconstruction planning,
428

conservation of agricultural, 16

conservation of local, 398

conservation of national parks and

nature reserves, 373

corridor and dune systems, 169

disaster mitigation and, 378

DRR and, 6

EBA integrates sustainable use, 192

ecosystem services and, 382

ecosystem services loss and, 372–73

- biodiversity (cont.)
 ecosystem-based adaptation and, 38
 ecosystems and, 395
 flood prevention by restoring lakes and floodplains, 37
 forest cover and, 362–63
 forests as protected areas for watershed and, 374
 human activities and loss of, 84
 infrastructure investment and, 380
 mangrove ecosystems and, 95, 97
 marine, decline after storms, 197
 natural forest and, 33
 networks and coastal dynamic processes, 186
 protected areas and, 372, 374, 383
 protection in Argentina, 379
 Whangamarino Ramsar wetlands and, 375
- C
CAMP. *See* coastal area management plan (CAMP)
Cape Town, South Africa. *See* coastal adaptation strategy for Cape Town
carbon sequestration, 11, 31, 38, 97–98
carbon storage and forest cover, 362
Caribbean Community (CARICOM), 40, 47n7, 420
Caribbean Development Bank (CDB), 40, 420
 Tools for Mainstreaming Disaster Risk Reduction, 420
CARICOM. *See* Caribbean Community (CARICOM)
CbA. *See* community-based adaptation (CbA)
CBA. *See* cost–benefit analysis (CBA)
CBD. *See* Convention on Biological Diversity (CBD)
CCA. *See* climate change adaptation (CCA)
CCSR. *See* Center for Climate Systems Research (CCSR)
CCT. *See* City of Cape Town (CCT)
CDB. *See* Caribbean Development Bank (CDB)
CEA. *See* country environmental analysis (CEA)
CENOE. *See* Centro Nacional Operativo de Emergência (National Emergency Operations Centre) (CENOE)
Center for Climate Systems Research (CCSR), 142, 144
Centre for Research on the Epidemiology of Disasters (CRED), 13, 394
Centro Nacional Operativo de Emergência (National Emergency Operations Centre) (CENOE), 275
CF. *See* community forest (CF)
CFUG. *See* Community Forest User Group (CFUG)
City of Cape Town (CCT), 19, 164, 166–68, 172, 175–76, 179–87
Climate Adaptation Fund, 15
climate change
 anthropogenic, 191
 deforestation and, 294
 droughts and, 223, 293, 304, 372, 438
 environmental changes in coastal areas, 99
 floods and, 223
 induced, 20n1
 resilience to, 16, 38, 192, 208
 strategic environmental assessment (SEA) and, 47n8
 tropical cyclones and, 5
 United Nations Framework Convention on Climate Change (UNFCCC), 7, 15–16, 38, 194
climate change adaptation (CCA)
 coastal adaptation strategy, Cape Town, 184
 DRR, relevance of ecosystems for, 7–8, 15–16
 Eco-DRR and, 37–38, 438–39, 449–50, 452
 EIAS and SEAs in disaster management, 422, 431
 integration of ecosystems, DRR and, 15–16
 IPCC Special Report (2012), 7–8
 IWRM and, 249, 260, 262
 mangroves as natural coastal defences, 85
 New York and Connecticut area, 152, 159n2
 PROFOR reforestation project and, 33
 RiVAMP and Negril, Jamaica, 110, 112, 121, 133
 sustainable water supply and sanitation, 276
 in Tonga, 194–95, 201–2, 212–13

- climate-related risk and vulnerability, 16
- coastal adaptation strategy for Cape Town
 - apartheid legacy and coastal development, 168–72
 - Cape Town map showing apartheid planning, 166
 - City of Cape Town (CCT), 19, 164, 166–68, 172, 175–76, 179–87
 - city's rates base *vs.* retaining open spaces, 185
 - climate change adaptation (CCA), 184
 - coastal ecosystems, 167, 178–80, 186–87
 - coastal hazards and, 167, 170
 - Coastal Protection By-Law, 182
 - crime, 185–86
 - ecosystem-based DRR, 187n5
 - ecosystem-based management and socioeconomic imperatives, 179–82
 - ecosystem-based management approach, 164, 167, 170–72, 177–80, 182
 - GIS, 173, 181, 188n16
 - ISDR and, 187n2, 187n4
 - population distribution across the City, 165
 - risks and vulnerability, current, 172–79
 - sea level rise (SLR), 167, 170–75, 180–81, 186
 - storm surges and, 167, 169–76, 178–80, 186
 - Table Mountain National Park, 167
- coastal area management plan (CAMP), 58
- coastal areas, 5
 - of Camps Bay, Cape Town, 164, 171
 - casualties in tropical, 88
 - climate change and environmental changes in, 99
 - coastal frontage property, Cape Town, 179
 - ecological resilience of, 85
 - ecosystems in the dynamic intertidal zone, 82
 - flooding events and other hazards in, 86–87
 - forest fires burned watersheds in Spain, 403
 - management with increasing populations, 99
 - mangrove planting in, 201
 - mangroves break up storm waves, 377
 - mangroves reduce vulnerability of, 380
 - multiple hazards, dense human populations and economic assets, 41
 - of Negril, Jamaica, 112, 128, 133
 - of New York and Connecticut, 150
 - risk reduction strategies, City of Cape Town, 19
 - of SIDS and RiVAMP methodology, 111
 - vegetation and, 11, 72
 - vulnerability of, to natural hazards, 88
 - wetlands and floodplains control floods in, 10, 34
- coastal ecosystems
 - barrier islands, 29, 34, 41, 376–77
 - coastal hazards and, 34, 57–58, 60–61, 72, 79, 82
 - coral reefs (*See* coral reefs)
 - cultural services of, 167
 - ecosystem services and, 141, 145
 - mangroves (*See* mangrove(s))
 - resilience of, 84–85, 110
 - saltmarshes, 10, 34, 82, 91–92, 143, 152, 155, 400
 - sand dunes, 10, 34, 41, 59, 61–64, 178, 376
 - shallow, 115–16
 - tsunamis and, 33–34, 61
- coastal hazards
 - Cape Town and, 167, 170
 - coastal ecosystems and, 34, 57–58, 60–61, 72, 79, 82
 - coastal forests, mangroves, seagrass and coral reefs, dunes and saltmarshes mitigate, 400
 - coastal reforestation projects in Asia protect against, 33
 - competing economic, public safety and ecological goals around, 444
 - coral reefs and, 400
 - earthquakes and, 57
 - ICZM reduce vulnerability to, 41
 - “Making Space for Water” programme and, 32
 - mangroves and coastal vegetation buffer, 19, 450
 - mitigation and biodiversity conservation, 148–49, 151
 - New York and Connecticut area, 140–41, 143–49, 153–54, 157–58
 - Tonga and, 199, 202
 - Coastal Resilience programme, 141–43, 146–50, 153–57, 159, 444

