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Vegetation Colonization of Landslides in the Blue Mountains, Jamaica[1]

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ABSTRACT

The floristics and nutrient relations of the vegetation on landslides 15 yr old and >50 yr old were studied in a montane rain forest. A total of 33 species were recorded on the 15-yr-old sites and 50 species on the >50-yr-old sites. The dominant woody species on all sites was *Clethra occidentalis*; fast-growing pioneer species characteristic of the forest edge were generally absent. Vegetation development on these sites was slow. On the 15-yr-old sites almost all individuals were <1 m in stem length, and on older landslides all individuals were <5 m in stem length. For 15-yr-old sites, harvested aboveground biomass ranged between 350 and 820 g/m^2, 79 percent of which was accounted for by a nitrogen-fixing lichen. On the oldest landslides, biomass ranged between 970 and 4690 g/m^2 and was accounted for primarily by woody plants. Foliar concentrations of N, P, K, and Ca all increased (P < 0.01, data for all species combined) from the 15-yr-old to the older sites.

Key words: Clethra; *establishment; foliar nutrients; landslide scars; montane forest; regeneration.*

LANDSLIDES ARE A SIGNIFICANT DISTURBANCE event on steeply sloping forests, yet due to their inaccessibility have received little attention (Foster & Brokaw 1982). Existing investigations have mostly centered on instances where landslides form very large and conspicuous disturbances, for example, earthquake-triggered landslides in Panama (12% of land area affected; Garwood *et al.* 1979), Papua New Guinea (8% of area affected; Simonett 1967) and Chile (Veblen & Ashton 1978). More typically though, forests of mountainous areas are affected by "erosional" landslides triggered by rainstorms, and in general occupy smaller areas, and have lower turnover rates than those triggered by earthquakes, for example, 0.6 percent of 1031 ha of the Bisley watershed in the Luquillo Mountains affected by landslides following Hurricane Hugo in Puerto Rico (Scatena & Larson 1991), and 0.2 percent of 1150 ha affected over a period from 1979 to 1990 above Merida, Venezuela (Cannon 1991).

Erosional landslides may be important determinants of species diversity in tropical forests by providing sites for the regeneration of successional species unable to colonize other gap environments. For example, Whitmore (1975) noted the pine species *Pinus kesiya* and *Pinus merkusii* regenerated on landslides in Sumatra and the Philippines, and Guariguata (1990) concluded that landslides were important for the regeneration of *Cyrilla racemiflora* on slopes in lower montane rain forest in Puerto Rico. In montane rain forest in Jamaica, seedlings and saplings of some tree species are frequently seen on landslides which are rarely seen regenerating in treefall gaps or in the understory of the forest. The only two collections in Jamaica of *Tovaria diffusa* this century were made on recent landslides.

A number of factors may cause differences between the vegetation colonization of landslides and that of other forest disturbances. The erosion zones of landslides are harsh environments for plant establishment and growth, characterized by low nutrient availability, low water capacitance, and soil instability (Flaccus 1959, Nakamura 1984). As yet however, very little information has been collected on the composition of the flora and rates of regeneration of the vegetation on tropical landslides (but see Garwood 1985, Guariguata 1990), and no information exists for landslides in upper montane forest. In this study the structure, composition, and foliar nutrient concentrations of two age classes of landslides were compared.

STUDY SITES

The study was conducted in 1989 in a montane rain forest in Jamaica (18°05′N, 76°40′W), at an altitude between 1450 and 1800 m in undisturbed forest on the windward slopes of the Grand-Ridge of the Blue Mountains (Fig. 1). The forest is rel-

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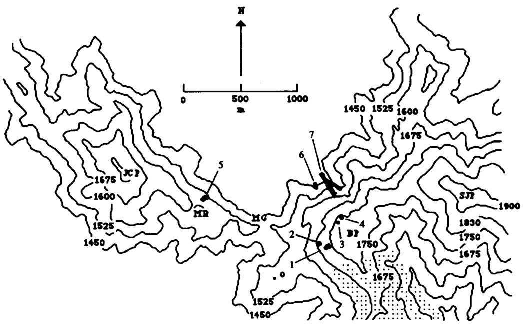

