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Effects of Landslide Erosion on Subsequent Douglas-fir Growth and Stocking Levels in the Western Cascades, Oregon

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ABSTRACT

Shallow, rapid landslides are common events in steep terrain of the Pacific Northwest. The effect of landslides on timber growth potential of forest land was estimated by examining a 30-yr history of clearcutting and landsliding in the western Oregon Cascades. The height growth of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] and stocking level of all commercial conifer species on naturally regenerated landslides were compared with the height growth and stocking level on nearby, artificially regenerated clearcut units of similar aspect, elevation, ages, and slope position. Average height growth of Douglas-fir trees 5 to 18 years old on the landslides was reduced 62% compared to trees on clearcuts, and the average stocking level was reduced 25% from the clearcut level. One-third of the landslide area was estimated to be nonstockable because of unstable or impenetrable substrate.

Additional Index Words: **forest productivity, soil disturbance, stocking potential.**

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SHALLOW, rapid soil mass movements, here called *landslides*, are common events and primary sources of sediment in steep terrain of the Pacific Northwest (Swanston and Swanson, 1976; Megahan et al., 1978). Land management activities can significantly accelerate the rate of occurrence of landslides (Dyrness, 1967; O'Loughlin, 1972; Swanson and Dyrness, 1975; Swanston and Swanson, 1976; Megahan et al., 1978). The most dramatic cause of accelerated landslide erosion in the Pacific Northwest is road-building, though clearcutting and slashburning can also significantly increase landslide incidence (Dyrness, 1967; O'Loughlin, 1972; Swanson and Dyrness, 1975; Swanston and Swanson, 1976).

Landsliding has a variety of negative effects on natural resources and property (Megahan et al., 1978; Swanson and Dyrness, 1975). These impacts include on-site damages to standing timber, site productivity, and roads, and off-site impacts such as clogging down-stream culverts, damage to aquatic habitat, sedimentation of reservoirs, and degradation of water quality.

The purpose of this study was to estimate potential decreases of forest productivity caused by landslides. This was done by comparing stocking levels and growth rate of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] on landslide scars of various ages with similarly aged trees in nearby clearcut units not on landslide sites. This study was restricted to landslides and clearcuts of up to 28 yr old, because inventoried landslides and clearcutting in the study area span that period only.

Several authors have examined vegetation development on landslide scars, including work in the Great Smoky Mountains (Bogucki, 1976), New Hampshire (Flaccus, 1959), Virginia (Hupp, 1982), New Zealand (Mark et al., 1964; Johnson, 1976), and Chile (Veblen and Ashton, 1978). Most of this work centered on plant succession, with no direct measurements of forest productivity. Flaccus (1959) measured the changes in tree species frequency and density on landslide scars of different ages to determine successional stages. Mark et al. (1964) compared tree basal areas of mature undisturbed forests with stands on landslide scars 15 to 78 yr old. Veblen and Ashton (1978) compared basal areas of trees on earthquake-triggered landslides with basal areas in the adjacent forest to describe species dominance and successional development.

METHODS

The site for the study was the H. J. Andrews Experimental Forest and the adjacent upper Blue River drainage of the Willamette National Forest in the western Cascades, about 80 km east of Eugene, OR. Elevation ranges between 450 and 1630 m, and the vegetation is dominated by Douglas-fir, with varying amounts of western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], and western red cedar (*Thuja plicata* Donn.). Average annual precipitation totals approximately 2400 mm, falling primarily as rain. Geology of the area includes volcanoclastic rocks and lava flows (Swanson and James, 1975). A network of access roads covers about 3% of the area, and timber harvesting has occurred on approximately 20% of the area, primarily as clearcut harvest units. Inventories of 257 landslides occurring in the 12 300 ha area since 1946 (Dyrness, 1967; Swanson and Dyrness, 1975, and Marion, 1981) provided a basis for selecting sites for forest productivity comparisons.

A random sample of 25 landslides was taken from the 257 inventoried landslides. Sampled landslides were primarily debris-avalanches, and ranged in surface area (horizontal projection) from 36 to 1287 m^2, elevation 460 to 1100 m, and age 6 to 28 yr (Table 1). A grid system established on each of the sampled landslides was used to locate 20 circular plots in an even distribution over the landslide surface. Where the landslide debris was deposited immediately downslope from the landslide scar, both areas were sampled. On each circular plot (radius = 2.27 m) stocking level was determined by the stocked-quadrat method (Haig, 1931). Where 20 plots would not fit on the landslide without overlap, the number of plots was reduced accordingly.