- coastal vegetation, 10–12, 19
 - coastal ecosystems protect against hazards, 59, 64–65
 - degradation of, and livelihood recovery efforts, 29
 - on dunes, energy dissipation and erosion resistance of, 62–63
 - extreme weather events, protection against, 35
 - flooding from the removal and degradation of, 132
 - natural defence against wave action, currents and flooding from storms, 61
 - physical modelling using a flume facility, 65
 - reduces wave heights and erosion from storms and high tides, 10
 - storm surges, buffer, 450
 - tsunami wave passing through, model of, 71–80
 - community forest (CF)
 - in Nepal, 19, 33, 343, 348, 350–53, 356, 363–64
 - Community Forest User Group (CFUG), 343, 348–49, 363
 - community-based adaptation (CbA), 229
 - in Tonga, 192, 194, 208, 210–13
 - Community-based Risk Screening Tool – Adaptation and Livelihoods (CRiSTAL), 192
 - Convention on Biological Diversity (CBD)
 - about, 47n6, 382, 395
 - 10th Conference of the Parties, 384
 - coral reefs
 - coastal hazards, mitigate small-and medium-scale, 400
 - degradation of, from invasive species, 114
 - in dynamic intertidal zone, 82
 - economic value of ecosystem services, estimated, 36
 - ecosystem services value for, 96
 - ecosystem-based measures for, 41
 - fishermen destroy, 62
 - geo-environmental information used/ converted in GIS, 116
 - Great Morass, Jamaica, 112, 114, 116–17, 119, 122, 131, 134–35
 - hydraulic performance of, 65
 - natural coastal ecosystems, 59
 - natural defences against wave action, currents and flooding from storms, 61–62, 110
 - natural submerged breakwaters for the dissipation of wave energy, 61
 - pollution and overexploitation destroys, 372
 - protected areas in DDR and, 374, 376–77
 - reduce wave heights and erosion from storms and high tides, 10, 34
 - RiVAMP and, 112, 115–29
 - temperature rise and ocean acidification stress, 85
 - tsunami wave propagation and, 65–71
 - cost–benefit analysis (CBA), 235, 260
 - country environmental analysis (CEA), 425–26
 - CRED. *See* Centre for Research on the Epidemiology of Disasters (CRED)
 - CRiSTAL. *See* Community-based Risk Screening Tool – Adaptation and Livelihoods (CRiSTAL)
 - cultural services of ecosystems, 31, 35, 167, 187n5
 - cyclones. *See also* tropical cyclones
 - Bangladesh, 86
 - climate change and tropical, 5
 - community's ability to cope with damage from, 26
 - damage or risks can be limited or managed, 26
 - DRR and, 212
 - Jamaica and tropical, 112, 119–21
 - Mahanadi Delta, India and, 230
 - mangrove ecosystems and, 89, 377
 - Mozambique and, 271, 273
 - Tonga and, 193–94
 - tropical (*See* tropical cyclones)
 - UNDP guidelines, 426
 - Viet Nam and, 307
- D
- dams
 - climate adaptation and, 378–79
 - construction of 45,000 large and 800,000 small, 239
 - delta sedimentation decreased by, 29
 - dynamic river basins and, 221, 223, 226, 239
 - environmental degradation from, 223
 - flood pulse, loss and disturbance of, 226

- forests *vs.*, 303
 in India, 420
 protection forests and, 333
 for regular and controlled water for irrigation, 252
 water infrastructure relies on water infrastructure, 256
- deforestation. *See also* forest(s); reforestation
 avalanches in Switzerland and, 373
 climate change and, 294
 deaths from earthquakes in mountainous areas and, 372
 drought conditions and, 109
 DRR and improved land-use and, 444
 emissions from, 363
 FAO report on, 304–5
 in Haiti, 13, 29
 of hillsides and flooding, 132
 landslide vulnerability and, 111
 landslides and, 305, 307, 372
 in Middle East, 374
 in Mozambique, 404
 by Nepali farmers and flooding, 346
 in Pakistan, 29
 of Rokko Mountain Range, Japan, 401
 Tacaná watersheds of Guatemala and flood risk, 262
 urban centres/expansion and, 401, 406
 watersheds disrupted and riverbed siltation from, 418
- Department for Environment, Food and Rural Affairs [UK] (Defra), 8, 32, 47n4, 256
- Department of Forests [Nepal] (DoF), 348, 350, 354
- disaster impact assessment (DIA), 432
- Disaster Management Plan (DMP), 422–24, 426, 431–32
- disaster risk, 408
 EIAS and SEAs in disaster management, 416, 418–22, 425–26, 430–33
 “Strategic Environmental Assessment and Disaster Risk Reduction” (OECD), 424
Tools for Mainstreaming Disaster Risk Reduction, 420
- disaster risk management (DRM)
 about, 9, 44, 110, 416
 Eco-DRR and, 426, 442, 450
 IWRM and, 257, 264
 role of ecosystems in, 9–15
 role of protected areas in mitigating disasters, 371, 384
- disaster risk reduction (DRR). *See also* ecosystem-based disaster risk reduction (Eco-DRR); urban DRR and ecosystem services
 climate change adaptation (CCA), 15–16
 coral reefs and protected areas, 374
 Eco-DRR and, 26–28, 40, 44–47, 48n15, 437–54
 ecosystem management and, 3, 6–9, 11, 16–17, 255, 263, 430, 437, 442–43, 445, 448, 454
 ecosystem-based, 187n5
 ecosystems’ relevance for, 6–9, 11–13, 15–17, 19
 EIAS and SEAs in disaster management, 416–18, 420–21, 424, 426–27, 430–31, 433
 hazard mitigation and, 6, 9, 27
 IWRM and, 249, 251–55, 257–60, 263, 264n3
 Mozambique and, 270–71, 275, 278
 Tonga and, 194–95, 201–2, 207–8, 212–13
 urban disaster risk reduction and ecosystem services, 408
- disasters in cities and metropolitan areas, notable, 392–94
- DMP. *See* Disaster Management Plan (DMP)
- DoF. *See* Department of Forests [Nepal] (DoF)
- Dominican Republic, 12–15, 30, 404
- DRM. *See* disaster risk management (DRM)
- drought(s)
 about, 4–5, 10–11, 32, 34–35
 ADB CEA for Tajikistan and, 425
 agro-ecological restoration and resilience to, 43
 agro-ecological restoration of drylands in Burkina Faso and Niger, 43
 Argentina, irregular rainfall patterns in, 379
 Botswana, EIA and mining projects in, 422
 climate change and, 223, 293, 304, 372, 438
 dams for water during, 234

drought(s) (cont.)

- deaths and injuries and economic losses from, 248
 - deforestation and, 109
 - EIAs and disaster risk management, 426
 - El Niño Southern Oscillation and, 193
 - Ethiopia and MERET, 453
 - Inner Niger Delta and, 235–36, CP7
 - Mahanadi Delta and, 230
 - management, 40
 - mitigation strategy, 40, 42, 276
 - Mozambique and National Water Policy, 448
 - Mozambique and Zambezi river, 273, 276, 283, 285
 - Mozambique's regular cycle of, 418
 - natural hydrological cycle and, 251
 - PAARSS water and sanitation programme and, 276, 282
 - periods, 42
 - resilience and flood pulse, 234
 - risk and downstream water users, 228
 - role of protected areas in preventing or mitigating, 377
 - siltation of riverbeds and, 418
 - in Southern and Eastern Europe and North Africa, 304
 - sustainable drylands management, 449
 - sustainable water and sanitation and risks of, 271
 - traditional cultural ecosystems and crops, 374
 - urban centres all over the world and, 391
 - watershed and, 408
- DRR. *See* disaster risk reduction (DRR)
- drylands, 10–11, 35, 42–43, 438, 449
- dykes, 16, 30
- about, 59, 307, 380, 405, 440
 - DDR and, xxv, 6, 16, 30, 41, 44
 - dynamic river basins and, 221, 223, 239, 241–42
- dynamic river basins and community resilience
- communities in flood-prone areas, 222–23
 - community-based adaptation (CbA), 229
 - disaster risk reduction, 221, 223–24, 228–29, 240, 242
- dynamic river systems provide resilience, 222
- economic relevance of pulsing systems, 225–26

- environmental degradation, 223, 229
- flood pulse, 224–26, 234–35
- floods, 221–22
- floodwaters, 222, 224–25, 228
- GIS, 231
- Inner Niger Delta in Mali, 235–38
- integrated ecosystem-based approaches to flooding, 223–24
- International Strategy for Disaster Reduction (ISDR), 222
- Mahanadi Delta, India, 230–33
- Netherlands and Room for the River Programme, 241–42
- risk and resilience, 221
- water-related hazards, 222–24, 226, 228–29, 234, 240
- wetland-integrated DRR, 228–29, 233–34, 238–40, 242
- wetlands role in flood and drought regulation, 226–28