FIGURE 1. Location of landslides investigated in this study. Contour interval is approximately 75 m (converted from 1:12,500 map). Lowest contour (1450 m) marks boundary of area mapped. Speckled area shows cleared forest. MG = Morce's Gap, MR = Mull Ridge, BP = Bellvue Peak, SJP = Sir John's Peak. 1–4 are 1974 landslides; 5–7 are Old landslides.

atively floristically homogeneous over this altitudinal range, and has been described in detail as "Wet Slope" forest by Grubb and Tanner (1976). Although landslides varied greatly in size, shape, and aspect (Table 1), landslide slope and substrate were similar for all sites with a layer of Richmond formation sandstone overlying Cretaceous volcanic rock. Formation processes of the landslides were probably also similar, the eroded area of all the landslides were uniformly shallow (<50 cm deep), the base of landslides graded into existing stream beds, and there were no "depositional zones" to the slides in which eroded material accumulated. This is consistent with the description of "debris flow" landslides as classified by Varnes (1978). All studies were carried out on the "upper" *sensu* Guariguata (1990), or "scar" *sensu* Nakamura (1984) zone of the landslides. Landslides also differed in age, and accordingly have been separated into two groups.

1974 LANDSLIDES.—These four landslides were triggered by heavy rains following construction of a now abandoned road in March 1974 (E. Tanner, pers. comm.).

OLD LANDSLIDES.—These three landslides are of uncertain age, but pre-date local farmers (R. Brian, A. Hall, pers. comm.) and have been assumed to be greater than 50 yr old (possibly over a century). These landslides may originate from the earthquake of 1906, which triggered numerous landslides elsewhere in the Blue Mountains (J. Healey, pers. comm.; Zans 1959).

TABLE 1. *Aspect, slope, size, and elevation of landslides investigated.*

Landslide	Aspect	Slope	Altitude (m)	Width (m)	Length (m)	Area (ha)
1974 landslides						
L1	240° SW	48°	1750	20	75	0.15
L2	240° SW	50°	1720	25	50	0.13
L3	270° W	55°	1770	7	10	0.007
L4	285° NW	55°	1780	10	15	0.015
Old landslides						
L5	030° NE	45°	1560	25	60	0.15
L6	280° W	40°	1440	5	10	0.005
L7	280° W	45°	1440	150	500	7.5

METHODS

ENUMERATION OF PLOTS.—For each of the seven landslides, a homogeneous area was selected away from landslide edges, with as well-developed a vegetation stand as possible, and without large rills and gullies. Areas were selected subjectively to prevent the inclusion of areas with differing disturbance histories, as occurs in landslides prone to "retrogressive" (recurrent) sliding. Within this area, 25 1-m^2 permanent plots were located in a grid of five rectangular blocks of 5-m × 1-m plots separated from each other by 0.5-m wide access paths. In the smallest Old landslide, the narrowness of the site permitted only fifteen 1-m^2 plots to be established.

BIOMASS AND STEM LENGTH MEASUREMENTS.—Two of the 1-m^2 plots on each landslide were selected at random and all aboveground biomass harvested. In the case of lichen and mosses, only one randomly selected quarter of the 1-m^2 plot was harvested, and estimated total biomass for the remainder of the plot calculated. Biomass was weighed in the field using a spring balance, and subsamples were taken back to the laboratory and dried at 110°C for 72 hr. In the remaining 23 plots, the maximum stem length of all woody individuals and herbaceous species with an erect habit was measured. Stem length rather than stem height was measured because not all plants grew vertically on these steep slopes.

