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Title: Impact of Landslide Erosion on Tree Growth and Vegetation in the Western Oregon Cascades

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Shallow, rapid soil mass movements are common events and primary sources of sediment in steep terrain of the Pacific Northwest. Poorly vegetated debris deposits and scars resulting from landslides remove land from the productive timber base, and are subject to continuing erosion. To examine the impact of these events on the timber growth potential of forest land, height growth of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) and stocking level of all commercial conifer species on landslides in the western Oregon Cascades were compared with height growth and stocking level on adjacent clearcut units of similar aspect, elevation, ages, and slope position. Cumulative height growth of Douglas-fir trees 18 years old on the landslides was reduced 38% compared to trees on clearcuts, and the stocking level was reduced to 75% of the clearcut level. One-third of the landslide area was estimated to be non-stockable because of unstable or impenetrable substrate. Calculations combining height growth and stocking level estimate a reduction of 40% in wood volume grown on landslides compared to clearcuts, when trees are

18 years old.

The persistence of unvegetated landslide scars and deposits was examined by sampling established vegetation on a chronosequence of landslides 6-28 years old in the western Oregon Cascades. Average vegetation cover for all landslides was 51%, ranging from 7-88%. No discernible trend in vegetation cover or species composition over time was detected. Variations in landslide distribution and topography resulted in a wide range of plant microhabitats, with 140 species identified. The combinations of wet-site, bare mineral soil, and droughty bedrock habitats disguised overall landslide vegetation recovery trends.

Impact of Landslide Erosion on Tree Growth and Vegetation in the Western Oregon Cascades

by

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CHAPTER I

INTRODUCTION

The steep, highly dissected terrain of the Pacific Northwest contains some of the most productive forest lands in the United States. Land management activities can be difficult, and poor management can have severe impacts on resources, productivity, and property. Shallow, rapid soil mass movements (landslides) are a major concern of land managers in the Pacific Northwest because they are common, major sources of sediment in steep forest land (Swanston and Swanson, 1976; Megahan et al., 1978). Land management activities, particularily road building, clearcutting, and slash burning can significantly accelerate the rate of occurrence of soil mass movements (Dyrness, 1967; O'Loughlin, 1972; Swanson and Dyrness, 1975; Swanston and Swanson, 1976; Megahan et al., 1978).

The negative impacts caused by shallow, rapid soil mass movements include on-site damages to standing timber, site productivity, and roads, and off-site impacts of clogging of downstream culverts, damage to aquatic habitat, sedimentation of reservoirs, and degradation of water quality. These damages occur principally from the original landslide event, but may continue if landslide scars and deposits remain unstable and exposed to subsequent additional erosion.

Quantification of the damages caused by landsliding can allow land management organizations to evaluate the cost-effectiveness of management practices designed to reduce landslide frequency. The purpose of this study was to examine the magnitude and duration of changes in forest productivity caused by landsliding in the western Oregon Cascades. This was accomplished by sampling the vegetation developing on a chronosequence of landslides 6-28 years old.

Elsewhere, several authors have examined vegetation development on landslide scars, with some implications for productivity changes, including work in the Great Smokey Mountains (Bugucki, 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 to mature undisturbed forests with stands on landslide scars 15 to 78 years old. Veblen and Aston (1978) compared basal areas of trees on earthquake-triggered landslides with basal areas in the adjacent forest to describe species dominance and successional development.

To more directly quantify potential decreases of forest productivity caused by landslides in the Oregon Cascades, stocking levels and growth rates of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) on landslide scars were compared with similarly aged trees in adjacent clearcut units not on landslide sites. Also, vegetation cover and species composition were measured.

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, Oregon. The elevation ranges between 450 and 1630 m, and the sites are in the western hemlock (Tsuga heterophylla (Raf.) Sarg.) zone of the Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) region (Franklin and Dyrness, 1973). The overstory of mature forests is dominated by Douglas-fir, with varying amounts of western hemlock and western red cedar (Thuja plicata Donn.). Average annual precipitation totals approximately 2400 mm, primarily as rain. Geology of the area includes volcano-clastic rocks, and unaltered lava flows (Swanson and James, 1975). The area is covered with a network of access roads covering 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[3]) provided a basis for selecting sites for forest productivity comparisons.

The portion of this study dealing with Douglas-fir growth rate and conifer stocking level is presented in Chapter II. Those portions pertaining to vegetation cover, species composition, and plant succession are in Chapter III.