E

earthquake(s)

- in Antioch, Turkey, 394
- in Beijing, China, 394
- casualties and damages from, 86
- Christchurch, New Zealand, 392
- coastal hazards, mitigation of, 57
- deadliest events worldwide (1980–2011), 4
- development efforts, undermines local and national, 3
- disaster relief in Pakistan, 382
- DRR and, 26
- economic losses from, 146, 248
- events impact the most people, 86
- Great East Japan, 5
- Great Hanshin earthquake, Kobe, Japan, 392, 401
- Great Kantō earthquake, Tokyo, 393
- in Haiti, 4, 86, 392
- in Izmit, Turkey and widespread environmental damage, 391
- landslides and loss of life from, 372
- landslides cause economic losses from, 293
- in Lima-Callao, Peru, 394
- in Lisbon, Portugal, 394
- in Managua, Nicaragua, 393
- in Messina, Italy, 393
- in Mexico City, Mexico, 393

- in Peru, 258
- in Port-au-Prince, Haiti (2010), 4, 86, 392
- in San Francisco (1906), 391, 393
- in Tajikistan, 425
- in Tangshan, China, 393
- in Tōhoku, Japan, 20n1, 391–92
- in Tonga, 193
- in Turkey, 391–92
- urban poverty an disaster risk, 403–4
- in Wenchuan, China, 392
- EbA. *See* ecosystem-based adaptation (EbA)
- Eco-DRR. *See* ecosystem-based disaster risk reduction (Eco-DRR)
- The Economics of Ecosystems and Biodiversity (TEEB), 35–36, 96, 378, 445
- ecosystem(s)
 - based flood management, 8
 - contribution to biodiversity, climate change mitigation and social and cultural heritage, 131
 - cultural services of, 31, 35, 167, 187n5
 - definition of, 31
 - multiple benefits of, 31
 - provisioning services of, 31, 167, 187n5
 - regulating services of, 31, 35, 234, 239
 - resilience, 46–47, 61, 84, 88, 93, 95, 150–51, 372
 - supporting services of, 31
- ecosystem management
 - DRR and, 3, 6–9, 11, 16–17, 255, 263, 430, 437, 442–43, 445, 448, 454
 - eco-DRR and, 27–28, 38–39, 46, 438–39, 449
 - ecosystem-based DRR and, 187n5
 - integrated, cross-sectoral approach to DRR and CCA and, 439–40, 450
 - land-use planning to reduce disaster risks, 444
 - mangroves and, 85
 - PAARSS and, 273
 - RiVAMP and Negril, Jamaica, 111
 - in Tonga, 192
 - for urban risk reduction, 404–5, 408–9
- ecosystem services
 - biodiversity and, 38
 - to the city, 180
 - coastal ecosystems and, 141, 145
 - coastal habitats and, 82
 - community stakeholders and evaluation of, 408
 - in cost–benefit analyses for DRR measures, 452
 - current losses of, 372–73
 - defined, 31
 - disaster reduction strategies and, 372
 - disaster risk assessments and, 450
 - in disaster-prone environment, 288
 - for DRR, 9, 111, 453
 - EBA and sustainable use of biodiversity and, 192
 - economic benefits of, 452
 - economic benefits vs. decline of valuable, 226
 - economic value of, 35–36, 47, 134, 445–46
 - economic value of mangroves, 96, 98
 - ecosystem health and productivity, 234
 - ecosystem resilience and, 85
 - Global Partnership for Ecosystems and Ecosystem Services Valuation and Wealth Accounting, 47n6
 - habitat communities and, 82
 - habitat restoration and protection and, 159
 - hazard regulatory functions, 256
 - heterogeneity in, 242
 - human demand for, 32
 - IWRM helps regulate stress on, 252
 - livelihoods, dependence on for, 262
 - local communities understand the value of, 255
 - of Mahanadi Delta, India, 230, 233
 - mangrove ecosystem resilience and, 95
 - mangrove provide, 83–84, 98, 100
 - monetary undervaluation of, 371
 - natural resources and, 30
 - neighbouring habitats and, 249
 - PAARSS and, 273
 - payments for, 371, 385, 447
 - people derive indispensable benefits from nature, 30
 - protected areas and, 381–84
 - protection and restoration of, 371
 - revival of important, 239
 - risk management and quantification of, 153
 - risk-averse approach to urban development and, 179
 - scientific research on, 47
 - SEA and, 425

- ecosystem services (cont.)
 - sustainable reconstruction and reduction invulnerability, 428
 - UDDTs sanitation technologies and, 282
 - urban centres and, 395–98
 - valuing for DRR, 445–47
 - water infrastructure and, 256
 - watershed or river basin, 400
- ecosystem-based adaptation (EbA)
 - ecosystems' relevance for DRR and, 7, 16, 38
 - mangroves as resilient natural coastal defences, 96
 - in Tonga, 192, 194–95, 199, 207–13
- ecosystem-based climate change work in Tonga
 - climate change adaptation (CCA), 194–95, 201–2, 212–13
 - coastal hazards and, 199, 202
 - community-based adaptation (CbA), 192, 194, 208, 210–13
 - cyclones and, 193–94
 - DRR and, 194–95, 201–2, 207–8, 212–13
 - ecosystem-based adaptation (EbA), 192, 194–95, 199, 207–13
 - NGOs in, 195, 197, 199, 201, 206, 209–12
 - non-governmental organization (NGO), 195, 197, 199, 201, 206, 209–12
 - sea level rise (SLR), 191, 196–97, 201, 206
 - seawalls in, 199–202, 206–7, 210
 - tsunami(s) and, 193, 206–7
- ecosystem-based disaster risk reduction (Eco-DRR). *See also* disaster risk reduction (DRR); urban DRR and ecosystem services
 - about, 26–54
 - climate change adaptation (CCA), 37–38, 438–39, 449–50, 452
 - disaster risk management (DRM), 426, 442, 450
 - DRR and, 26–28, 40, 44–47, 48n15, 437–54
 - environmental impact assessment (EIA), 39–40, 440, 444, 447–48, 450
 - hazard mitigation and, 30
 - Intergovernmental Panel on Climate Change (IPCC) and, 27, 30, 38, 47
 - International Strategy for Disaster Reduction (ISDR), 26–30, 38, 47, 437, 447–48, 454
 - land-use planning and, 441–45, 449, 454
 - non-governmental organization (NGO), 443, 445, 449
 - Partnership for Environment and Disaster Risk Reduction (PEDRR), 30–31, 35–37, 39–40, 42, 44, 46, 48n16, 437–38, 447
 - sea level rise (SLR), 438–39
 - United Nations International Strategy for Disaster Reduction (UNISDR), 3–8, 18, 26–30, 38, 47, 437, 447–48, 454
- ecosystems' relevance for DRR
 - climate change adaptation (CCA), 7–8, 15–16
 - DRR and, 6–9, 11–13, 15–17, 19
 - ecosystem-based adaptation (EbA), 7, 16, 38
 - International Strategy for Disaster Reduction (ISDR), 7–8, 15, 18
 - IPCC and, 3–5, 7, 15, 18
- EIA. *See* environmental impact assessment (EIA)
- EIAS and SEAs in disaster management
 - Botswana, 421
 - China, 421
 - civil disasters and conflicts, 418
 - climate change adaptation (CCA), 422, 431
 - country environmental analysis (CEA), 425–26
 - disaster management, paradigm shifts in, 417
 - disaster risk, 416, 418–22, 425–26, 430–33
 - disasters based on hazards, classification of, 418
 - DRR and, 416–18, 420–21, 424, 426–27, 430–31, 433
 - EIA and humanitarian response, 429
 - EIA of mining projects in Botswana, 422
 - EIAS in disaster management, 426–27
 - EIAS in post-disaster relief and recovery, 428–30
 - environmental assessments, 417, 420, 426, 429
 - environmental degradation, 418
 - environmental impact assessment (EIA), 418–24, 426–33
 - environmental management, 418, 421–25, 431–33
 - Environmental Protection Act, 424
 - Germany, 420–21

