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Chapter 7 Large scales and future directions for landslide ecology from Landslide Ecology

Lawrence R. Walker
University of Nevada, walker@unlv.nevada.edu

Aaron B. Shiels
USDA/APHIS/WS National Wildlife Research Center, Aaron.B.Shiels@aphis.usda.gov

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7 · *Large scales and future directions for landslide ecology*

Key points

1. Landslide ecology is an emerging discipline that provides insights into both scientific and management issues. Scientifically, it explores nutrient cycling and soil development, plant physiological adaptations, dispersal and colonization dynamics, novel mixes of native and non-native species, and successional trajectories in an often inhospitable environment. Landslide ecology also integrates biological aspects of landslides into efforts to manage slope hydrology, soil erosion, and the stabilization of slopes.
2. Human–landslide interactions are becoming more common as human populations expand into mountainous terrain and climate change increases landslide frequency.
3. A landscape-level approach to landslide rehabilitation integrates topography, broad-scale climatic conditions, landslide density, patch dynamics, propagule dispersal, and coarse-scale predictive models.
4. We expect future contributions to landslide ecology will come from more effective technological tools to mitigate erosion and predict landslide hazards, an increased understanding of how plant–animal–soil interactions determine colonization patterns and successional trajectories, and practical contributions from efforts to use biological methods to stabilize landslides. Finally, we hope that the emergence of landslide ecology as a discipline will also improve our cultural perspectives of landslides, including the promotion of more sustainable uses of slopes and avoidance of erosion-prone areas.

7.1 Introduction

This book has demonstrated how landslides are not just geological processes but also ecological processes that structure landscapes and

ecosystems in montane areas around the world. The physical aspects of landslides are complex but well studied; the biological and ecological aspects are equally complex but poorly studied. In addition to providing habitats for species that are gap specialists and initiating a series of species interactions over successional time, landslides also alter ecosystem parameters such as light regimes, nutrient cycling, and slope hydrology. Humans are key participants in the ecology of landslides because we use them, suffer from them, cause them, and sometimes try to manage them. Humans therefore have a multi-faceted and ambiguous relationship with landslides. We are vulnerable to the destruction that landslides cause, yet we also increase landslide frequency and severity by our inappropriate land use. We attempt to minimize potential damage by predicting the occurrence and location of landslides and by mitigating slope instability using dams, plantings, and other physical and biological tools. Once the damage has occurred, we try to restore slope stability, biodiversity, and ecosystem functions and services. Human-landslide interactions therefore occur across a wide range of spatial scales, from local, immediate concerns to the inclusion of populations and communities of landslides and their influence at larger spatial and temporal scales.

An understanding of landslide ecology is critical for several reasons: (1) landslides increase habitat heterogeneity and therefore have the potential to increase local and regional biodiversity; (2) landslides challenge our ability to understand a complex, rapidly changing ecosystem on often unstable and nutrient-poor substrates where retention of propagules, leaf litter, and soil is difficult (Larson *et al.*, 2000) and productivity is low; and (3) landslides re-shape landscapes by exposing rock-bound nutrients to weathering, thereby altering cycles of nutrients both locally and regionally through down slope influences on rivers and watersheds. Over geological time, landslides have influenced most landscapes and they continue to have widespread ecological and social effects (Sassa *et al.*, 2007). Further examination of these issues will help us pinpoint sources of altered water quality and hazardous terrain, understand physiological adaptations of landslide colonizers and their roles in succession, focus our efforts to conserve biodiversity, and evaluate the interplay of landscapes and disturbances. Ecological perspectives can advance both the understanding and manipulation of landslides. This chapter places the details of the previous chapters into the context of larger spatial and temporal scales and explores the future of ecological approaches to the study of landslides.