FOLIAR NUTRIENT ANALYSIS.—At each site mature leaves from apical shoots of at least three individuals of each woody and herbaceous species were collected. Samples were oven-dried at 70°C, ground and pooled prior to analysis, to give one sample per species per site. Samples were redried at 70°C, weighed and digested for the determination of both nitrogen and phosphorus, using sulphuric acid and hydrogen peroxide (with mercury as a catalyst). The resulting solutions were analyzed by established methodologies (ChemLab Instruments 1982, 1983). A sample of standard leaf material was also processed with each batch of analyses to check for consistency, and samples of this standard material were analyzed by independent laboratories which confirmed my analysis. Digest samples were also used to measure potassium by flame photometry, and magnesium and calcium by atomic absorption spectrophotometry (Baird Ltd., 1981).

RESULTS

TAXONOMIC COMPOSITION OF LANDSLIDES.—A total of 33 species (18 woody) were found in the 100 m² of the 1974 landslides and 50 species (24 woody) in the 65 m² of the Old landslides (Appendix). Species area curves approached the asymptote, with the exception of woody species on Old landslides (Fig. 2). Only seven species had an importance value of >1 percent of the total for all individuals on 1974 landslides, and ten species on Old landslides (Table 2). *Clethra occidentalis* dominated both the 1974 and Old landslides. Two additional ericoid species *Vaccinium meridionale* and *Lyonia octandra* were common on 1974 landslides but were relatively uncommon on Old landslides.

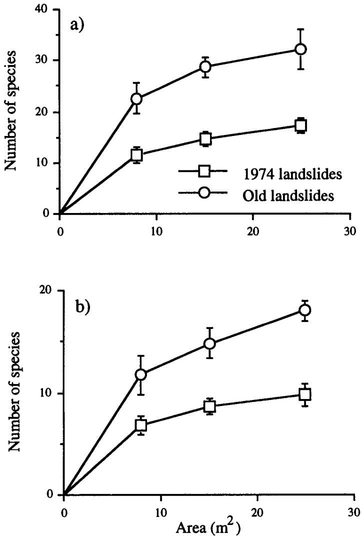

FIGURE 2. Mean species area curves (±1 SE) for (a) total species, and (b) woody species.

TABLE 2. *Species importance values (IV). Calculated as the [mean of relative frequency in 1 m² plots + relative density of individuals + relative dominance as a percentage of the sum of stem lengths to the total stem length of all species]/3. Mean values for 1974 (N = 4) and Old landslide (N = 3) sites are reported.*

Rank	Species	Relative density	Relative frequency	Relative dominance	I.V.
1974 landslides					
1	*Clethra occidentalis*	60.6	26.9	37.4	41.6
2	*Lyonia octandra*	19.2	20.7	29.4	23.1
3	*Vaccinium meridionale*	11.8	23.6	24.9	20.1
4	*Cyrilla racemiflora*	3.3	8.6	2.4	4.7
5	*Pittosporum undulatum*	2.1	6.8	1.5	3.6
6	*Baccharis scoparia*	0.5	3.0	1.4	1.6
7	*Podocarpus urbanii*	0.5	2.4	0.5	1.1
	Other	2.0	8.0	2.5	4.2
Old landslides					
1	*Clethra occidentalis*	53.8	23.8	45.0	40.9
2	*Miconia quadrangularis*	8.5	13.8	12.5	11.6
3	*Vaccinium meridionale*	5.6	8.3	10.1	8.0
4	*Viburnum alpinum*	4.6	8.8	3.9	5.7
5	*Pittosporum undulatum*	5.2	6.7	1.6	4.5
6	*Rhamnus sphaerospermus*	3.9	5.3	3.1	4.1
7	*Baccharis scoparia*	2.2	4.2	5.9	4.0
8	*Garrya fadyenii*	3.0	5.0	2.6	3.5
9	*Myrica cerifera*	2.0	4.6	3.6	3.4
10	*Podocarpus urbanii*	1.9	4.1	1.9	2.8
11	*Lyonia octandra*	0.6	1.3	0.8	0.9
	Other	0.5	7.0	1.0	1.9