- Hyogo Framework for Action (HFA), 416–17
- India, 420, 423
- integration of environmental and natural disaster management, 432
- International Strategy for Disaster Reduction (ISDR), 416
- key challenges and recommendations, 430–33
- natural hazards, 418, 420–21, 425, 430
- Nepal, 421
- OECD and “Strategic Environmental Assessment and Disaster Risk Reduction,” 424–25
- The Philippines, 421
- strategic environmental assessments (SEAs), 419
- technological hazards, 418
- EM-DAT. *See* Emergency Events Database (EM-DAT)
- Emergency Events Database (EM-DAT), 4, 13, 20n2–3, 86, 88, 394
- environmental degradation
- difficulty of disentangling natural and human attributes, 149
 - disaster loss from, 418–20
 - disasters and, 3
 - human vulnerability to disasters and, 223, 372
 - restoring degraded ecosystems and local and national disaster reduction strategies, 372
 - risk of landslides due to, 33
 - “Theory of Himalayan Environmental Degradation,” 346
 - water-related hazards from, 229
- environmental impact assessment (EIA), 19
- Eco-DRR and, 39–40, 440, 444, 447–48, 450
 - EIAS and SEAs in disaster management, 418–24, 426–33
- European Union’s Flood Directive, 8
- European Union’s Water Framework Directive, 8
- extreme weather events, 30, 35, 37–38, 372, 374, 379–80
- F
- FAO. *See* Food and Agriculture Organization (FAO)
- FECOFUN. *See* Federation of Community Forest Users [Nepal] (FECOFUN)
- Federal Emergency Management Agency [USA] (FEMA), 146, 158
- Federation of Community Forest Users [Nepal] (FECOFUN), 348–49
- FEMA. *See* Federal Emergency Management Agency [USA] (FEMA)
- flood(s)
- climate change and, 223
 - control, 33, 131, 375–76, 378–79
 - deaths and injuries and economic losses from, 248
 - defence by maintenance and/or restoration of wetlands and conservation of agricultural biodiversity, 16
 - defence structures, 8, 41, 379, 446
 - gates, 41
 - generating weather event, 12
 - management, 8, 19
 - mitigation, 36–37, 402, 405, 407
 - natural hydrological cycle and, 251
 - risk management, 32
 - walls, 30, 45
- floodplains
- about, 5, 10, 34, 36–37
 - Boston’s Charles River Basin, 402
 - in Cambodia, 225
 - communities living in, 257, 281
 - delta sedimentation and, 29
 - diversity and, 37
 - downstream flooding reduced by, 226
 - economic relevance of, 225
 - flood control in coastal areas, inland river basins and mountain areas, 34
 - Inner Niger Delta, 235–38
 - Mahanadi Delta, India, 230–33
 - natural ecosystems buffer sudden natural hazards, 374
 - Netherlands and “Room for the River” concept, 241
 - protection and/or restoration, 256
 - regulation of water and sediment flows, 441
 - restoring, 374
 - urban development on, 391, 409
 - water control and protection of assets from flooding, 252
 - wet season flows released slowly during drought periods, 34
- Whangamarino Ramsar bog and swamp complex, 375

- floods (flooding), 3–6, 10–11
 - damage, 43, 59, 232
 - Eco-DRR and, 29, 32, 34, 36, 40–41, 43–44
 - in Haiti and the Dominican Republic, 12–13
 - large-scale, 44
 - reforestation and, 13
 - sanitation initiatives during major, 19
 - vegetation/forest cover and, 12
 - waterborne diseases and, 37
 - wetland and swamp preservation and, 41, 43
- floodwaters
 - aquatic/terrestrial transition zone created by, 224
 - from dams, and the Indus Basin, 252
 - drinking water supply in Negril, Jamaica, 37
 - Hubei Province wetlands store 285 million m³ of, 37
 - periodic rise and retreat of, 224–25
 - wetlands and on-site or upstream flooding hazards, 228
 - wetlands and the regular advance and retreat of, 222
- flume simulations of coastal features
 - dissipating energy of tsunami waves, 19, 65, 73–79
- Food and Agriculture Organization (FAO), 12, 15, 33, 44, 61–64, 72, 79, 304
- forest(s). *See also* deforestation; mountain forests
 - agroforestry systems, 374
 - alpine space and protection, 328
 - in Amazon, protected areas and indigenous reserves, 383
 - in Argentina, for flood control, 379
 - Austrian Forest Act, 309
 - for avalanche and landslide control, 32, 373
 - avalanche-prone slopes, stabilize, 44
 - on and beneath slopes, 376
 - carbon sequestration and, 38
 - catchment, 34
 - in China, 374
 - coastal, provide protection from wind and wave surges, 41, 377, 400, 403
 - community, in Dolakha District, 19, 353, 356
 - community forest (CF) in Nepal, 19, 33, 343, 348, 350–53, 356, 363–64
 - conservation of soil and water, avalanche control, sand dune stabilization, desertification control or coastal protection, 308
 - conserved by indigenous peoples lose less forest than other management systems, 383
 - to control natural hazards, 308
 - economic value of temperate, 400
 - fires in Kutai National Park, Indonesia and the Amazon, 377
 - fires remove, 294
 - flood control and natural, 379
 - flooding damage reduced in lowland agrarian communities, 43
 - floodplain, in New Orleans, 380
 - Forest Law, Japan, 401
 - fruit tree, in arid lands, 374
 - indigenous reserves and natural forests, 381
 - in Jamaica, 131
 - kelp, 175
 - landslide areas in 1992 covered by, 358
 - logging of, 294–95
 - mangrove, 44, 64, 82–84, 89, 92, 94, 96, 307, 380
 - in Middle East, 374
 - of mixed tree species, 10
 - mountains in Madagascar and flood control, 376
 - natural storage and recharge properties of, for flood control, 378
 - in Paraná river basin Argentina for flood control, 376
 - peri-urban, 400
 - protect against rock fall and stabilize snow, reducing the risk of avalanches, 34
 - in protected areas accounted for just 3 per cent of tropical forest losses, 383
 - protected areas and riparian corridors, 376, 378
 - protecting against natural hazards in mountainous areas, 308–9
 - protection, 6, 19, 36, 43, 295, 303, 308–10, 313
 - protection, against rock fall and avalanches, 10, 303

