Landslide Ecology

Despite their often dangerous and unpredictable nature, landslides provide fascinating templates for studying how soil organisms, plants, and animals respond to such destruction. The emerging field of landslide ecology helps us to understand these responses, aiding slope stabilization and restoration and contributing to progress made in geological approaches to landslide prediction and mitigation.

Summarizing the growing body of literature on the ecological consequences of landslides, this book provides a framework for the promotion of ecological tools in predicting, stabilizing, and restoring biodiversity to landslide scars at both local and landscape scales. It explores nutrient cycling; soil development; and how organisms disperse, colonize, and interact in what is often an inhospitable environment. Recognizing the role that these processes play in providing solutions to the problem of unstable slopes, the authors present ecological approaches as useful, economical, and resilient supplements to landslide management.

LAWRENCE R. WALKER is a Professor of Plant Ecology at the University of Nevada, Las Vegas. His research focuses on the mechanisms that drive plant succession, particularly primary succession on volcanoes, landslides, glacial moraines, floodplains, dunes, mine tailings, and abandoned roads. His landslide research has involved field work in Alaska, Hawaii, Puerto Rico, and New Zealand.

AARON B. SHIELS is a postdoctoral research associate with the USDA National Wildlife Research Center in Hilo, Hawaii. His research is focused on understanding the local and large scale impacts of disturbance and invasive species on plant communities and ecosystems. He has worked on landslides in China, Hawaii, and Puerto Rico.

ECOLOGY, BIODIVERSITY AND CONSERVATION

The world's biological diversity faces unprecedented threats. The urgent challenge facing the concerned biologist is to understand ecological processes well enough to maintain their functioning in the face of the pressures resulting from human population growth. Those concerned with the conservation of biodiversity and with restoration also need to be acquainted with the political, social, historical, economic, and legal frameworks within which ecological and conservation practice must be developed. The new Ecology, Biodiversity and Conservation series will present balanced, comprehensive, up-to-date, and critical reviews of selected topics within the sciences of ecology and conservation biology, both botanical and zoological, and both "pure" and "applied". It is aimed at advanced final-year undergraduates, graduate students, researchers, and university teachers, as well as ecologists and conservationists in industry, government, and the voluntary sectors. The series encompasses a wide range of approaches and scales (spatial, temporal, and taxonomic), including quantitative, theoretical, population, community, ecosystem, landscape, historical, experimental, behavioral, and evolutionary studies. The emphasis is on science related to the real world of plants and animals, rather than on purely theoretical abstractions and mathematical models. Books in this series will, wherever possible, consider issues from a broad perspective. Some books will challenge existing paradigms and present new ecological concepts, empirical or theoretical models, and testable hypotheses. Other books will explore new approaches and present syntheses on topics of ecological importance.

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Preface

Landslides are fascinating because they are dangerous and remind us how powerless we are in the face of overwhelming geological forces. Some progress has been made on how to predict their occurrence and how to avoid or reduce the damage that they cause, but humans are still vulnerable to landslides. We find landslides fascinating for another reason. They create a new surface of exposed rock and soil to which plants, animals, and microbes respond. These habitat gaps in the landscape provide great habitats for rock hounds, plant collectors, bird watchers, and other outdoor enthusiasts, in addition to research opportunities for geologists and ecologists. Landslide surfaces are not at all homogeneous, but vary greatly in degree of plant and soil removal, subsequent stability, and soil fertility. Organisms respond to that variability with different patterns of colonization and community development. Understanding these responses can greatly improve landslide stabilization and ecosystem restoration. The new field of landslide ecology examines the biological responses to landslides, including human responses because we avoid, use, cause, and manage landslides. This book synthesizes the growing literature on landslide ecology and provides the first comprehensive examination of landslides as dynamic ecosystems rather than simply as physical phenomena to be predicted, avoided, and mitigated.

We begin this book by emphasizing the relevance of landslides to ecological processes. For instance, landslides act as conduits of soil nutrients and organic matter down slopes and into aquatic habitats including rivers and oceans. Landslides also provide habitats for colonization by early successional species. The spatial complexity of landslides comes both from the contrast with more stable, vegetated surfaces at the undisturbed edge and from variation in fertility and stability along lateral and vertical gradients within a landslide. Such heterogeneity often supports high regional biodiversity. We also discuss the physical causes and consequences of landslides, which is necessary information for any ecological study. These topics have been thoroughly addressed by geomorphologists, so we focus

on their potential ecological consequences. For example, post-landslide erosion can reduce rates of ecosystem recovery, which are generally faster in warm, tropical regions than in cooler, temperate ones.

The organisms that colonize landslides are typically adapted to survive on the newly exposed, low-nutrient, and unstable substrates where they may also experience temperature and water stress. These gap specialists are not unique to landslides because they also colonize other disturbed habitats. Microbes, widely dispersed plants, and arthropods such as mites and ants are among the first colonists and they are followed by various plant groups and vertebrates, the latter often just visitors rather than residents on landslides. The colonists interact over time and have both positive and negative influences on each other and on the successional pathways.