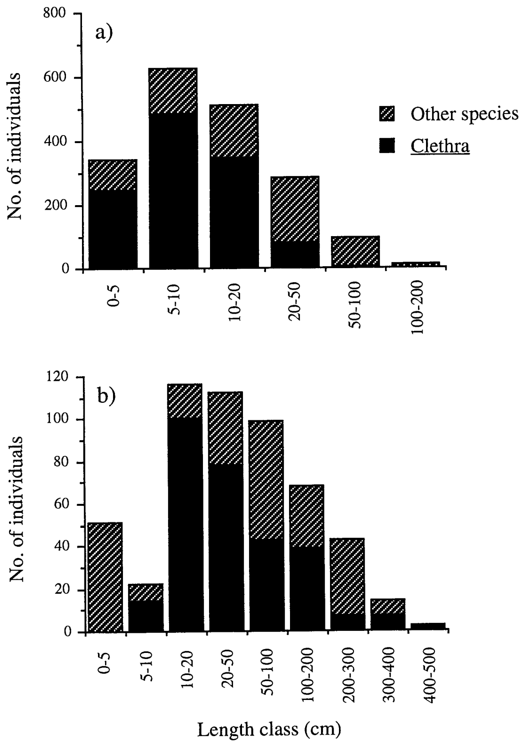

FIGURE 3. Stem length distribution for *Clethra occidentalis* and all other woody species on (a) 1974 landslides, and (b) Old landslides.

STEM LENGTH AND BIOMASS.—Stem growth on these sites appears to be very slow. On 1974 landslides 33.5 percent of individuals were in the 5–10 cm size class. Only 0.7 percent of individuals (mostly *Vaccinium meridionale*) exceeded 100 cm in length, and no individuals were greater than 200 cm in length (Fig. 3a). On Old landslides, the modal size class was similarly small (10–20 cm) accounting for 22.0 percent of individuals, with only 11.2 percent exceeding 200 cm. The largest individuals in these sites were nitrogen-fixing *Myrica cerifera* trees, but even these were <500 cm tall (Fig. 3b).

Harvested biomass was very variable, in part due to inadequate sampling (Table 3). On the 1974 landslides mean total biomass was 625 g/m² (range 350 g to 820 g), with woody plants accounting for an average of 17 percent of the total biomass, while herbaceous plants together with Cyperaceae, Bromeliaceae, and Lycopodiaceae accounted for only 2 percent. The largest components of the biomass were mosses and lichens, with moss biomass accounting for 4 to 54 percent of total plot biomass according to site, and lichens for 23 to 79 percent of total plot biomass. Observations suggested that lichens occupied the drier, and mosses the wetter microsites within the plot; however, some sites were covered with a complete canopy of the lichen *Stereocaulon virgatum* about 10 cm deep.

TABLE 3. *Estimated total aboveground biomass (g/m²) from harvested 1 m² plots from each of 1974 and Old landslide sites; means from* N = 4 *1974 landslides and* N = 3 *Old landslides; 1 SE is given in parentheses.*

Life-form	1974 landslides	Old landslides
Woody plants	100 (10)	1860 (870)
Herbaceous plants	1 (1)	120 (40)
Cyperaceae	10 (5)	6 (6)
Bromeliaceae	1 (1)	130 (10)
Lycopodiaceae	3 (3)	0 (—)
Mosses	160 (70)	330 (20)
Lichens	350 (130)	0 (—)
Total	625 (100)	2440 (1110)

On Old landslides, mean total biomass was 2440 g/m² (range 970 g to 4690 g), with woody plants accounting for 50 to 83 percent of the total plot biomass. Herbaceous plants accounted for a small proportion of biomass (ranging between 1% and 21%) and moss biomass was similar to that on the 1974 landslides (range 7% to 26%). Lichens were absent from all but exposed rock bluffs on the Old landslides, and completely absent from my plots.

FOLIAR NUTRIENT ANALYSES.—Foliar N, P, K, and Ca concentration tended to be higher on Old landslides than on 1974 landslides for all species with the exception of *Lyonia octandra* (Table 4). Magnesium showed the opposite trend to other nutrients, with lower foliar concentrations on the Old landslides. For individual species, differences in foliar nutrient concentrations were significantly different between the two classes of landslides for *Baccharis scoparia* (K and Mg), *Clethra occidentalis* (N, P, and Ca), and *Pittosporum undulatum* (N, P, K, and Mg). When nutrient concentration data were combined by species (*i.e.,* using species as a factor in a 2 factor ANOVA) there was a significant effect for all nutrients.