A clearcut harvest unit was located wherever possible within 1.5 km of each sampled landslide, on a similar aspect, elevation, slope position, and topographic feature. These nearby artificially regenerated clearcuts were used as a reference for comparison with tree growth and stocking levels on naturally regenerated landslides. No purely naturally regenerated clearcuts were present in the study area. Plots were estalished in the clearcut using the same procedure used for landslides, with all plots at least 10 m removed from the nearby landslide. Total age of the oldest post-disturbance

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Table 1—Sampled landslide-clearcut pairs site, tree growth, and stocking data.

Landslide age	Site type†	Elevation	Aspect	Slope	Landslide map area	Tree age	Landslide 5-yr ht. growth	Landslide (S)‡	Landslide Stocking	Clearcut 5-yr ht. growth	Clearcut (S)‡	Clearcut Stocking
yr		m	°	%	m²	yr	cm		%	cm		%
6	RF	850	335	74	105	§	§		29	¶		¶
9	RF	550	000	80	312	§	§		0	¶		¶
10	FO	790	350	100	237	§	§		0	¶		¶
11	RF	670	165	75	193	§	§		0	¶		¶
11	RF	1100	180	52	177	5	53.6	(20.5)	100	60.1	(13.6)	50
11	FO	760	350	173	36	6	33.5	(11.7)	17	¶		¶
11	RF	730	335	67	942	9	132.9	(92.6)	80	262.1	(49.8)	73
11	CC	730	015	70	550	10	97.9	(75.8)	95	225.9	(55.5)	90
11	FO	790	190	70	858	10	123.0	(41.2)	100	¶		¶
12	CC	820	010	79	79	§	§		54	¶		¶
14	RF	750	150	85	318	10	171.6	(54.4)	80	¶		¶
16	FO	670	235	80	145	§	§		14	¶		¶
16	RF	720	010	82	563	10	183.6	(55.2)	100	258.0	(59.7)	100
16	FO	760	100	57	325	11	67.4	(29.0)	88	236.4	(47.3)	77
16	RF	760	170	50	500	12	52.9	(35.5)	100	357.5	(112.4)	55
16	RF	580	130	85	1115	13	42.3	(31.2)	10	311.5	(81.3)	75
17	RC	730	130	40	452	11	75.9	(31.2)	80	164.5	(85.5)	100
17	CC	760	245	78	512	14	279.2	(66.4)	55	298.2	(58.5)	55
17	CC	910	130	50	236	14	338.9	(50.7)	50	348.5	(81.7)	90
18	RC	560	240	50	373	18	383.0	(141.2)	80	407.5	(85.8)	82
19	RF	490	090	70	1065	13	150.1	(70.7)	100	342.0	(55.9)	95
24	CC	690	280	80	1287	15	126.8	(81.2)	45	237.4	(88.9)	100
24	RF	760	020	70	307	18	417.3	(80.7)	80	395.4	(95.0)	100
26	CC	690	105	85	192	15	203.8	(94.6)	70	302.5	(97.1)	92
28	RF	460	110	70	586	9	81.3	(50.5)	30	158.9	(49.4)	100

† RF = roadfill, RC = roadcut, CC = clearcut, FO = forest.
‡ Standard deviation of height growth.
§ Landslide trees too young (less than 5 years old) or not Douglas-fir.
¶ No landslide trees measured, or no clearcuts suitable for comparison.

trees was determined for each landslide and clearcut pair. Growth measurements were made on trees of the oldest age that a clearcut-landslide pair had in common. For example, if the oldest trees on a clearcut were 20 yr old, and the oldest trees on a landslide were 18 yr old, growth was measured when both sets of trees were 18 yr old. Total tree age was determined by boring or cutting at soil level.

Height growth of one Douglas-fir seedling or sapling located within each plot was measured when plants were at least 5 yr old and relatively undamaged by disease or animals. Where several Douglas-fir seedlings occurred within the plot, a dominant or codominant individual was measured. To average growth years, height growth was measured as the total of the 5 yr of growth preceding the total age.