7.2 Human–landslide interactions

7.2.1 Land use changes

Human population growth has led to the expansion of human influences into most terrestrial and many submarine environments. Simultaneously, growing concentrations of humans in urban areas increase the local intensity of human influences on slopes. Because most human cultures exploit natural resources with little concern for long-term sustainability, higher densities of people lead to more resource extraction. Clearing vegetation and extracting soil, rock, and even water can destabilize slopes (see Chapters 3 and 6). Landslide frequencies have often increased as a demand for food, fuel, and shelter leads to expanded forestry and agriculture. Deforestation is driven by site-specific combinations of expansion of human activities for agriculture and infrastructure plus extraction of wood (Geist & Lambin, 2002). Expanding global markets provide economic incentives to clear forested slopes for crops such as coca leaves, corn, or tea (Sidle & Ochiai, 2006; López-Rodríguez & Blanco-Libreros, 2008). Fires, either accidental or intentional, and urbanization can also destabilize slopes (see Chapter 6; Goudie & Boardman, 2010). Fires are increasing in intensity and urbanization is expanding as human populations continue to grow. About half of all humans live in urban areas, and this ratio, which is steadily increasing, generally holds true for humans living in mountainous areas (Slaymaker, 2010). Mountain cities result in increased erosion because people build roads, homes, and other buildings on slopes; we also dam and channel the rivers for water and power. Mountain societies (e.g., many urban areas in the Andes) are increasingly likely to be composed more of low-income people who may lack adequate resources to adjust to disturbances caused by land use changes such as fires and landslides (Hewitt, 1997). Where human land use is so intense that terraforming has reduced landslide frequency and severity, the main loss is not of human lives but of ecosystem functions that landslides supply. These losses include reductions in nutrient redistribution and landscape heterogeneity (Restrepo & Alvarez, 2006).

7.2.2 Novel ecosystems

The rapid globalization of flora and fauna through human movements has led to the creation of novel mixtures of native and non-native species,

often with poorly understood ecosystem consequences (Hobbs *et al.*, 2009). In most cases, we do not know whether such novel mixtures of species are more or less effective than native communities at stabilizing slopes. Our understanding of novel ecosystems is further complicated by novel, anthropogenic disturbances. For example, anthropogenic fires now denude slopes and promote erosion in areas not previously prone to erosion (Sidle *et al.*, 2004; Sidle & Ochiai, 2006). Insights into the relationships between novel ecosystems and landslide stability will influence future landslide mitigation and restoration efforts. Eventual dominance of landslide scars by a few successful, widespread, and usually introduced species is one scenario that would reduce biodiversity in landslide communities, but possibly increase predictability of landslide colonists across large geographical ranges. For example, non-native grasses invaded several Hawaiian landslides and reduced establishment and growth of native species (Restrepo *et al.*, 2003) but made it easier to predict the composition of further landslides. Novel ecosystems are likely to become more common in the future, not only from mixing of native and non-native species, but from realignments of species distributions due to climate change.

7.2.3 Climate change

Some studies have correlated landslide activity with changes in climate, particularly precipitation (Bovis & Jones, 1992; González-Diez *et al.*, 1996; Dale *et al.*, 2001), while other studies have found no such correlation (Innes, 1985). Linking climate change to landslides (Trauth *et al.*, 2003) is challenging because of the many variables that influence landslides in addition to climate (Sidle & Ochiai, 2006), including ones that are geological, hydrological, biological, and anthropogenic (Table 7.1; Fig. 7.1). Each of these factors may vary in time. For example, landslide triggers such as a particular rainstorm or earthquake are influenced by shifts in long-term trends in slope uplift, short-term temperature influences on evapotranspiration and pore pressure, and recent history of rainfall. At millennial time scales, landslides appear to be most frequent during cool, humid climates; at decadal scales the El Niño Southern Oscillation, the North Atlantic Oscillation, Asian monsoons, and the frequency and intensity of cyclones all appear linked to landslide occurrence (Borgatti & Soldati, 2010). Many prehistoric landslides were triggered by tectonic uplift from glacial retreats such as those that occurred at the end of the

Table 7.1. *Climate change implications and nine future directions for landslide ecology*