DISCUSSION

PATTERNS OF REGENERATION ON LANDSLIDES.—Despite differences in age, location, and size, both 1974 and Old landslides were dominated by the ericoid

TABLE 4. *Mean foliar nutrient concentrations (1 SE) of plants growing on 1974 (N = 4) and Old landslides (N = 3).*

Species	Landslide	N	P	K	Mg	Ca
Baccharis scoparia	1974	1.13 (0.09)	0.10 (0.01)	1.97 (0.11)	0.34 (0.07)	1.46 (0.24)
	Old	1.26 (0.06)	0.13 (0.02)	2.80 (0.23)*	0.08 (0.01)*	2.52 (0.41)
Clethra occidentalis	1974	1.08 (0.05)	0.08 (0.01)	1.60 (0.07)	0.42 (0.04)	0.99 (0.14)
	Old	1.44 (0.10)*	0.14 (0.01)*	2.03 (0.38)	0.29 (0.08)	1.74 (0.21)*
Lyonia octandra	1974	0.99 (0.04)	0.06 (0.01)	0.56 (0.01)	0.23 (0.01)	1.03 (0.05)
	Old	0.88 (0.06)	0.05 (0.01)	0.59 (0.12)	0.18 (0.03)	0.99 (0.08)
Myrica cerifera	1974	1.42 (0.06)	0.05 (0.02)	0.50 (0.07)	0.12 (0.02)	1.02 (0.04)
	Old	1.54 (0.19)	0.08 (0.02)	0.81 (0.11)	0.09 (0.01)	1.17 (0.06)
Pittosporum undulatum	1974	0.83 (0.08)	0.08 (0.01)	2.02 (0.17)	0.25 (0.03)	1.38 (0.15)
	Old	1.22 (0.11)*	0.13 (0.01)*	2.83 (0.06)*	0.09 (0.01)*	1.74 (0.14)
Vaccinium meridionale	1974	0.77 (0.08)	0.05 (0.01)	0.56 (0.05)	0.17 (0.02)	0.83 (0.08)
	Old	0.94 (0.04)	0.10 (0.02)	0.46 (0.01)	0.16 (0.03)	0.96 (0.05)
Mean all species	1974	1.04 (0.05)	0.07 (0.01)	1.16 (0.15)	0.26 (0.03)	1.11 (0.07)
	Old	1.23 (0.07)*	0.11 (0.01)*	1.65 (0.26)*	0.15 (0.02)*	1.55 (0.15)*

* Indicates significantly different at $P < 0.05$.

tree species *Clethra occidentalis,* a species present in all upper montane forest types identified in the Blue Mountains (Grubb & Tanner 1976). Old landslides bore a greater resemblance to mature forest than the 1974 landslides, having greater tree species richness and a number of shade tolerant species (*sensu* Healey 1990) present as seedlings (*e.g., Guarea swartzii, Eugenia virgultosa*). At the same time though, several orchid and bromeliad species, which in mature forest have an epiphytic habit (*e.g., Stelis micrantha, Vreisea sintenisii*), were present on the landslide surface and accounted for a considerable proportion of the biomass on at least one landslide.

A comparison of my results with other studies of vegetation colonization on landslides in the tropics exhibits two main differences: the relative unimportance of ferns, and the absence of large-gap pioneer trees and shrubs. Four years following the triggering of landslides by an earthquake in a lowland forest in Panama, fern sporophytes, especially *Pityrogramma* were common, and far outnumbered woody individuals (Garwood 1985). At one site, ferns climbed over and shaded out woody colonizers (N. Garwood, pers. comm.). Similarly, on the upper zone of landslides 8 to 37 yr old in a lower montane forest in Puerto Rico, *Dicranopteris* ferns formed thick canopies up to 1.5 m tall, with a relative cover of >80 percent (Guariguata 1990). *Dicranopteris* and *Gleichenia* ferns are present in upper montane forests in Jamaica, but do not dominate landslide sites. Burned areas however, are rapidly colonized by *Gleichenia.*