At each plot the number of established conifer seedlings of commercial species (Douglas-fir, western hemlock, western red cedar, and Pacific silver fir [*Abies amabilis* (Dougl.) Forbes] was recorded. To be considered established, the tree had to be at least 2 yr old and apparently healthy. All plant species occurring on each plot were recorded. Each plot was subjectively classified into one of four stocking-potential classes, based primarily on presence or absence of established seedlings, and on substrate conditions, especially stability and presence of soil or other suitable rooting medium. If any portion of a plot could have been classified into a more favorable category, the whole plot was so classified, since a seedling established anywhere on a plot stocks the plot. Stocking potential classes used were: (i) stocked plot—contained at least one established seedling of a commercial conifer species; (ii) unstocked plot, stockable—a commercial conifer seedling could become established naturally or artificially, and would have a reasonable chance for survival under standard management practices, soil rooting medium present and apparently stable; (iii) unstocked plot, marginally stockable—potential for natural or artificial establishment, but seedlings would have a poor chance for survival under standard managment practices, shallow or stony rooting medium and/or moderately unstable substrate; and (iv) unstocked plot, unstockable—seedling establishment and survival unlikely under standard management practices, rooting medium absent and/or extremely unstable substrate.

Each plot was also classified into substrate type and condition groups, including erosional, angle of repose, bedrock, secondary accumulation, and primary depositional areas. The erosional class included those areas of the landslide scar experiencing a significant net loss of substrate material caused by surface erosion following initial landsliding. The angle of repose class included steep sections of the landslide scar through which erosional material may move, but would not experience major net loss or gain of material. The secondary accumulation areas included those in which post-landslide erosional materials are deposited. The primary depositional areas were those which received the original landslide debris, but do not receive secondary accumulations of erosional material. General site data were also obtained, including slope gradient, aspect, elevation, and size, type, and age of landslide (Table 1).

RESULTS

Douglas-fir height, present conifer stocking level, and stocking potential were compared between recent landslide surfaces and nearby clearcuts. Douglas-fir seedlings old enough to be measured for height growth occurred on 19 of the 25 landslides sampled. Clearcut units comparable to the landslides were located near 16 of the 25 landslides. Landslides sampled ranged in age from 6 to 28 yr (Table 1).

Five-year height growth measurements were made for ages ranging from 5 to 18 yr. Average age for trees in clearcuts and landslides was 12 yr, excluding unpaired landslide data. Average annual height growth for trees on clearcuts sampled, 54.6 cm, was significantly greater ($P < 0.005$, paired t-test) than that of trees on landslides, 33.6 cm. In comparisons of height growth of seedlings between individual landslide-

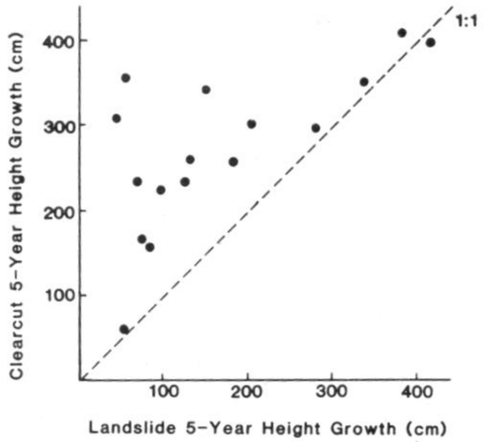

Fig. 1—Comparison of Douglas-fir average height growth among landslide-clearcut pairs.

clearcut pairs, the 5-yr growth of trees in clearcuts exceeded that of trees on landslides in all but one pair ($N = 16$) (Fig. 1). Individual regression lines relating 5-yr height growth with tree age were calculated for trees in clearcuts and for trees on landslides (Fig. 2). For clearcuts $Y = -5.52 + 22.6X$ ($R^2 = 0.70$, $s_y = 2803$, $n = 16$), and for landslides $Y = -159.0 + 26.6X$ ($R^2 = 0.54$, $s_y = 7443$, $n = 16$), where $Y =$ 5-yr height growth and $X =$ tree age. Tests for equal slope revealed no significant differences between landslide and clearcut regression lines ($P = 0.61$). Tests for common intercepts revealed highly significant differences between the regression lines ($P = 0.001$).

Information on stocking potential was recorded on 262 clearcut plots and 472 landslide plots. Eighty-two percent of plots on clearcuts were stocked, with an additional 17% stockable, while only 62% of the plots on landslides were stocked, with another 7% stockable (Table 2). Stocking levels on clearcuts ranged from 50 to 100%; on landslides stocking ranged from 0 to 100%, with 36% of the landslides less than 50% stocked. Distribution of landslide and clearcut units in stocking classes are expressed in percentages in Fig. 3 because of unequal number of clearcuts, and landslides. In addition to low stocking on some landslides, landslides also had a wider range in average tree densities (0–33.1 trees per plot), compared to clearcuts (0.6–8.2 trees per plot).