- protection, in the Alps, 321–31, 333, 335–37, 373
- protection against regolith
 - destabilization, 300
- protection and risk management in the Alps
 - GIS, 349–50
- protection for buildings, 302–3
- protection forest management, 32
- “Protection Forest Platforms,” 310
- protection in Japan, 373
- reduce risk of floods by increasing
 - infiltration of rainfall and delaying peak floodwater flows, 34
- regeneration projects In Djibouti, Day Forest National Park, 377
- slope stability and, 300, 313
- on steep slopes, 362, 376
- in Taiwan, 403
- temperate, in Mount Kitanglad Range Natural Park, Philippines, 377
- in tropics, clearing of, 372
- urban landscape and, 397, 400
- vegetation cover and root structures
 - protect against erosion, 34
- on watersheds, 34
- forest cover
 - community forests, flooding and, 356
 - Dolakha District, Nepal and, 343–44, 346–54, 356–57, 359, 361–63
 - Dominican Republic and, 14
 - Haiti and, 13–14
 - linked to slope angle for study area, 356
 - mangrove, 89
 - methodology scheme for, 350
 - protected areas and, 383
 - protection against shallow landslides, 300, 307
 - rock fall risk and, 335
 - tree regeneration and, 329
 - trends in landslide and, 357
 - trends in Nepal’s, 347
 - wind destroys, 294
- G
- GCM. *See* Global Circulation Model (GCM)
- GDP. *See* gross domestic product (GDP)
- Geographic Information System (GIS)
 - about, 19, CP4, CP6–CP7
 - coastal adaptation strategy for Cape Town, 173, 181, 188n16
 - dynamic river basins and community resilience, 231
 - forest protection and risk management in the Alps, 349–50
 - New York and Connecticut area, 144, 146
 - RiVAMP and Negril, Jamaica, 115–16, 119, 128, 133
 - sustainable water supply and sanitation, 276, 287
- GIS. *See* Geographic Information System (GIS)
- Global Assessment Reports, 7, 401
- Global Circulation Model (GCM), 144–45
- Great East Japan Earthquake, 5
- Green Recovery and Reconstruction Toolkit (GRRT), 429
- greenbelts, 10, 35, 41
- gross domestic product (GDP)
 - of Cambodia, 226
 - of Cape Town, South Africa, 164
 - of Dominican Republic, 14
 - flood damage and, 270
 - of Haiti, 14, 30
 - of Jamaica, 112, 114
 - of Mozambique, 273
 - sustainable ecosystem management and, 11
 - of Tonga, 193, 211
 - urban activities and, 390
- GRRT. *See* Green Recovery and Reconstruction Toolkit (GRRT)
- H
- Haiti, 12, 30
 - deforestation, massive, 13, 29
 - earthquake, 4, 86, 392
 - meteorological events, 13
 - social, economic and governance indicators for, 14–15
- hazard, defined, 18
- hazard event (disaster), 3, 5, 20n2, 63–64, 134, 270, 391, 442
- hazard mitigation
 - coastal vegetation and, 19
 - DRR and, 6, 9, 27
 - Eco-DRR and, 30
 - ecosystem management and, 11
 - ecosystem services, economic value of, 35–36, 47, 445–46

- hazard mitigation (cont.)
 ecosystems and built infrastructure and,
 relationship between, 256–57
 functions of ecosystems, 34–35
 hydro-geological, 406
 in Jamaica, 112
 land-use planning decisions and, 151
 mitigation measures and, 57
 monetized values of, 55
 in New York and Connecticut area, 142,
 149–52, 154–55, 157–58
 performance of coastal ecosystems for,
 57–81
 UK's "Making Space for Water"
 programme, 32
- Hazards U.S.–Multi-Hazards tool
 (HAZUS-MH), 146
- HAZUS-MH. *See* Hazards U.S.–
 Multi-Hazards tool (HAZUS-MH)
- heatwaves, 5, 293
- HFA. *See* Hyogo Framework for Action
 (HFA)
- Hispaniola (island), 12–13
- Hurricane Katrina in New Orleans, xxiv, 5,
 29, 41, 87, 380, 392
- Hyogo Framework for Action (HFA), 6–7,
 16, 251–52, 254, 295, 416, 448
 "Building the Resilience of Nations and
 Communities to Disasters," 7, 251
 Mid-Term Review, 8
- I
- ICZM. *See* integrated coastal zone
 management (ICZM)
- INGC. *See* Instituto Nacional de Gestão
 das Calamidades [National Disaster
 Management Institute] (INGC)
- inland river basins, 10, 34
- Instituto Nacional de Gestão das
 Calamidades [National Disaster
 Management Institute] (INGC),
 275–76, 280, 283
- integrated coastal zone management
 (ICZM), 41
- integrated water resources management
 (IWRM)
 about, 239, 249–54, 257–63, 264n2, 444
 climate change adaptation (CCA), 249,
 260, 262
 disaster risk management (DRM), 257,
 264
 DRR and, 249, 251–55, 257–60, 263,
 264n3
 International Strategy for Disaster
 Reduction (ISDR), 249, 251–55,
 257–58, 264n3
 United Nations International Strategy for
 Disaster Reduction (UNISDR),
 251–55, 257–58, 264
- Intergovernmental Panel on Climate
 Change (IPCC)
 anthropogenic climate change, 191
 climate change affects natural systems
 worldwide, 5
 climate change and increased frequency
 and intensity of extreme events such
 as heatwaves, droughts and floods,
 293
 climate change and trends in global
 environmental and natural resource
 concerns, 372–73
 climate change may aggravate impacts of
 floods and droughts, 223
 coastal flooding event, by the 2080s up to
 561 million people may be at risk of
 a 1:1000 year, 87
 definitions and UNISDR, 27
 Eco-DRR and, 27, 30, 38, 47
 ecosystems' relevance for DRR and, 3–5,
 7, 15, 18
 Fourth Assessment Report of, 5, 145,
 147–48
 Global Circulation Models (GCMs),
 144–45
 human-created risk exposure and
 vulnerability owing to poor land-use
 planning, poverty, urbanization and
 ecosystem degradation, 5
 resilience, defined, 264n1
 Special Report on Managing the Risks of
 Extreme Events and Disasters to
 Advance Climate Change
 Adaptation (SREX) (2012), 5, 7–8,
 15, 293, 431, 452
- International Strategy for Disaster
 Reduction (ISDR)
 coastal adaptation strategy for Cape
 Town, 187n2, 187n4
 dynamic river basins and community
 resilience, 222
 Eco-DRR and, 26–30, 38, 47, 437, 447–48,
 454

- ecosystems' relevance for DRR and, 7–8, 15, 18
- EIAS and SEAs in disaster management, 416
- Global Review of Disaster Reduction Initiatives*, 371
- integrated water resources management (IWRM), 249, 251–55, 257–58, 264n3
- New York and Connecticut area, 149
- protected areas for mitigating natural disasters, 371, 375, 384
- urban DRR and ecosystem services, 390–91, 398, 401, 404–5
- International Union for Conservation of Nature (IUCN), 10, 101n4, 192, 253, 258
- IPCC. *See* Intergovernmental Panel on Climate Change (IPCC)
- Ireland's "Environmental Enhancement of Rivers," 8
- ISDR. *See* International Strategy for Disaster Reduction (ISDR)
- IUCN. *See* International Union for Conservation of Nature (IUCN)
- IWRM. *See* integrated water resources management (IWRM)
- J**
- Jamaica. *See* RiVAMP and Negril, Jamaica
- L**
- land-use planning
- about, 5, 7, 27, 40, 99–100, 110, 304, 312
 - Eco-DRR and, 441–45, 449, 454
 - New York and Connecticut and, 140–41, 151, 156–57
- levees, xxiv, 29, 41, 230, 256, 379
- LiDAR. *See* Light Detection and Ranging (LiDAR)
- Light Detection and Ranging (LiDAR), 144, 159n3
- M**
- Managing Environmental Resources to Enable Transitions to More Sustainable Livelihoods (MERET), 11, 453
- mangrove(s)
- in Bangladesh and India help to stabilize wetland and coastlines against cyclones, 377
 - climate change adaptation (CCA), 85
 - coastal areas, planting in, 201
 - coastal areas, reduce vulnerability of, 380
 - coastal defences, resilient natural, 85, 87, 96, 99–100
 - coastal protection and characteristics of, 93
 - ecosystem management and, 85
 - ecosystem resilience and ecosystem services, 95
 - ecosystem services and, 83–84, 98, 100
 - ecosystem-based adaptation (EbA), 96
 - ecosystems and biodiversity, 95, 97
 - ecosystems and cyclones, 89
 - ecosystems and tsunamis, 88–89, 91–94
 - forest cover, 89
 - forests, 44, 64, 82–84, 89, 92, 94, 96, 307, 380
 - Green Coasts and Mangroves for the Future, 33
 - investing in, 380
 - plantations in the Kolovai project area, 197
 - pollution and overexploitation destroys, 372
 - reforestation, 100, 201, 233, 441
 - "Relating Ecosystem Functioning and Ecosystem Services by Mangroves," 101
 - sea level rise and, 85, 87, 99–100
 - sociocultural services of, 95
 - in the Sopa area, 203
 - storm surges, buffer, 100, 376, 400, 450
 - storm waves during cyclones, break up, 377
 - swamp protecting the coastline in Popua, 203
 - value of ecosystem services for, 96
 - wave heights and erosion from storms and high tides reduced by, 10
- Mangrove Ecosystems for Climate Change Adaptation and Livelihoods (MESCAL), 192
- Many Strong Voices (MSV), 192
- Maximum Envelopes of Water (MEOW), 144
- mean sea level (MSL)
- RiVAMP and Negril, Jamaica, 110–11, 114, 117, 119, 130
- MEOW. *See* Maximum Envelopes of Water (MEOW)