Fast-growing pioneer trees species common at the forest margin, and in large treefall gaps (*e.g., Alchornea latifolia, Trema floridanum, Brunellia comocladifolia*) were rare or absent on landslides. Likewise, light-demanding herbaceous species (*e.g., Bocconia frutescens, Clibadium terebinthinaceum, Lobelia assurgens*) were also rare despite growing vigorously in the forest understory and along the margins of landslides triggered by Hurricane Gilbert in 1988.

A variety of biotic and abiotic factors may explain the pattern of regeneration on landslides. Biotic factors include poor dispersal to landslides, differential activities of seed predators on landslides, and the possible absence of mycorrhizae. Abiotic factors include altered temperature and soil moisture conditions on the landslide surface affecting seed germination and seedling establishment, soil instability, and low nutrient availability.

Poor dispersal seems unlikely, given that landslide colonizers do not share a common set of dispersal characteristics (Tanner 1982), and that the landslides were very small. Temperature, soil moisture, and soil stability are likely to have the greatest effect at the early establishment phase, as 5 cm tall seedlings transplanted onto nearby landslides triggered in 1988 were unaffected by a soil stabilization treatment, and showed lower dry season mortality than seedlings transplanted into the forest understory (Dalling 1992).

The role of nutrient limitation deserves more attention. Soil bioassays and fertilizer addition experiments have shown that both nitrogen and phosphorus limit plant growth in mature forest soils in the montane forests of Jamaica (Healey 1990, Tanner *et al.* 1990). Likewise, the growth of transplanted seedlings on landslides was promoted by the addition of organic fertilizer (Dalling 1992). A further role of nutrients in determining the species composition of landslides might be hypothesized. In general, mature forest species with high foliar nitrogen and phosphorus concentrations (data from Tanner 1977) were absent from landslides, and foliar nutrient concentrations and species diversity increased concurrently between the 1974 and Old landslides. Additional fertilization experiments are needed to elucidate the role of soil nutrient availability in the recovery of vegetation on landslides.

Persistence of landslides.—Montane forests are characterized by very slow growth in comparison to lowland tropical forests. Mean trunk diameter increment for trees ≥25 cm girth in upper montane forests in Jamaica is only 0.2 mm/yr (Tanner *et al.* 1990). This slow growth can be attributed in part to low daily temperatures and insolation throughout the year. As a consequence, vegetation recovery following disturbance is very slow, and the difference between successional and mature forest vegetation is less marked than that in the lowlands (Ewel 1980).

Comparing biomass accumulated on the landslide with that in mature forest around these sites (in Tanner 1980), reveals that the biomass accumulated in the forest types with the lowest above-ground biomass was ten times that of the Old landslides, and 36 times that of the 1974 landslides. Assuming a linear rate of biomass accumulation on landslides, the 1974 landslides would take 540 yr to reach the biomass of mature forest, and the Old landslides 500 yr. This would make these landslides among the most persistent of disturbances to tropical forests, and undoubtedly longer-lasting than the secondary successions of Jamaican montane forest resulting from treefalls and hurricane damage (Sugden *et al.* 1985, Healey 1990).

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LITERATURE CITED

Adams, C. D. 1972. Flowering plants of Jamaica. University of the West Indies, Mona, Jamaica.

Baird, Ltd. 1981. Standard conditions for atomic absorption and flame emission spectroscopy. Baintree, Essex, England.

Chemlab. 1982. Ammonia, method sheet CW2-008-11. Chemlab Instruments, Hornchurch, Essex, England.

———. 1983. Phosphate, method sheet CW2-075-01. Chemlab Instruments, Hornchurch, Essex, England.

Cannon, J. 1991. Landslide disturbance, revegetation and nutrient status in Venezuelan montane forest. Unpublished B.A. Dissertation, Cambridge University, England.