Climate change implication	Approach	Future directions
More variable weather and extreme events	Technology	Improve longevity of soil retention mechanisms; development of modular, replaceable units
	Ecology	Improve manipulation of succession for long-term slope stability
	Culture	Promote sustainable use of slopes and avoidance of erosion-prone areas
Spread of novel ecosystems	Technology	Improve mapping and modeling of native and novel ecosystems to forecast change and assist native ecosystem restoration
	Ecology	Determine optimal species mixes, optimal root architecture, and other biological tools to stabilize slopes
	Culture	Recognize and minimize the human role in spreading non-native species via land use patterns
More landslides; different slope failure thresholds	Technology	Improve predictive models and local applications
	Ecology	Develop robust, flexible restoration principles and applications that apply within and among ecosystems
	Culture	Develop flexible policies and infrastructures that recognize changing threats from landslides

Little Ice Age (Holm *et al.*, 2004). However, such variations in climatic factors are most applicable for predicting landslides at large spatial scales and are not as useful for understanding local slope dynamics (Schmidt & Dikau, 2004).

Current anthropogenic activities have altered climatic conditions and such changes will likely increase landslide activity (Bromhead & Ibsen, 1997; Lateltin *et al.*, 1997). Along with the expected 2–4 °C increase in global average temperature within the next 60–100 years (IPCC, 2007), we expect more variability in climatically controlled processes that trigger landslides. These include intensity and duration of rainfall, rate and extent of snow melt and glacial melt, frequencies of droughts and floods, stability of permafrost, river channel migration, and sediment loads in rivers (Dale *et al.*, 2001; Borgatti & Soldati, 2010). The exact nature and extent of

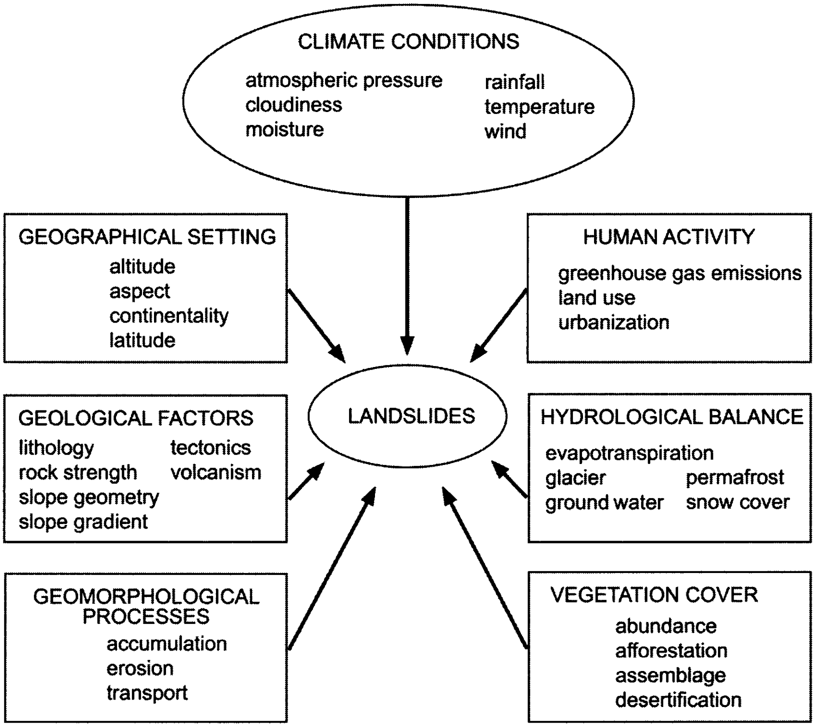

Fig. 7.1. A complex set of background factors influence slope instability and lead to specific triggers (capital letters) of landslides. Climatic influences are modified by geological, hydrological, biological, and anthropogenic variables. Modified from Borgatti & Soldati (2010) with permission from Cambridge University Press.

these climate changes on soil erosion will be measurable at local scales, but increased climatic variation, coupled with extensive, destabilizing land use changes, appears to be driving an increase in landslides. Factors that might offset a trend of increased erosion include stabilization of slopes by increased growth of plants in once arid regions, increased evapotranspiration that could lower pore pressure, and increased root growth due to higher carbon dioxide levels (Rogers *et al.*, 1994; Borgatti & Soldati, 2010).

