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Erosion and Sediment Transport in Pacific Rim Steeplands. I.A.H.S. Publ. No. 132 (Christchurch, 1981)

Analysis of debris-avalanche erosion in steep forest lands: An example from Mapleton, Oregon, USA

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Abstract

Inventories of shallow, rapid soil mass movements (debris avalanches) are useful for assessing impacts of forestry practices such as clearcutting and road construction. Analysis of inventory data from steep Pacific Rim forest land indicates a several-fold increase in debris-avalanche erosion from clearcutting relative to the rate in forested areas and even greater increases from roads. Some of the limitations of interpretation of inventory data can be overcome with improved data analysis.

Analyse de l'érosion par avalanche de débris en forêt à pente raide: un exemple de Mapleton, Oregon, Etats-Unis.

Résumé

Les inventaires de mouvements superficiels rapides de terrain (avalanche de débris) sont utiles à l'étude des effets d'activités forestières telles que le déboisement systématique et la construction de routes. L'analyse des données d'inventaires sur les terrains forestiers raides du rebord Pacifique indique un accroissement multiple de l'érosion par avalanche de débris due au déboisement systématique (par contraste avec les terrains boisés), et un accroissement encore plus grand dû aux routes. Certains problèmes dans l'interprétation des données d'inventaire peuvent être résolus par des améliorations dans l'analyse des données.

Shallow, rapid, soil mass movement is a common, if not predominant, erosion process in much of the steep mountain land of the Pacific Rim. These events, here termed debris avalanches, pose particular problems for forest-land managers who must consider their impacts on forest productivity, aquatic resources, human life, and structures. Rates of soil erosion by debris avalanches--and the effects of forest management practices on occurrence of these events--are commonly assessed with inventories of debris avalanches from forest, clearcuttings, and road rights-of-way. Results of such inventories may be used to (1) identify specific management activities in the past that have accelerated the occurrence of debris avalanches which can be reduced with improved practices, (2) assess the effectiveness of improved practices in reducing debris-avalanche erosion, and (3) predict impacts of future management activities. We discuss results and limitations of inventories as a means of assessing debris-avalanche erosion and related impacts of forest practices. Examples are mainly from the Mapleton Ranger District, Siuslaw National Forest, in the Coast Ranges of western Oregon, USA (Lat. 44 N, Long. 124 W).

The Mapleton area is characterized by steep, highly dissected, debris avalanche-prone slopes carved in gently dipping Tertiary greywacke sandstone and siltstone. Forests of 100- to 200-year-old Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), younger stands of alder (*Alnus rubra* Bong.), and early successional vegetation in clearcuttings cover the area. About 40 per cent of the area has been clearcut in the past 30 years. Annual rainfall totals about 200 cm at the town of Mapleton and six-hour intensities in excess of 7.5 cm have been recorded. A three-day storm totalling 19.7 cm of rainfall in November 1975 triggered over

250 debris avalanches in the 83 400-ha District and led to a series of studies of debris-avalanche erosion (Swanson et al., 1977; Ketcheson, 1978; Creswell et al., 1979).

Debris avalanches in the study area are typically initiated from sites at the head of incipient drainage depressions termed "hollows" by Dietrich and Dunne (1978). Slump and block-glide types of deeper, slower mass movement also occur and sometimes trigger debris avalanches.

METHODS

Estimation of the rate of debris-avalanche erosion is based on (1) area in which a set of events has occurred, (2) period in which they took place, and (3) volume of soil transported. For each land-use condition (forest, clearcut, road right-of-way), we estimated these three types of data for events that moved more than 7.6 m^3 of soil, using different combinations of field methods and interpretation of aerial photographs (color, scale = 1:15 840). Size distribution of debris avalanches were measured in the field because volumes of soil moved could not be accurately determined from aerial photographs. Analysis of photos, however, is an efficient way to inventory areal and temporal frequencies over large areas where time is determined by bracketing events between the dates of the photographs. These methods were used for clearcuttings and road rights-of-way. We analyzed events in forested areas using field traverses to locate debris-avalanche scars and dendrochronologic methods to date them. The steep, dissected terrain, heavy forest cover, and small size of debris-avalanche scars preclude effective use of aerial photographs for analysis of events in forests. Methods are discussed further by Swanson et al. (1977).