Dalling, J. W. 1992. Regeneration on landslides in the Blue Mountains, Jamaica. Ph.D. Dissertation, Cambridge University, England.

Ewel, J. J. 1980. Tropical succession: manifold routes to maturity. Biotropica 12: 2–7 (supplement).

Flaccus, E. 1959. Revegetation of landslides in the White Mountains, New Hampshire. Ecology 40: 692–703.

Foster, R. B., and N. V. L. Brokaw. 1982. Structure and history of the vegetation of Barro Colorado Island. *In* E. G. Leigh, A. S. Rand, and D. M. Windsor (Eds.). The ecology of a tropical forest: seasonal rhythms and long-term changes, pp. 67–82. Smithsonian Institution, Washington, D.C.

Garwood, N. C. 1985. Earthquake caused landslides in Panama: recovery of vegetation. Nat. Geog. Soc. Res. Rep. 21: 181–183.

———, D. P. Janos, and N. V. L. Brokaw. 1979. Earthquake-caused landslides: a major disturbance to tropical forests. Science 205: 997–999.

Grubb, P. J., and E. V. J. Tanner. 1976. The montane forests and soils of Jamaica: a reassessment. J. Arnold Arbor. Harv. Univ. 57: 314–367.

Guariguata, M. R. 1990. Landslide disturbance and forest regeneration in the Upper Luquillo Mountains. J. Ecol. 78: 814–832.

Healey, J. R. 1990. Regeneration in a Jamaican montane tropical rain forest. Ph.D. Dissertation, Cambridge University, England.

Nakamura, T. 1984. Vegetational recovery of landslide scars in the upper reaches of the Oi river, Central Japan. J. Jpn. For. Sci. 66: 328–332.
Proctor, G. R. 1985. Ferns of Jamaica, British Museum (Natural History), London, England.
Scatena, F. N., and M. C. Larsen. 1991. Physical aspects of Hurricane Hugo in Puerto Rico. Biotropica 23: 317–323.
Simonett, D. S. 1967. Landslide distribution and earthquakes in the Bewani and Torricelli mountains, New Guinea. *In* N. J. Jennings and J. A. Mabbut (Eds.). Landform studies from Australia and New Guinea, pp. 64–84. Cambridge University Press, Cambridge, England.
Sugden, A. M., E. V. J. Tanner, and V. Kapos. 1985. Regeneration following clearing in a Jamaican montane forest: results of a ten year study. J. Trop. Ecol. 1: 329–351.
Tanner, E. V. J. 1977. Four montane forests of Jamaica: a quantitative characterization of the floristics, the soils and the foliar mineral levels, and a discussion of the interrelations. J. Ecol. 65: 883–918.
———. 1980. Studies on the biomass and productivity in a series of montane rain forests in Jamaica. J. Ecol. 68: 833–848.
———. 1982. Species diversity and reproductive mechanisms in Jamaican trees. Biol. J. Linn. Soc. 18: 263–278.
———, V. Kapos, S. Freskos, J. R. Healey, and A. M. Theobald. 1990. Nitrogen and phosphorus fertilization of Jamaican montane forest trees. J. Trop. Ecol. 6: 231–238.
Varnes, D. J. 1978. Slope movement types and processes. *In* R. L. Schuster and R.S. Krizek (Ed.). Landslides: analysis and control, pp. 11–33. Special report, 176. United States National Academy of Sciences Transportation Research Board, Washington, D.C.
Veblen, T. T., and D. H. Ashton. 1978. Catastrophic influences on the vegetation of the Valdivian Andes, Chile. Vegetatio 36: 149–167.
Whitmore, T. C. 1975. Tropical rain forests of the Far East. Clarendon Press, Oxford, England.
Zans, V. A. 1959. Judgement cliff landslide in the Yallahs Valley. Geonotes 2: 43–48.