Table 2—Average proportion of landslide and clearcut area in four stocking potential classes.

Stocking potential classes	Area in class: Clearcut†	Area in class: Landslide‡
	%	%
Stocked	82	62
Unstocked		
Stockable	17	7
Marginally stockable	0	24
Unstockable	1	7

† $n = 262$.
‡ $n = 472$.

Table 3—Proportion of landslide area and stocking levels in five substrate source and condition groups.

Substrate source and condition group	Area†	Stocking average
	%	%
Erosion	11.4	31.5
Angle of repose	63.8	61.5
Bedrock	4.5	14.3
Secondary accumulation	6.1	89.7
Primary deposition	14.2	91.0

† 472 plots on 25 landslides.

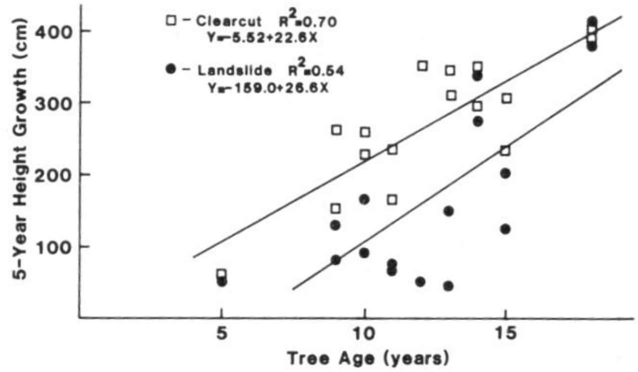

Fig. 2—Relationship between sapling age and height growth for trees on landslides and clearcuts.

The erosional zone of substrate type and condition groups of the scour zone (erosion, angle of repose, bedrock) constituted a larger proportion of the landslide surface (79.7%) than did those of the depositional zone (primary deposition and secondary accumulation) (20.3%). Stocking level was higher in the depositional zone Table 3).

DISCUSSION

Landslides on forest land in the western Cascades of Oregon caused (i) reduced Douglas-fir height growth over the 5- to 18-yr range of ages sampled, (ii) decreased stocking levels, and (iii) decreased stocking potential.

Growth rate of trees on landslides was lowest on the scour zone and highest on the depositional zone. This agrees with Bogucki's (1976) observation that revegatation was most advanced in the depositional zone. Mark (1964) observed more advanced forest vegetation development on debris fans than on slipfaces of landslides he examined in New Zealand. Average depositional area in this study was 14.2% of the total landslide area. Depositional areas are small primarily because much transported material moves di-

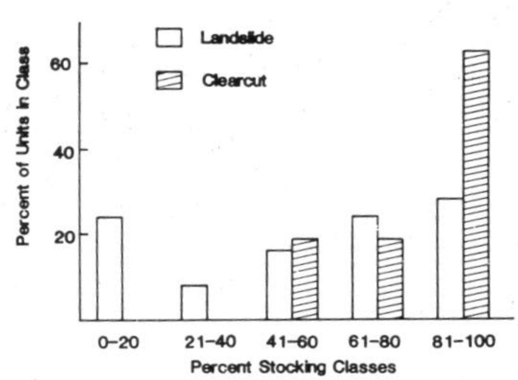

Fig. 3—Distribution of landslide and clearcut units in five stocking classes.

rectly into stream channels, because many slides occur at the head of incipient drainages. Areas covered by original landslide deposits may have been underestimated because of relatively quick revegetation of thin deposits.

A slow recovery trend of height growth rate of trees on landslides relative to those on clearcuts is expected, possibly within the period of one timber rotation, and certainly on the time scale of soil development. The limited time scale available in the documented history of landslides and young stands created by clearcutting which serve as controls in the study area, and limited sample size, prevented detection of a significant recovery trend as evidenced by no significant difference in slopes (Fig. 2). Apparent recovery of tree growth on landslide sites can be expected because of vegetation competition and modification of soil on landslide area. Although landslide areas may be harsh environments for seedling establishment and early growth, saplings may be subject to less competition from other trees, brush, and herbaceous vegetation, than in young Douglas-fir stands which support higher average stocking levels, greater canopy cover, and taller vegetation. The older clearcuts used as controls in this study, for example, have reached the age of precommercial thinning because growth of individual trees in suppressed by overstocking.