- MERET. *See* Managing Environmental Resources to Enable Transitions to More Sustainable Livelihoods (MERET)
- MESCAL. *See* Mangrove Ecosystems for Climate Change Adaptation and Livelihoods (MESCAL)
- Millennium Ecosystem Assessment, 5, 23, 28, 30–31, 35, 239, 445
- mountain forests. *See also* forest(s)
Bavarian high mountains, 323
climate and environmental change
 modify vegetation patterns of, 313
community forests' role in protection and livelihoods, 343, 348–49
forest cover and land degradation in Nepal, 346–47
forest degradation in Nepal, 343
forest management in Nepal, 343, 347–48, 363
forest management to control natural hazards in, 309
Government of Switzerland protective measures for, 323, 327–33, 335
INTERREG project "Network Mountain Forest," 337
protect against riverbed erosion, snow avalanches, rock fall and landslides, 32, 308–9, 322
protection forests, 337
slopes, deforestation of, 305
Swiss project Protect-BIO, 333–35
vegetation cover and root structures
 protect against
 erosion and increase slope stability, 34, 36
- Mozambique. *See* sustainable water supply and sanitation
- MSL. *See* mean sea level (MSL)
- MSV. *See* Many Strong Voices (MSV)
- Myanmar, 4, 29, 86, 392
- N
- Nairobi Work Programme (NWP), 7, 16
- National Disaster Management Authority [India], 431
- National Disaster Management Authority [Pakistan] (NDMA), 432
- National Estuary Program [USA] (NEP), 155
- National Oceanic and Atmospheric Administration's Coastal Services Center (NOAA-CSC), 142, 155, 159n6
- Nature Conservancy, the Center for Climate Systems Research (CCSR), 142
- NDMA. *See* National Disaster Management Authority [Pakistan] (NDMA)
- NEP. *See* National Estuary Program [USA] (NEP)
- Netherlands "Room for the River," 8
- New York and Connecticut and coastal hazards
 climate change adaptation (CCA), 152, 159n2
 coastal hazards, 140–41, 143–49, 153–54, 157–58
 GIS, 144, 146
 hazard mitigation in, 142, 149–52, 154–55, 157–58
 International Strategy for Disaster Reduction (ISDR), 149
 land-use planning, 140–41, 151, 156–57
 sea level rise (SLR), 140, 143, 147, 154
- NGO. *See* non-governmental organization (NGO)
- NOAA-CSC. *See* National Oceanic and Atmospheric Administration's Coastal Services Center (NOAA-CSC)
- non-governmental organization (NGO)
 about, 97, 115, 242, 382
 Eco-DRR and, 443, 445, 449
 sustainable water supply and sanitation, 278, 280
 in Tonga, 195, 197, 199, 201, 206, 209–12
- NWP. *See* Nairobi Work Programme (NWP)
- O
- Organisation for Economic Co-operation and Development (OECD), 40, 47n8, 417, 424
- P
- PAARSS. *See* Projecto de Abastecimento de Água Rural e Saneamento em Sofala [Programme for Rural Water Supply and Sanitation] (PAARSS)
- PARPA. *See* Plano de Acção para a Redução da Pobreza Absoluta [National Poverty Reduction Strategy] (PARPA)

- Partnership for Environment and Disaster Risk Reduction (PEDRR)
 about, 17, 20n4, 259
 Eco-DRR and, 30–31, 35–37, 39–40, 42, 44, 46, 48n16, 437–38, 447
 urban DRR and ecosystem services, 402, 408
- peat bogs, 8, 376
- peatlands, 10, 34, 38, 131, 135, 222, 228, 240, 375, 400
- PEDRR. *See* Partnership for Environment and Disaster Risk Reduction (PEDRR)
- PIOJ. *See* Planning Institute of Jamaica (PIOJ)
- Planning Institute of Jamaica (PIOJ), 112, 119
- Plano de Acção para a Redução da Pobreza Absoluta [National Poverty Reduction Strategy] (PARPA), 275
- poverty reduction, 11, 30, 43, 260, 275, 345, 454
- precipitation patterns, 5, 30
- PROFOR. *See* Programa de Repoblamiento Forestal (PROFOR)
- Programa de Repoblamiento Forestal (PROFOR), 33
- Projecto de Abastecimento de Água Rural e Saneamento em Sofala [Programme for Rural Water Supply and Sanitation] (PAARSS), 271, 273, 276–77, 279–80, 282–84, 286–87
- protected areas role in mitigating natural disasters
 community forest (CF) in Nepal, 343, 348, 350–53, 356, 363–64
 disaster risk management (DRM), 371, 384
 The Economics of Ecosystems and Biodiversity (TEEB), 35–36, 96, 378, 445
 ecosystem services, current losses of, 372–73
 ecosystems, restoration of degraded, 385
 environmental management, 371
Global Assessment Report, 2011 (UNISDR), 371, 375
Global Review of Disaster Reduction Initiatives (UNISDR), 371
 International Strategy for Disaster Reduction (ISDR), 371, 375, 384
 mangroves, maintenance or restoration of, 380
Natural Hazards, Unnatural Disasters: The Economics of Effective Prevention (World Bank), 375
 protected areas and disaster mitigation strategies, 381–82
 protected areas maintain vegetation cover, 383
 protected areas reduce vulnerability to disasters, 373–75
 protected areas vs. infrastructure, investing in, 375, 378–80
 protected natural forests and flood control in Argentina, 379
 role of protected area habitat type and the hazards, 376–77
 United Nations International Strategy for Disaster Reduction (UNISDR), 371, 375, 384
 wetland protection for regulating floods in New Zealand, 375
- provisioning services of ecosystems, 31, 87n5, 167
- R
- Ramsar Convention on Wetlands, 10, 45, 256, 382
- rapid environmental impact assessment (REA), 427–29
- REA. *See* rapid environmental impact assessment (REA)
- REDD+. *See* Reducing Emissions from Deforestation and Degradation (REDD+)
- Reducing Emissions from Deforestation and Degradation (REDD+), 98
- reforestation. *See also* deforestation; forest(s)
 coastal reforestation projects in Asia, 33
 in Haiti, 13
 in Honduras, 376
 landslide hazards, to manage, 307
 mangrove, 100, 201, 233, 441
 PROFOR reforestation project, 33
 project in New Zealand for erosion control, 310
 to replace vegetation removal, 312
 in Rokko Mountain Range, Japan, 401
 in Spain for flood control, 376
 of upland areas to reduce sediment inflow, 240