Our sampling concentrated on land type 47 (Soils Resource Inventory, Siuslaw National Forest), the most intensely dissected and steepest land in the Forest.

RESULTS AND DISCUSSION

Inventoried debris avalanches in forested areas of land type 47 occurred with a frequency of about 0.5 events km^{-2} yr^{-1}, average volume of 54 m^3, and a rate of soil transfer of 28 m^3 km^{-2} yr^{-1} (Table 1). The rate of soil transfer by debris avalanches in clearcuttings was 111 m^3 km^{-2} yr^{-1} or about 4 times the rate in forested areas. The rate for road rights-of-way was about 120 times greater than the forest rate. These observations are in general agreement with those of Ketcheson (1978) for land type 47 in the same area (Table 1). He measured a rate of debris-avalanche erosion of 11 m^3 km^{-2} yr^{-1} in forested areas and a rate 11 times higher in clearcuttings.

Comparison with the study of Greswell et al. (1979) is difficult, because they examined the impact of a single storm rather than the history of debris avalanches over 10 or more years as did Swanson et al. (1977) and Ketcheson (1978). This difference in sampling period provides an opportunity to examine changes in effects of management activities with changing practices. Based on aerial photo interpretation of debris avalanches in clearcuttings for the period 1962-1972, Swanson et al. (1977) observed 0.56 events km^{-2} yr^{-1}, in contrast with 0.95 events km^{-2} in the 1975 storm (Greswell et al., 1978). Road right-of-way events in 1957-1972 occurred at a rate of 4.12 km^{-2} yr^{-1}; the 1975 storm had 2.91 events km^{-2}. This apparent pattern of increasing occurrence in clearcuttings and a decrease in frequency of events from road rights-of-way may reflect the combined effects of (1) improved road siting, construction, and maintenance, particularly during storms when field crews attempt to maintain road drainage systems, and (2) increased proportion in successive years of clearcut area in the most unstable terrain, because easiest sites have been cut first.

Results of these studies in the Oregon Coast Ranges offer interesting comparisons with results of debris-avalanche inventories elsewhere in the Pacific Rim (Table 1). Rate of debris-avalanche erosion in clearcut areas at five of the six sites exceeds forest rates by 2.2 to 22 times. Rates from road rights-of-way exceed forest rates by 26 to 350 times. Most of the increase in soil transfer at disturbed sites is because of greater frequency rather than increased average volume of debris avalanches. Rates of debris-avalanche erosion in forested areas are about the same at all sites. Events in forest and clearcut areas of highly dissected terrain, such as the Oregon Coast Ranges and Notown, New Zealand (O'Loughlin and Pearce, 1976), are characterized by much higher frequency but lower average volume than the less-dissected areas. Apparently these intricately dissected areas provide many sites for potential failure, but thin soils and steep side slopes limit the volume of each event.

The high rate of debris-avalanche erosion from roads relative to clearcuttings is somewhat misleading, because roads affect much less of managed forest land than does clearcutting. If we assume that 6 per cent of an area is in road right-of-way, we can calculate the debris-avalanche erosion from roads as [(6 per cent of area X road erosion rate) - (6 per cent of area X forest erosion rate)]. This takes into account that some erosion may occur from the road area even if it is in forest. A similar calculation can be made for the 94 per cent of the area clearcut. These calculations for debris-avalanche data for all soil types in the Mapleton District indicate that clearcuttings contribute about 23 per cent of total accelerated debris-avalanche erosion in the area, and roads account for the remainder.

Several short- and long-term factors limit this means of estimating impacts of clearcuttings and roads on debris-avalanche erosion. The more important short-term (scale of decades) limitations center on (1) changes in management practices and type of landscape operated in through time, (2) temporal changes in proportion of land areas in forest, clearcuttings, and road rights-of-way, and (3) initial increase and subsequent decrease in rates of soil transfer in individual clearcut and road right-of-way areas. The last two factors cause estimates of management impact of the type shown in Table 1 to vary with length of record. The net effect is to underestimate initial impacts of management. These problems may be overcome with an accounting system that uses units of cumulative area per unit time (CAT units) such as hectare-years for clearcuttings and roads of different age classes. Rather than dividing total volume of soil transferred by (1) the area in each land-use class at the end of the record and (2) the period of record in years, the denominator should be CAT units, such as cumulative ha-yr in clearcuttings 0 to 5 years old. Such a system appropriately considers rates of soil transfer in clearcuttings and roads of different ages. The difficulty is that a full management history is required.