Development of vegetation on landslides and movement of soil and organic matter from adjacent areas can improve the suitability of the landslide scar for support of Douglas-fir growth. Veblen and Ashton (1978) concluded that, on the landslides they studied, since the dominant trees were established at the same time as the shrubs, herbs, and cryptogams, the trees were not dependent on prior modification of the site for their establishment, but that the development of other vegetation probably increased the rate of stand growth. Nitrogen fixation by symbiotic and free-living organisms can increase the nutrient supply of the site. Red alder (*Alnus rubra*), a symbiotic nitrogen-fixing plant, was the second leading pioneer species of over 140 species sampled on landslides in this study. Vegetation contributes organic matter to soils on landslide scars, increasing nutrient availability and retention capacity. Landslide scars are incised into the surrounding soil mass, allowing sloughing of soil, including organic matter, nutrients, and inoculum of mycorrhizae, onto the landslide surface. These effects would be more important on smaller landslides which have a higher perimeter/area ratio, and Douglas-fir height growth rate appears particularly suppressed on the few sampled landslides larger than 600 m^2. Another possible effect of landslide size is the greater thickness of soil removed by larger landslides, exposing less weathered, nutrient deficient subsoil or bedrock.

Comparing height growth and stocking level of naturally regenerated trees on landslides with artificially regenerated trees on clearcuts introduces an unquantified source of error. Specially selected seed sources may have improved growth rates of artificially propagated seedlings; however, this technique was uncommon in the 1960s when most of the measured trees were established, and detection of improved growth rates is unlikely for the young trees measured. Natural local seed sources that produced the stands on landslides are more likely to be adapted to local site conditions than are artificially selected seed sources. Transplant shock experienced by artificially propagated seedlings may also reduce the growth rate of young trees on clearcuts compared to naturally established trees on landslides. All sampled clearcuts contained a mixture of natural and planted stock, which were virtually indistinguishable at the time of sampling.

The ages of the trees measured (5–18 yr old) differ from the ages of the landslides on which they are growing (5–28 yr old) because of delay in natural regeneration on many of the landslides. A period of physical stabilization of potential sites for establishment, and possibly erratic production of conifer seed may have caused this delay. The problem of seed availability can be eliminated by standard artificial regeneration practices, but stabilization of landslide surfaces and their revegetation is difficult to accelerate artificially.

To estimate the stocking that would result from the artificial regeneration of landslide areas, a stocking potential was calculated. More than 99% of the clearcut area was either stockable or stocked. The operational stocking success rate, 82.4%, was considered the measured stocking on the clearcut units. To estimate the average potentially stockable percent of landslide areas, the existing stocked area, 61.9%, was added to the potentially stockable, 7.2%, plus one half of the marginally stockable, 11.8%. Fifty percent is the authors' estimate of the potential stocking of marginally stockable areas. The total stockable percent, 80.8%, was then multiplied by the operational stocking rate, for a total potential stocking of the landslides of 66.6%.

Results of this study can be extended to other regions only after consideration of differences in landslide size, frequency, and depth, soil characteristics, climate, geology, and revegetation tree species. Landslide size is important because soil sloughing from edges of scars, organic matter additions by litter fall, shading from adjacent vegetation, and size effect on depth of sliding favor recovery of small landslide areas. In areas characterized by very small slides, such as the southern Coast range of Oregon (Swanson et al., 1981), trees rooted in adjacent soil may use much of the canopy space over most landslide scars. Soil depth and bedrock characteristics affect the suitability of substrates remaining after landsliding for support of tree growth. Interactions among soils, vegetation, bedrock, and climate determine long-term stability of landslide sites, which affects the reestablishment of vegetation. Characteristics of tree species influence potential for reforestation of sites disturbed by landslides. Douglas-fir was the leading pioneer species of over 140 species sampled on landslides in this study, and is the preferred commercial species. In areas where prime commercial species are not well adapted for establishment on bare mineral soil, decline in timber production on landslide areas would be greater.

The main effects of landslides on forest timber productivity appear to be reduced height of trees and a reduction in the proportion of area occupied by trees. To estimate the overall impact of landsliding on the timber resource, a determination of the areal extent of the landsliding problem is required, as well as information on growth reductions on the time scale of at least one rotation. Clearcutting and known landslide histories for the study area span about 30 yr, about one-third of a rotation. Therefore, a complete analysis of landslide effects on timber production is not possible.

Future landsliding could be estimated based on road and clearcut landslide rates per unit area of individual soil/landform inventory units calculated using data on past landslides. These estimates could then be projected into the future, based on harvest and road building plans on those soil/landform units. Adjustments for altered forest practices could be incorporated into this model. Once future landsliding has been estimated, effects on timber production could be predicted using careful extrapolation of methods and data developed in this study.

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