- regulating services of ecosystems, 31, 35, 234, 239
- resilience
 - to climate change, 16, 38, 192, 208
 - coastal, 144
 - of coastal ecosystems, 84–85, 110
 - Coastal Resilience programme, 141–43, 146–50, 153–57, 159, 444
 - community, 19, 27, 33, 42, 140, 234–35, 271
 - community-managed risk reduction and, 240
 - defined, 18, 140–41, 264n1
 - to disasters, 6–7, 11, 249, 425, 454
 - to droughts, 10–11, 35, 43
 - DRR measures and, 271
 - dynamic river systems provide, 222
 - EbA and, 192
 - ecosystem, 46–47, 61, 84, 88, 93, 95, 150–51, 372
 - ecosystem services enhance, 239
 - to extended dry periods and landslides, 33
 - to flood and drought, 234
 - of forest structure, 93
 - of hazard-prone communities, 31
 - to hazards, 30, 33, 38, 254
 - of human and natural communities, 140, 148
 - of the landscape, 258
 - livelihood, 36–37
 - for managing disaster risks, 258
 - of mangrove ecosystems, 94–95
 - of natural systems, 65
 - PAARSS water and sanitation programme and, 276–86
 - refugee camps and, 430
 - rehabilitation measures contribute to, 239
 - of residents to hazards, 131
 - of rural communities during seasons of extreme weather, 279
 - in rural livelihoods, 33
 - to sea-level rise, hurricanes and river flooding, 41
 - social, economic and ecological, 424
 - of social-ecological systems, 17
 - of society to disaster risk, 226
 - threshold values of, 72
 - of the vegetation to tsunami waves, 77
 - to water-related hazards, 223–24, 229, 234
 - of wetland-dependent communities, 228
- Rio+20 conference, 7, 15, 453
- risk, defined, 18
- Risk and Vulnerability Assessment Methodology Development Project (RiVAMP), 19, 110–12, 115, 118, 120, 133–35
- risk governance, 27, 408
- RiVAMP. *See* Risk and Vulnerability Assessment Methodology Development Project (RiVAMP)
- RiVAMP and Negril, Jamaica
 - climate change adaptation (CCA), 110, 112, 121, 133
 - coral reefs, 112, 114, 116–17, 119, 122, 131, 134–35
 - GIS, 115–16, 119, 128, 133
 - mean sea level (MSL), 110–11, 114, 117, 119, 130
 - sea level rise (SLR), 110–11, 114, 117–18, 123, 125–26, 128, 134–35
 - storm surges and, 114, 117, 120–21, 126, 128, 131–32, 135
 - tropical cyclones and, 111–12, 119–21, 134
 - UNEP and, 111–15, 119, 121, 125–26, 128–30, 132–34
- S
- saltmarshes, 10, 34, 82, 91–92, 143, 152, 155, 400
- sand dunes, 10, 34, 41, 59, 61–64, 178, 376
- SBSTA. *See* Subsidiary Body for Scientific and Technological Advice (SBSTA)
- SEA. *See* strategic environmental assessment (SEA)
- Sea, Lake and Overland Surges from Hurricanes (SLOSH), 144
- sea grasses, 10
- sea level rise (SLR)
 - about, 5, 34, 38, 41, 57, 241
 - coastal adaptation strategy for Cape Town, 167, 170–75, 180–81, 186
 - Eco-DRR and, 438–39
 - mangroves as resilient natural coastal defences, 85, 87, 99–100
 - New York and Connecticut area, 140, 143, 147, 154
 - RiVAMP and Negril, Jamaica, 110–11, 114, 117–18, 123, 125–26, 128, 134–35
 - in Tonga, 191, 196–97, 201, 206
 - urban DRR and ecosystem services, 380, 400
- Sea Level Rise Task Force (SLRTF), 154

- seawalls
 about, 16, 44, 60, 63, 188n11, 256
 in Tonga, 199–202, 206–7, 210
- shallow coastal ecosystems, 115–16
- shelterbelts, 10, 35, 42
- SIDS. *See* Small Island Developing States (SIDS)
- SLOSH. *See* Sea, Lake and Overland Surges from Hurricanes (SLOSH)
- SLR. *See* sea level rise (SLR)
- SLRTF. *See* Sea Level Rise Task Force (SLRTF)
- Small Island Developing States (SIDS)
 about, 87, 111, 134
 Tonga, 191–94, 198, 204, 208, 212
- social mapping, 33
- Social Vulnerability Index (SOVI), 146–47, 149, 151
- SOVI. *See* Social Vulnerability Index (SOVI)
- Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (2012), 5, 7–8, 15, 293, 431, 452
- storm surges
 Cape Town and, 167, 169–76, 178–80, 186
 CCT and, 180, 186
 cities exposed to, 249
 coastal defences against, 379
 coastal wetlands, tidal flats, deltas and estuaries reduce the height and speed of, 34
 coral reefs and, 131
 DRR and dykes, 6
 dune ecosystems and coastal wetlands and, 179
 dunes and, 63, 169–70, 178
 ecosystems and natural buffers mitigate, 405
 ecosystems reduce physical exposure to, 32
 environmental pollution; damage infrastructure and ecosystems, and seriously affect human lives and livelihoods, 59
 groundwater and, 439
 integrating ecosystem management and, 439
 Jamaica and, 114, 117, 120–21, 126, 128, 131–32, 135
 mangroves, barrier islands, coral reefs and sand dunes create barriers to, 376
 mangroves, coastal forests, seagrass, coral reefs, dunes and saltmarshes mitigate, 400
 mangroves and, 100, 450
 New York and Connecticut, 144, 153
 sand dunes and barrier islands dissipate wave energy from, 34
 Small Island Developing States (SIDS) and, 111
 Tonga and, 193
 vegetation protects coastal areas against erosion or the impacts of, 11
 wetlands, tidal flats, deltas and estuaries absorb water from, 10
 wetlands and, xxiv, xxv
- strategic environmental assessment (SEA)
 adaptation to climate change and, 47n8
 in disaster risk management, 19, 426
 for DRR, 40, 424–26, 431–32
 environmental impact assessments (EIAs) and, 39–40, 419, 430–31, 440, 444, 447
 framework for agricultural policy, 425
- Subsidiary Body for Scientific and Technological Advice (SBSTA), 7, 16
- supporting services of ecosystems, 31
- sustainable water supply and sanitation
 climate change adaptation (CCA), 276
 disaster preparedness, 283–86
 disaster risk reduction, 270–71, 275, 278
 disasters, living with, 273–74
 GIS, 276, 287
 National Adaptation Programme of Action, 270, 276, 289
 National Water Policy, 271, 276–78, 284, 448
 non-governmental organization (NGO), 278, 280
 Projecto de Abastecimento de Água Rural e Saneamento em Sofala [Programme for Rural Water Supply and Sanitation] (PAARSS), 271, 273, 276–77, 279–80, 282–84, 286–87
 risk reduction innovations and deep groundwater tables, 282–83
 tropical cyclones, 271, 273–75, 285
 Swiss Development Cooperation, 33, 348, 352