One dramatic response to global warming is the unequivocal acceleration of glacial melting. In the short term (decades), this melting will probably lead to greater sediment transfer down slope and increased flooding (Slaymaker, 2010); both of these changes could cause an increased frequency of landslides in mountainous regions (Holm *et al.*, 2004; Hewitt,

2006). Newly exposed glacial sediments, not yet stabilized by plant growth or soil development, could be particularly vulnerable to erosion (Fischer *et al.*, 2006). These glacial sediments sometimes dam rivers during earthquake- or flood-triggered landslides, forming so-called glacial lakes. These lakes then can empty in catastrophic outburst floods (see Section 2.2.1). China, Nepal, and Tajikistan are examples of countries highly vulnerable to glacial lakes. In Tajikistan, earthquake-triggered landslides create lakes as large as the 17 km^3 Lake Sarez (Alford *et al.*, 2000). In 2008 in Szechwan, China, 30 lakes were formed by earthquake-triggered landslides. In Nepal, pro-active draining has been attempted to reduce the threat of glacial outburst floods (Slaymaker, 2010). In the long term (centuries), the frequency of landslides due to glacial melt water, high sediment loads in rivers, and channel instability may decline. However, that trend could be offset by an increased frequency of intense rainstorms, thereby maintaining high fluvial sediment loads and channel instability (Korup *et al.*, 2004). Similarly, changes in cyclone frequency, intensity, and direction can have widespread consequences for landslide erosion in such places as Taiwan (Dadson *et al.*, 2003).

Coupled with climate change, unprecedented manipulation and destabilization from anthropogenic land use will likely produce more landslides in the future. Local conditions will promote landslides if projections of more humidity and more irregularity in rainfall and temperature occur. Because landslide activity is likely to remain largely where it has always been (e.g., mountain slopes), efforts to mitigate future landslide damage have a clear, albeit broad geographical focus. Expansion of landslides to previously stable areas may occur, however (e.g., where permafrost melts or stabilizing vegetative cover is removed; Goudie, 2010). Predictive modeling can best contribute to specific recommendations for landslide hazard management at local scales, particularly where the critical details of land use effects on slope erosion can be incorporated (Sidle & Ochiai, 2006).

7.2.4 Landscape rehabilitation

A landscape perspective can aid rehabilitation efforts because it will incorporate spatial and temporal constraints common to all nearby landslides (Swanson *et al.*, 1988; Foster *et al.*, 1998). Landslides created by the same disturbance (populations of landslides; Restrepo & Alvarez, 2006) share a common date of origin and may therefore be linked through similar post-landslide disturbance regimes, common suites of colonizers, and similar

successional trajectories. Alternatively, landslide successional trajectories can vary (Myster & Walker, 1997; Shiels *et al.*, 2006), even when the landslides are triggered by the same storm (Shiels *et al.*, 2008). Rehabilitation tactics should vary depending on such landscape-level attributes of landslides as patchiness, topographical location, climatic variables, and frequency (Swanson *et al.*, 1988). Landslide patchiness at a landscape scale influences succession in several ways. First, the variation in successional stage of all landslides in a given area influences the availability of airborne propagules for landslide colonization; and second, the degree of connectivity (e.g, corridors) among landslides influences the dispersal of colonists (see Chapter 4). The nature and distribution of landslide patches is highly influenced by human activities (Larsen & Santiago Román, 2001; Velázquez & Gómez-Sal, 2008). Topographical location influences rehabilitation success because landslides at ridge tops or on convex slopes are more likely to be rehabilitated than landslides found mid-slope or on concave slopes (Swanson *et al.*, 1988). One climatic variable influenced by landscapes is rainfall. Landslides facing the prevailing wind will receive more rainfall and can be harder to stabilize and revegetate than those in rain shadows. Conversely, drought can be an obstacle for landslides in the lee of the prevailing wind (rain shadow). Finally, frequency can affect rehabilitation, because landscapes with infrequent landslides (e.g., distant from tectonically active terrain) may be easier to re-vegetate than those with more frequent landslide disturbances. Large-scale landscape and even regional perspectives on rehabilitation benefit from models (e.g., of geochemical cycling and climate change) that are most effective at larger spatial and temporal scales than individual landslides (see Section 7.2.3; Restrepo *et al.*, 2003, 2009; Sidle & Ochiai, 2006).