Historically, humans could never ignore landslides but as our population grows and we utilize more landslide-prone slopes, landslides become increasingly frequent (we trigger more of them) and lethal (larger human populations are more vulnerable). Humans directly cause landslides through expanding construction, road building, logging, and agriculture, and indirectly (and at broad spatial scales) by altering temperature and precipitation regimes that influence landsliding. Landslide risk assessment continues to improve, with new mapping and modeling tools. In addition, mitigation of landslide damage and restoration of ecosystem processes has become more successful, particularly by the inclusion of ecological principles into restoration plans. We view landslide ecology as a fascinating and emerging discipline, which provides opportunities for understanding temporal and spatial dynamics in heterogeneous habitats; opportunities for management to integrate these insights into improving prediction, prevention, mitigation, and restoration; and opportunities for cultural development through improved approaches to more sustainable use of erosion-prone slopes and education about the dangers posed and damages caused by landslides.

We both have explored the mysteries of landslides through long-term monitoring, experimental manipulations, and modeling. Lawrence is a plant ecologist who studies temporal dynamics of communities in the process of ecological succession. He specializes in primary plant succession, which occurs when a disturbance leaves little or no biological legacy. Landslides are good examples of primary succession because they generally remove all plants and most soil layers. However, the destruction is often patchy, and sometimes islands of original vegetation, soils, and animals result in localized examples of secondary succession. Lawrence

has studied landslides in Puerto Rico, Alaska, Hawaii, and New Zealand. Aaron is an ecologist who also studies disturbance and succession, and much of his research is focused on the many factors (e.g., plants, animals, soils) that alter plant communities after a disturbance, including disruptions caused by invasions of non-native species. Most of Aaron's research is in tropical environments, particularly on islands, where he applies his findings to improve restoration and conservation of native ecosystems. He has worked on landslides in Puerto Rico, Hawaii, and China. We have attempted to present a global perspective on both terrestrial and submarine landslides, although inevitably, many local publications were not readily available. We hope that, through our broad approach, this book will advance the search for generalities about landslide ecology, even as we recognize that successional trajectories and specific restoration techniques will always be heavily influenced by both local and stochastic factors.

We thank the many geologists and geomorphologists who have described the physical aspects of landslides. Notable among these is the late David Varnes, whose 1958 drawings of landslide structures are still widely used. Robert Schuster has produced an impressive compilation of landslides around the world, which was helpful in assembling this book. Seminal work by Matthew Larsen on landslides in the Caribbean has influenced us, and a book entitled *Cliff Ecology: Pattern and Process in Cliff Ecosystems* by Larson *et al.* (2000) provided a good model for the organization of this book. A recent contribution that we drew extensively from, particularly for human–landslide interactions and numerous examples of landslides from around the world, is the book *Landslides: Processes, Predictions, and Land Use* by Sidle & Ochiai (2006). We were involved in the first global gathering of landslide ecologists in China in 2006, organized by Carla Restrepo, with a subsequent publication in *BioScience* by Restrepo *et al.* (2009). We are grateful for these resources and collaborations as well as for our interactions among colleagues at conferences on ecological aspects of slope stability, which have provided us with helpful insights about landslide ecology.

We thank our wives, Elizabeth Powell and Laura Shiels, for support and collegial assistance on many landslide projects, our parents for their continual support, and our colleagues Peter Bellingham, Wendy Boneta, Ned Fetcher, Arthur Johnson, Paul Klawinski, Frederick Landau, Roger del Moral, Randall Myster, Liz Neris, Carla Restrepo, Honghua Ruan, Joanne Sharpe, Ashley Sparrow, Sandra and Stephen Talbot, Daniel Thompson, Eduardo Velázquez, Christine West, Xiaodong Yang, and Daniel Zarin with whom we have measured, analyzed, and written

about landslides and related phenomena. We also thank Paula Garrett for her fine work on the figures and Richard Bardgett, Peter Bellingham, Marian Chau, Beatrice Cohen, Peter Scott, Eduardo Velázquez, and Xiaodong Yang for kind permission to use their original photographs. We are grateful for the support of our series editor, Michael Usher, and the publishing team at Cambridge University Press, especially Dominic Lewis and Megan Waddington. The staff members at the El Verde Field Station from the University of Puerto Rico deserve special thanks for many years of data collection and plot maintenance under difficult field conditions. We would like particularly to highlight the outstanding and long-term contributions of Rafael De León and Maria Aponte. Eda Melendez-Colom and her data management team at the University of Puerto Rico were also essential to the success of many of our landslide projects. Eduardo Velázquez and Frederick Landau have been wonderful companions and supporters of landslide work in Puerto Rico. Eduardo also has contributed many helpful insights from his work on a landslide in Nicaragua.

We are indebted to the many reviewers of our book who read one or more chapters and contributed their valuable perspectives. These include Peter Bellingham, James Dalling, Claudia Dislich, Rui Elias, Ned Fetcher, Douglas Larson, Jean Lodge, Roger del Moral, Karel Prach, Joanne Sharpe, Alexia Stokes, Frederick Swanson, Eduardo Velázquez, and Margery Walker. Finally, we thank our various sponsors, including the Luquillo Long Term Ecological Research Program (most recently NSF grant DEB-0620910), for supporting us during 20 years of research in Puerto Rico. Lawrence also thanks the US Fish and Wildlife Foundation for work in Alaska; the Wilder Chair Program in the Botany Department at the University of Hawaii at Manoa for support during the 2009–2010 academic year; and Landcare Research in New Zealand. Aaron thanks the Dai Ho Chun fellowship from the University of Hawaii at Manoa; the US Department of Agriculture, National Wildlife Research Center for support during 2011–2012; Xishuangbanna Tropical Botanical Gardens, Chinese Academy of Sciences for work in China; and the Commonwealth Scientific and Industrial Research Organization (CSIRO) for support while working in Alice Springs, Australia.

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