Limitations of these assessments of management impacts on debris-avalanche erosion over several rotations are (1) failure to account for the importance of major, natural, episodic forest disturbances, such as wildfire, in many ecosystems, and (2) the possibility that documented short-term increase in debris-avalanche erosion after clearcutting is simply because of changes in timing of erosion with no change in long-term erosion rate. Perhaps the 10- to 15-year increase after cutting is followed by an extended period of debris-avalanche occurrence significantly below the rate observed in areas of older, established vegetation usually used in determining a reference "natural" or undisturbed rate. If this is true, alteration of processes--such as surface erosion, creep, and root throw which slowly reload sites prone to fail by debris avalanching--may be the most significant effect of management on increases of soil erosion on the time scale of centuries.

CONCLUSIONS

Inventory of debris avalanches through a period of forest-management activity provides a means of assessing impacts on erosion. Results of inventories in steep forest land of the Pacific Rim indicate that clearcutting generally causes several-fold increases in debris-avalanche erosion over 10- to 20-year periods after cutting, and roads have a much higher impact in the relatively small area they affect. Very steep, highly dissected terrain has much higher frequency of debris-avalanche occurrence, but the small average volume of events results in soil transfer rates similar to other areas studied. A series of factors limit the usefulness of interpretations of inventory data on debris avalanches, but some of these problems can be overcome with improved data analysis.

ACKNOWLEDGMENTS

This work was supported by the USDA Forest Service--Siuslaw National Forest and the Pacific Northwest Forest and Range Experiment Station. We thank George Bush and Dave Heller for assistance throughout the project.

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TABLE 1. Frequency, average volume, and soil transfer rate of debris avalanches under forested, clearcut, and road right-of-way conditions in Mapleton land type 47, Siuslaw National Forest (Swanson et al., 1977; Ketcheson, 1978); H. J. Andrews Experimental Forest (Swanson and Dyrness, 1975); Alder Creek, Willamette National Forest, Oregon (Morrison, 1975); Stequaleho Creek, Olympic Peninsula, Washington (Fiksdal, 1974); selected drainages in the Coast Mountains, British Columbia (O'Loughlin, 1972, and personal communication); and Notown, Westland, New Zealand (O'Loughlin and Gage, 1975 cited in O'Loughlin and Pearce, 1976). Shown in parentheses is the factor by which each value exceeds the comparable value for forest conditions.

Site	Period of record (yr)	Frequency (events km^{-2} yr^{-1})	Average volume (m^3)	Soil transfer rate (m^3 km^{-2} yr^{-1})
Forest				
Mapleton (land type 47)				
Swanson et al.	15	0.533	54	28
Ketcheson	15	0.432	25	11
H. J. Andrews	25	0.025	1,460	36
Alder Creek	25	0.023	1,990	45
Stequaleho Creek	84	0.015	4,660	72
Coast Mtns., B.C.	32	0.004	3,040	11
Notown, N.Z. (estimates)		0.2	500	100
Clearcut				
Mapleton (land type 47)				
Swanson et al.	10	1.03 (1.9)	110 (2.0)	111 (4.0)
Ketcheson	15	1.50 (3.5)	34 (1.4)	130 (12)
H. J. Andrews	25	0.097 (3.9)	1,340 (0.9)	132 (3.7)
Alder Creek	15	0.267 (12)	440 (0.2)	117 (2.6)
Stequaleho Creek	6	0	—	—
Coast Mtns., B.C.	32	0.021 (5.2)	1,150 (0.4)	24 (2.2)
Notown, N.Z.	4	4.1 (20)	540 (1.1)	2,200 (22)
Road right-of-way				
Mapleton (land type 47)				
Swanson et al.	15	8.23 (15)	425 (7.9)	3,500 (125)
H. J. Andrews	25	1.38 (55)	1,380 (0.95)	1,770 (49)
Alder Creek	15	8.33 (360)	1,870 (0.94)	15,600 (350)
Stequaleho Creek	6	19.8 (1300)	560 (0.12)	11,800 (160)
Coast Mtns., B.C.	32	0.88 (220)	3,530 (1.2)	282 (26)