APPENDIX. *Occurrence of tree species, herbaceous species, epiphytes and climbers, and "ruderal" species on each of the landslide sites (numbers 1 to 7). Nomenclature after Adams (1972), and Proctor (1985).*

	1974 landslides				Old landslides		
Species	1	2	3	4	5	6	7
Trees							
Clethra occidentalis (Clethraceae)	X	X	X	X	X	X	X
Vaccinium meridionale (Ericaceae)	X	X	X	X	X	X	X
Ilex macfadyenii (Aquifoliaceae)			X		X		X
Dendropanax sp. (Araliaceae)					X		X
Brunellia comocladiifolia (Brunelliaceae)		X					
Viburnum alpinum (Caprifoliaceae)				X	X	X	X
Maytenus jamaicensis (Celastraceae)							X
Hedyosmum arborescens (Chloranthaceae)				X			
Cyrilla racemiflora (Cyrillaceae)	X	X	X	X			
Lyonia octandra (Ericaceae)	X	X	X	X		X	
Rhodendron arboreum				X			X
Alchornea latifolia (Euphorbiaceae)		X					X
Xylosma nitida (Flacourtiaceae)							X
Garrya fadyenii (Garryaceae)					X	X	X
Clusia havetioides (Guttiferae)						X	X
Miconia quadrangularis (Melastomataceae)		X	X	X	X	X	X
Guarea swartzii (Meliaceae)					X		X
Myrica cerifera (Myricaceae)			X		X	X	X
Myrsine coriacea (Myrsinaceae)					X	X	X
Eugenia virgultosa (Myrtaceae)					X		X
Myrcianthes fragrans					X		
Pittosporum undulatum (Pittosporaceae)	X	X		X	X	X	X
Podocarpus urbanii (Podocarpaceae)		X	X	X		X	X
Rhamnus sphaerospermus (Rhamnaceae)					X		X
Cinchona pubescens (Rubiaceae)	X						
Palicourea alpina			X				
Psychotria corymbosa			X	X	X		X
Dodonea viscosa (Sapindaceae)	X						
Cleyera theaeoides (Theaceae)							X
Laplacea haemotoxylon					X		

APPENDIX. *Continued.*

Species	1974 landslides				Old landslides		
	1	2	3	4	5	6	7
Herbaceous vegetation, climbers and epiphytes							
Rhynchospora spp. (Cyperaceae)	X	X	X	X	X	X	X
Begonia acutifolia (Begoniaceae)							X
Vriesea sintenisii (Bromeliaceae)				X	X		X
Lobelia martagon						X	
Hedyosmum nutans (Chloranthaceae)							X
Baccharis scoparia (Compositae)	X	X		X	X	X	
Bidens shrevei	X		X	X		X	
Erigeron karvinskianus							X
Eupatorium adenophorum		X		X			
Eupatorium parviflorum						X	X
Eupatorium riparium		X			X	X	X
Eupatorium triste						X	
Gnaphalium americanum	X	X		X			
Lapsana communis	X						
Vernonia pluvialis		X	X	X			
Besleria lutea (Gesneriaceae)		X				X	X
Columnea hirsuta							X
Chusquea abietifolia (Graminae)							X
Melinis minutiflora	X	X					
Zeugites americanum						X	X
Malvaviscus arboreus (Malvaceae)							X
Phaius tancarvilleae (Orchidaceae)							X
Stelis micrantha						X	X
Peperomia crassicaulis (Piperaceae)				X			
Peperomia stellata							X
Piper hispidum							X
Polygonum chinense (Polygonaceae)						X	
Rubus ellipticus (Rosaceae)	X			X	X	X	X
Relbunium hypocarpium		X	X		X	X	
Pilea microphylla							X
Pilea weddellii					X	X	X
Viola patrinii (Violaceae)	X						
Hedychium gardnerianum (Zingiberaceae)						X	X
Ferns							
Cyathea spp. (Cyatheaceae)						X	X
Gleichenia jamaicensis (Gleicheniaceae)	X	X	X				
Lycopodium spp. (Lycopodiaceae)			X			X	
Blechnum lineatum (Polypodiaceae)			X				X
Pityrogramma ebenea			X		X	X	
Polystichum cf. *muricatum*						X	