7.3 Lessons learned

Investigation of the ecology of landslides provides insights for science and management. Scientifically, landslides help us understand disturbance ecology, soil formation and erosion, nutrient cycling in terrestrial and submarine habitats, species adaptations to disturbed environments, and ecological change or succession. Landslides provide insights into a broad array of other types of disturbances, including earthquakes, volcanoes, tsunamis, floods, and various anthropogenic activities (e.g., road construction, logging). Landslides are important to soil ecology because they expose rock-bound nutrients, trigger mixing of organic and inorganic layers, and result in net down slope movement of organic matter.

Landslides link terrestrial and aquatic ecosystems through sediment and nutrient transfers from river deltas, fjords, volcanic island shorelines, and continental shelves, with delayed effects on deeper submarine canyons and seafloors (Masson *et al.*, 2006). Terrestrial landslides transfer nutrients and carbon down slope but also promote colonization by new, often fast-growing plants (Sidle & Ochiai, 2006). Species adapted to landslides have met the challenges associated with dispersal, establishment on often unstable, dry, and infertile substrates, spatially heterogeneous microsites, steep environmental gradients, and competition with other colonists. Many kinds of species are successful colonists of landslides. These colonists may include cyanobacteria, fungi, ants, birds, rodents, ferns, grasses, various nitrogen fixing species, and wind-dispersed species of shrubs and trees. These species appear to be gap specialists rather than landslide specialists. Landslides, as examples of locations where succession occurs, inform us about how plants and other organisms colonize severe disturbances and then interact with each other and the physical environment over time. These lessons can augment knowledge obtained by studies of other types of primary succession where environmental conditions of severity (e.g., volcanic surfaces), instability (e.g., dunes, floodplains), and infertility (e.g., mine tailings) overlap with landslides (Walker & del Moral, 2003).

When other options are available, humans tend to avoid slopes prone to sliding. However, population pressures and the many resources found on sloped terrain (e.g., minerals, fertile soil, medicinal plants, firewood, and scenic vistas) mean that some humans decide to live with the danger of landslides. The unpredictability of a particular landslide event can lull people into thinking that where they live is stable (Larson *et al.*, 2000). It is harder to ignore more frequent landslides (e.g., on unconsolidated sands or clays) where erosion can occur with each severe rainstorm. Humans have also created new sources of slope instability from both additions of structures and fluids (e.g., reservoirs), to removal of rocks and soils for the construction of roads and buildings. Therefore, there is a positive feedback loop between expansion of humans onto unstable slopes and increased frequency and damage by landslides.

Human modifications of landslide-prone slopes provide opportunities to address experimentally the effects of various management scenarios. The study of erosion-prone slopes provides additional lessons about how to manage water and sediment flow and how to use plants and soil organisms to promote stabilization and restoration of ecosystem services. Hazard management can ameliorate local and sometimes even regional landslide problems. In a comparison of regional landslide hazards in the

Indian Himalayas and British Columbia (Canada), Singh & Pandey (1996) noted the positive role of management. Development of remote regions for logging, mining, agriculture, and tourism, and the road and railroad corridors used to access these regions, has led to increased landslides in both countries within the last few decades. Landslide damage has been more severe in India with limited management than in British Columbia with more widespread management. Lower population densities and public and financial support for mitigation efforts in British Columbia also helped minimize landslide frequency and severity. However, local human efforts at landslide mitigation and restoration are largely ineffective against stochastic natural disturbances (e.g., earthquakes) and global-scale anthropogenic disturbances (e.g., climate change and resulting changes in rainfall patterns).

7.4 Future directions

We suggest several areas where landslide ecology could develop in the next few decades. We organize them by technological, ecological, and cultural approaches following Walker (2012). We recognize that all of these approaches are essential to maximize flexibility in the face of the uncertainties of human land use and climate change (Table 7.1).

