Landslides significantly alter land cover and the distribution of biomass: an example from the Ninole ridges of Hawai‘i

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Abstract

In the Ninole ridges of Hawai‘i we investigated how landslides influence ecosystem development and modify land cover and the distribution of biomass. We estimated above and below-ground biomass, and N and P concentration in leaves (Metrosideros polymorpha) and very fine roots (all species), for vegetation developing on landslides of three age classes (young, < 18 yr; intermediate, ≈ 42 yr; and old ca. 124 yr) and on undisturbed soils (ca. 430 yr). The undisturbed soils were derived from ash underlain by basalt. To quantify changes in land cover and the distribution of biomass we combined our estimates of biomass with estimates of the area covered by each vegetation class. The latter estimates were obtained from the analysis and classification of color-infrared aerial photographs. Average above- and below-ground biomass for the herbaceous vegetation (young landslides) was 10.4 and 3.2 t/ha, whereas for the ohia-non ash forest (intermediate and old landslides) was 37.5 and 5.2 t/ha, respectively. For the ohia-ash forest (undisturbed sites), average above and below-ground biomass was 354.6 and 9.5 t/ha, respectively. Average foliar N for the herbaceous and ohia-non ash forest ranged between 0.80–0.84%, whereas root P between 0.056–0.040%, respectively. For the ohia-ash forest, average foliar and root P was 0.918% and 0.036%, respectively. Based on changes in vegetation cover during the last 430 yr, we estimated rate of disturbance at 15% per century or equivalently that 53 t/ha biomass per century exited through the system. The removal of ash-derived soils by landslides significantly alters successional trajectories and by doing so may be transforming the Ninole ecosystems in irreversible ways.

Introduction

Landslides strongly influence forest ecosystems developing in humid tropical mountains. It has been estimated that rates of disturbance by landsliding vary between 0.1–20% per century (Gardwood et al. 1979; Spencer and Douglas 1985; Guariguata 1990; Scatena and Lugo 1995). As a consequence, an unestimated amount of biomass and soil organic matter is removed from these systems potentially impacting regional and global carbon budgets (Stallard 1998). In most studies it is assumed that biomass and soil organic matter will eventually reach pre-disturbance levels, however, rates of accumulation can be highly variable (Pandey and Singh 1984; Reddy and Singh 1993; Zarin and Johnson 1995a; Walker et al. 1996). Landslides remove nutrients in addition to biomass and soil organic matter (Lundgren 1978; Zarin and Johnson (1995a, 1995b)). These studies suggest that rates of nutrient accumulation are highly variable, potentially impacting rates of ecosystem development as it has been shown in agricultural landscapes affected by landslides (Douglas et al. 1986; DeRose et al. 1995).

The influence of landslides on humid tropical montane ecosystems goes beyond the slope scale. In fact, landslides redistribute biomass and nutrients between slopes and valleys leaving the mountain ridges almost intact. As a consequence, biomass of forests
developing on slopes is generally lower than that of forests developing on mountain ridges. It has been suggested that the unstable conditions found on the slopes, and not the availability of nutrients, accounts for the observed differences: soils found on mountain slopes are relatively nutrient-rich (Burgess 1975; Silver et al. 1994; Scatena and Lugo 1995; Chen et al. 1997). Therefore, landslides are an important process structuring ecosystems at regional scales.

The islands of Hawaii are well known for their high erosion rates that result primarily from the activity of landslides (Wentworth 1943; Li 1988; Reid and Smith 1992; Keefer 1994; Hill et al. 1997). Surprisingly, little is known about the overall effect of landslides on Hawaiian ecosystems. Steep slopes become the dominant feature of old Hawaiian landscapes, and landslides may play an important role in ecosystem and landscape development. The only estimate available indicates that rate of disturbance by landsliding is 0.6% per century; this figure, however, is based on storm-triggered landslides (Wentworth 1943; Peterson et al. 1993). In addition to disturbing ecosystems developing on steep slopes, landslides may contribute to the overall diversity of geologic substrates and landforms, thus ecosystems, found in the islands. Tephra ejected from the volcanoes has buried basaltic substrates that may be subsequently exposed through the activity of landslides (Sato et al. 1973).

In this paper we evaluate the influence of landslides on a Hawaiian mesic to wet montane ecosystem. Specifically we ask: (1) how do biomass and (2) nutrient concentration of leaves and roots change over time after disturbance by landsliding, (3) what is the rate of disturbance by landsliding in an earthquake-prone environment, and (4) how does disturbance by landsliding translate into changes in land cover and the distribution of biomass. We conducted this work in the highly dissected Ninole ridges of Hawaii for several reasons. First, knowledge of the age of the geologic substrates on the island of Hawaii provides a means to estimate rates of ecosystem development (Raich et al. 1997; Aplet et al. 1998; Herbert and Fownes 1999; Ostertag 2001). In particular, comparing the Ninole ecosystems with those developing on steep, undissected substrates can help us understand differences between ecosystems developing on different landforms. Second, factors controlling ecosystem productivity, such as geological substrate, are relatively well understood for those ecosystems developing on the stable, undissected, substrates of the islands (Kitayama and Mueller-Dombois 1995; Kitayama et al. 1995; Raich et al. 1997; Vitousek and Farrington 1997). In particular, comparing the Ninole ecosystems with those developing on basalt and ash-derived soils may provide insights into those controlling productivity in ecosystems developing on steep terrain. Lastly, the Ninole ridges combine two geological substrates, ash and basalt, a feature found in many active mountains around the Pacific Rim. The removal of ash-derived soils by landsliding and the subsequent exposure of basalt may account for important changes in ecosystem attributes over time.

**Methods**

**Study site**

We conducted this study in the Ninole ridges, a group of hills located in the SE portion of the island of Hawaii (155°34′35″ W and 19°10′14″ N). Overall, the altitude of these ridges ranges from 480–1,116 m and that of our sampling sites at Puu One, Kaioholena, and Kaumaiokeou from 752–900 m (Figure 1, Table 1). The Ninole ridges are composed of theleitic basalt and represent remnants of the second oldest volcanic structure of the island (Hitchcock 1906; Stearns and Macdonald 1946; Lipman et al. 1990; Moore and Mark 1992; Wolfe and Morris 1996). Due to their old age they have some of the steepest terrain on the island. The ridges are surrounded by young (10,000 – 200 yr BP) valley-filling Mauna Loa lavas and thick weathered ash deposits (Lipman et al. 1990; Wolfe and Morris 1996).

Our sites have a mean annual temperature of 20 °C (based on a 5.8 × 10⁻³ °C/m lapse temperature rate) and mean total annual rainfall of 4,094 ± 1,099 mm (Atlas of Hawaii 1983; DNLR 1983). A climatological station that operated at the base of Kaioholena between 1964–1972 yielded a total annual average rainfall of 2,954 ± 586 mm (DNLR 1983). According to these data our sites can be classified as subtropical wet forest (Holdridge 1967) or montane mesic to wet forest (Loope 2000) dominated by ohia trees (Metroxsdiores polymorpha). Most of the hills comprising the Ninole system are within the Kau Forest Reserve. In part because of their relatively remoteness and steepness, and in part because of the high rainfall, the Ninole ridges where we conducted this study have been little influenced by present day human activities, including road construction, logging, and hunting.