T

TEEB. *See* The Economics of Ecosystems and Biodiversity (TEEB)

tropical cyclones. *See also* cyclones
about, 3–5, 86, 194
Jamaica and, 111–12, 119–21, 134
Mozambique and, 273, 285
Viet Nam and, 307

tropical storms, 33, 86, 114, 131–33, 144

tsunami(s)
Asian (2004), xxiv, 88, 92, 94, 100, 392
causing coastal erosion, flooding, damage to infrastructure and ecosystems, and environmental pollution, 59
coastal development and resilience-building for, 33
coastal ecosystems and, 34, 61
coastal vegetation as buffer to, 11–12, 44
damage is high in areas of coral mining, 62
DRR and, 212
dunes and, 63
dykes and seawalls in areas prone to, 6
ecosystems for protection, research on, 451
environmental pollution, damaged infrastructure and ecosystems, 59
episodic hazards of limited predictability, 57
flume simulations of coastal features dissipating energy of, 19, 65–71
forests and protection against, 44
Great East Japan Earthquake and, 5
Green Coasts and Mangroves for the Future and, 33
high-magnitude disaster events, 86
Indian Ocean (2004), 4, 6–7, 11–12, 33, 61–62, 71, 79, 86, 428
Italy and, 393
Lima-Callao earthquake and, 394
Lisbon Portugal and, 394
long waves of high amplitude accompanied by massive inundation and flooding, 59
mangrove ecosystems and, 88–89, 91–94
mitigation potential of coastal ecosystems, 33
Tōhoku (2011), 391–92
Tonga and, 193, 206–7
vegetation for hazard reduction, 307
wave and waterlogged coastal vegetation, 71–79

U

UDDT. *See* urine-diverting dry toilet (UDDT)

UN General Assembly
Thematic Debate on Disaster Risk Reduction, 7

UNDP. *See* United Nations Development Programme (UNDP)

UNEP. *See* United Nations Environment Programme (UNEP)

UNESCO. *See* United Nations Educational, Scientific and Cultural Organization (UNESCO)

UNFCCC. *See* United Nations Framework Convention on Climate Change (UNFCCC)

UNISDR. *See* United Nations International Strategy for Disaster Reduction (UNISDR)

United Kingdom
“Living Rivers,” 8
“Making Space for Water” programme, 8, 32

United Nations (UN)
Department of Humanitarian Affairs and the International Decade for Natural Disasters Reduction, 86
High Commissioner for Refugees, 430
United Nations Development Programme (UNDP), 40
Disaster Risk Index, 273
Human Development Index, 345
integrated SEA process in Sri Lanka, 40
Nepal and, 345, 363
risk, defined, 18

United Nations Educational, Scientific and Cultural Organization (UNESCO), 382

United Nations Environment Programme (UNEP)
about, 19, 28, 29, 37, 40, 48n15, 110
RiVAMP and Negril, Jamaica, 111–15, 119, 121, 125–26, 128–30, 132–34

United Nations Framework Convention on Climate Change (UNFCCC), 7, 15–16, 38, 194
Bali Action Plan, 15
Cancun Adaptation Framework, 16
ecosystem-based approaches to adaptation, 16

United Nations International Strategy for Disaster Reduction (UNISDR)

- about, 149, 187n2, 187n4, 222, 249, 416
 - Eco-DRR and, 3–8, 18, 26–30, 38, 47, 437, 447–48, 454
 - forest cover and landslide trends in
 - Nepal, 371, 375, 384
 - Global Assessment Reports on Disaster Risk Reduction* (2011), 7, 371, 375, 401
 - integrated water resources management (IWRM), 251–55, 257–58, 264
 - Making Cities Resilient campaign, 390, 405
 - urban DRR and ecosystem services, 390–91, 398, 401, 404–5
 - United Nations University Institute for Environment and Human Security (UNU-EHS), xvii, xviii, xxi, xxviii
 - University of the West Indies (UWI), 112–14, 128, 132, 134, 136n7
 - UNU-EHS. *See* United Nations University Institute for Environment and Human Security (UNU-EHS)
 - urban DRR and ecosystem services. *See also* disaster risk reduction (DRR); ecosystem-based disaster risk reduction (Eco-DRR)
 - disaster risk, 408
 - disasters in cities and metropolitan areas, notable, 392–94
 - DRR and, 408
 - ecosystem management for urban risk reduction, 404–5, 408
 - flood reduction in Boston's Charles River Basin, USA, 402
 - globalization and, 391
 - green aeration corridors in Stuttgart, Germany, 399
 - Green Permit Program in Chicago, USA, 399
 - ISDR and, 390–91, 398, 401, 404–5
 - local ecosystems, 397–98
 - "Natech" events, 391
 - Partnership for Environment and Disaster Risk Reduction (PEDRR), 402, 408
 - policy measures dealing with various natural hazards and their relationship with the local ecosystem in various regions, 406–7
 - reforestation in the Rokko Mountain Range, Japan, 401
 - regional ecosystems of cities, 398–401
 - risk governance, 408
 - sea level rise (SLR), 380, 400
 - sustainable environmental management, 405
 - UNISDR Making Cities Resilient campaign, 390, 405
 - United Nations International Strategy for Disaster Reduction (UNISDR), 390–91, 398, 401, 404–5
 - urban centres and ecosystem services, 395–401
 - urban flood reduction in New York, USA, 398
 - urban poverty and disaster risk, 403–4
 - urban risk and disasters, interaction of social and ecological systems in urban areas in the production of, 396
 - urbanization, 389–90, 395, 399, 401, 403–4, 406, 408–9
 - urbanization, environmental degradation and disaster risk, 401–3
 - wetlands in the urban periphery, 400
 - urbanization, 389–90, 395, 399, 401, 403–4, 406, 408–9
 - urine-diverting dry toilet (UDDT), 282, 287
 - UWI. *See* University of the West Indies (UWI)
- V
- VDC. *See* Village Development Committee (VDC)
 - Village Development Committee (VDC), 344, 346, 349, 351, 353–54, 356, 363–64
 - volcanic eruptions, 3, 17, 91, 193, 393–94
 - vulnerability, defined, 18
 - vulnerable populations, 273, 391
- W
- water risk management, 8
 - water-related hazards, 222–24, 226, 228–29, 234, 240
 - Wealth Accounting and the Valuation of Ecosystem Services (WAVES), 47n6
 - weather-related hazards/events
 - deadliest events worldwide 1980–2011, 4
 - human pressure and impacts of extreme, 63
 - risk governance capacities and economic loss risk, 27
 - wet grasslands, 10, 34

- wetland(s)
 - about, 8, 10, 34
 - absorb water from upland areas, storm surges and tidal waves, 10
 - carbon-rich, 96–98
 - coastal, 34, 109, 179, 236, 376, 378, 446
 - coastal, in New York and Connecticut, 140, 145, 147, 150, 154
 - coastal vegetation and, 72
 - drought mitigation strategy and restoration of, 40
 - “Environmental Enhancement of Rivers” (Ireland), 8
 - flood control in coastal areas, inland river basins and mountain areas, 10
 - flood defence by maintenance and/or restoration of, 16
 - flood management and community resilience, role in, 19
 - for flood mitigation in China, 36–37
 - for flood protection in New Orleans, 41
 - hazard mitigation functions, 34
 - integrated coastal zone management and, 41
 - intertidal, 91, 96
 - in Mississippi Delta, xxiv
 - preservation of natural and constructed, xxv
 - Ramsar Convention on Wetlands, 10, 45, 256, 382
 - restoration programme, Hubei Province, 37
 - as shoreline buffers during extreme events, 100
 - store water and release it slowly, reducing the speed and volume of runoff, 34
 - tidal, 148, 151
 - for water retention capacity, 32
 - Whangamarino Ramsar site, New Zealand, 43
- wetland-integrated disaster risk reduction, 228–29, 233–34, 238–40, 242
- WFP. *See* World Food Programme (WFP)
- wildfire management, ecosystem-based, 48n15
- wildfires, 17, 32, 42, 392, 395
- windstorms, 4
- World Bank
 - Natural Hazards, Unnatural Disasters: The Economics of Effective Prevention*, 375
- World Conference on Disaster Reduction, 7
- World Food Programme (WFP), 11
- World Rain Forest Movement, 101n4
- World Summit on Sustainable Development (WSSD), 250, 264n2
- X
- Xynthia (Atlantic storm), 5