1. Technology is useful to mitigate local landslide disturbances and many slopes can now be engineered to reduce or avoid further erosion – at least during average rainstorm events. However, dams, walls, retention basins, and other erosion controls are all vulnerable to extreme rainstorms or earthquakes and also to eventual decay. Future technological advances could improve the longevity of such structures and develop modular units that can be more flexible in responding to a particular disturbance (e.g., allowing a dam to drain before it collapses) and can be replaced as needed.
2. Plants are potentially cheaper, longer-lasting, and more resilient to future disturbances than physical structures. Despite recent advances in understanding plant effects on soil stability (Ghestem *et al.*, 2011), there is still much to be learned about root morphology and its consequences for preventing erosion, planting techniques, and individual species performances on different substrates. We expect continued improvement in such research and its applications.
3. Technological approaches are most effective when coupled with robust predictive models about slope stability. Models that incorporate the

latest knowledge in GIS, statistics, and remote sensing with ecological lessons about landslide and landscape dynamics have yet to be developed, but will represent a synergism of approaches and result in wider applicability of the models. Much benefit would be derived, for example, by successfully scaling robust climate model predictions about rainfall intensity down to local levels where, with appropriate accounting of local condition, direct action could be taken.

4. An important ecological topic to address is how plant and animal communities on landslides change over time. Succession on landslides involves plant–animal–soil interactions and is infrequently investigated, particularly as a vital, three-way dynamic. Examining these interactions on landslide communities across realistic time spans of years and decades will be an on-going challenge for landslide ecology. One unresolved question in this interaction is the role that nitrogen fixation and other symbioses have on soil development and successional trajectories of landslides. Another concern is the role that animals have on landslide stabilization and community development. How do pollinators, dispersers, burrowers, herbivores, and predators influence landslide succession? Also, is there any significant difference in stabilization rates or succession among landslides colonized by native plants and animals compared to those colonized by non-native species or landslides with novel mixtures of native and non-native species? To the extent that lessons learned from individual site studies can be extrapolated to other sites, the field of landslide restoration will benefit. Global generalizations across biomes are likely to be elusive, given the complexity and individuality of local conditions, but regional generalizations offer greater promise of success.
5. Another area of landslide ecology that could be improved is our understanding of the ecological responses to technological tools used in slope stabilization. Alterations of water flow on slopes can be technically sound but may not account for unexpected ecological responses such as weed invasions, root disruption of drains, or edge effects on surrounding vegetation. Research in the physiology of plants used to promote slope stability and individual plant effects on slope stability has outpaced its practical applications. How do plants with favorable root morphologies interact with each other? Under what environmental and substrate conditions are they most effective? How long do roots and plants on landslides live? Integrating the recent advances in physiological studies (Stokes *et al.*, 2007a, 2009) with practical slope management issues will be a fruitful avenue for further research.

6. Ecological restoration is the acid test of our understanding of ecosystem functions (Bradshaw, 1987) and of direct and urgent relevance to people affected by landslides. Successful, long-term, ecological restoration is less costly and more desirable than moving whole communities out of landslide zones, more resilient than physical structures to on-going disturbances, and a practical demonstration of a solid understanding of successional dynamics. Such restoration urgently needs exploration and will result in more resilient ecosystems when ecological lessons are incorporated (Hobbs *et al.*, 2007). Restoration will also benefit from a landscape perspective that incorporates plant and animal dispersal and topographical considerations.
7. Culturally, one approach to reduce future landslide damage is to discourage permanent settlements in landslide-affected areas, including both slopes and run-out zones below the slopes. Zoning or cultural taboos can help, particularly after a recent devastation when buildings are demolished (Hampton *et al.*, 1996). However, success will depend on broad community support of risk assessments, as recently conducted in Iceland (see Chapter 6; Bell & Glade, 2004). There is much need for future work on the cultural acceptance of risk assessment and its consequences for local community zoning choices. Developing an acceptable range of intensities of land use on unstable slopes (e.g., from minimal to limited to full access for grazing, recreation, construction) might facilitate the integration of societal and ecological requirements (Carreiro & Zipperer, 2011).
8. Another cultural approach is to promote more sustainable use of erosion-prone slopes. Intensive logging or urbanization on such slopes (and attendant roads and other construction) is untenable and is costly in the long term due to expense of future stabilization efforts and perhaps the loss of lives. Slopes where soils and vegetation are either kept intact or restored to maximize stability will have less cost and more benefits to communities (e.g., cleaner water and less danger of floods or landslides) than over-developed ones. Some of the potential benefits of not developing slopes include low-intensity recreational opportunities (hiking, skiing, berry-picking), wildlife refuges, and using slopes as educational tools (e.g., about geology, succession, or ecosystem services; Larson *et al.*, 2000). Future projects should integrate cultural attitudes with landslide management.
9. Changes in where we live and in how we use and value landslide-prone slopes will not be sufficient without policies to reinforce such approaches (Box 7.1). Education and warning systems help prepare a

Box 7.1 Will we ever learn?

When Europeans farmers colonized New Zealand in the mid 1800s, they found, to their delight, large swaths of native grasslands on which to graze their sheep. New Zealand quickly became a major wool exporter and the farmers introduced European grasses and removed native forests to improve grazing conditions. Efforts to maintain the grasslands included constant removal of secondary woody growth and the importation of rock phosphate from several Pacific Islands to fertilize the often nutrient-poor soils. By the 1970s, half of the country was in farmland, but the heavily grazed grasslands were not able to resist erosion and 10% of the land was considered severely eroded (Walker & Bellingham, 2011). Erosion was successfully reduced where trees such as Monterey pine (*Pinus radiata*) were grown, and in recent decades, many farmers switched to growing trees. However, when tree plantations are clear cut (typically every 25 years), the soils are again exposed and erode during rain storms (see Plate 15 and back cover image). In addition, many are again removing the trees to expand the lucrative dairy industry, with renewed soil exposure and extensive erosion. Kenneth Cumberland, a geographer from Auckland, wrote in the 1940s about the need to reforest New Zealand slopes (Cumberland, 1944). Recently, he lamented that, despite 60 years of knowledge about how to manage erosion and how costly each storm was, New Zealanders continue to overgraze their slopes. He ends a recent letter to a newspaper in Christchurch with the suggestion that the bill for tidying up the erosion from the next storm should perhaps go to those who have failed to address the problem (Cumberland & Cumberland, 2008). Would such a policy help improve the stewardship of the land?

population for the dangerous consequences of landslides, but green zones, nature reserves, or limits on roads and dwellings rarely succeed where they are strictly voluntary. Legislation at local levels can address specific concerns, while higher levels of government can tackle regional and larger issues such as the creation of national parks, limits to drilling, or locations of federal highways. Where destabilization is inevitable (e.g., along road cuts), enforceable guidelines can determine how stabilization is addressed and maintained while being realistic about local conditions and solutions to erosion.

Landslide ecology is a recent blend of the decades-old field of landslide science (Sassa *et al.*, 2007) and the century-old field of ecology (McIntosh, 1985). It is a natural extension of early work in primary succession that considered the ecological consequences of all severe disturbances on land (Clements, 1916). Landslide ecosystems resemble other severely disturbed habitats because they are colonized by pioneer species adapted to low nutrients, high light conditions, and on-going disruptions. Landslide ecosystems differ from many other severely disturbed habitats because of their chronic instability, the importance of gravity, and the central roles of rock, soil, and water movements. In other words, their geological aspects are more unusual than their biological characteristics. Nevertheless, for humans to stabilize effectively erosive slopes, the biological components of landslides cannot be ignored. We expect that as the field of landslide ecology develops it will serve to connect the field of landslide science, which has focused on physical aspects of landslides, with the field of ecology. We also foresee the applications of lessons from landslide ecology to a broad array of scientific and management topics including disturbance ecology, nutrient cycling, succession, biodiversity, and restoration. Progress in understanding landslide ecosystems will translate to more accurate predictions of future landslides and more resilient, long-term methods of ecosystem restoration on existing landslides. These improvements will be cost-effective, provide ecosystem services, and save lives.