CHAPTER II

IMPACT OF LANDSLIDE EROSION ON SUBSEQUENT DOUGLAS-FIR GROWTH AND STOCKING LEVELS IN THE WESTERN OREGON CASCADES[1]

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ABSTRACT

Shallow, rapid soil mass movements are common events and primary sources of sediment in steep terrain of the Pacific Northwest. To examine the impact of these events on the timber growth potential of forest land, the height growth of Douglas-fir (<u>Pseudotsuga</u> <u>menziesii</u> (Mirb.) Franco) and stocking level of all commercial conifer species on landslides in the western Oregon Cascades were compared with the height growth and stocking level on adjacent clearcut units of similar aspect, elevation, ages, and slope position. Cumulative height growth of Douglas-fir trees 18 years old on the landslides was reduced 38% compared to trees on clearcuts, and the stocking level was reduced to 75% of the clearcut level. One-third of the landslide area was estimated to be non-stockable because of unstable or impenetrable substrate. Calculations combining height growth and stocking level estimate a reduction of 40% in wood volume grown on landslides compared to clearcuts, when trees are 18 years old.

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INTRODUCTION

Shallow, rapid soil mass movements 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 soil mass movements (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 roadbuilding, though clearcutting and slash burning can also cause significant increases in 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 of clogging of downstream 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 rapid landslides. This was done by comparing stocking levels and growth rates of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) on landslide scars of various ages with similarly aged trees in adjacent clearcut units not on landslide sites.

Several authors have examined vegetation development on landslide scars, with some implications for productivity changes, including work in the Great Smoky Mountains (Bugucki, 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 years 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, Oregon. The elevations range 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, primarily as rain. Geology of the area includes volcanoclastic rocks, and unaltered lava flows (Swanson and James, 1975). The area is covered with a network of access roads covering 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[3]) 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 size from 36-1287 m^2, elevation 460-1100 m, and age 6-28 years (Table 1). A grid system established on each of the sampled landslides was used to locate 20 plots in an even distribution over the landslide surface. Where the landslide debris was deposited immediately down 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, and slope position. These adjacent, artificially regenerated clearcuts

3/Marion, Daniel A. 1981. Landslide occurrence in the Blue River Drainage, Oregon. M.S. Thesis. Dept. of Geography, Oregon State University, Corvallis.

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

Land-slide age	Site type†	Eleva-tion	Aspect	Slope	Land-slide map area	Growth measure age	Landslide 5-yr ht. growth	Landslide (S)	Landslide Stock-ing	Clearcut 5-yr ht. growth	Clearcut (S)	Clearcut Stock-ing
years		m	degrees	%	m^2	years	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.
‡Landslide trees too young (less than 5 years old) or not Douglas-fir.
#No landslide trees measured, or no clearcuts suitable for comparison.

were used as a reference for comparison with tree growth and stocking levels on landslides. Plots were established in the clearcut using the same procedure as for landslides, with all plots at least 10 m removed from the adjacent landslide. Total age of the oldest common (at least 10 trees) age class of trees was determined for each landslide and adjacent clearcut. The younger of those two ages was used as the tree age at which growth measurements were taken (hereafter called the growth measurement age).

Height growth of one Douglas-fir seedling or sapling located within each plot was measured when plants were at least 5 years old and relatively undamaged by insects, 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 years of growth preceding the growth measurement age. If the majority of the measurable Douglas-fir saplings growing in the landslide and adjacent clearcut were greater than five years old at breast height, the total height and age at breast height were measured for use with the King (1966) site index curves. The King curves were used because only young trees were available for measuring site index. Trees measured for site index were also measured for diameter growth increment for the same ages at which the height growth increment was taken. The diameter increment was measured in two directions if tree stem asymmetry was evident or suspected.

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 two years old and apparently healthy. Each plot was classified into one of four stocking potential classes, defined primarily by presence or absence of established seedlings, and by 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. Stocking potential classes used were: 1) stocked plot -- contained at least one established seedling of a commercial conifer species, 2) 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, 3) unstocked plot, marginally stockable -- potential for natural or artificial establishment, but seedlings would have a poor chance for survival under standard management practices, and 4) unstocked plot, unstockable -- seedling establishment and survival unlikely under standard management practices.

Each plot was also classified into substrate source 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 due to surface erosion since 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.

RESULTS

Douglas-fir height and diameter growth, Douglas-fir site index, present conifer stocking level, and stocking level potential were compared between recent landslide surfaces and adjacent clearcuts. Differences in height growth and stocking levels were also evaluated between different substrates within the landslides. 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 years (Table 1).

Five-year height growth measurements were made for ending tree ages ranging from 5 to 18 years. Average growth measurement age for trees in clearcuts was 12 years, and for the trees on landslides was 11 years. Average annual height growth for the 196 trees on clearcuts sampled, 52.6 cm, was significantly greater ($p<0.005$, non-paired t-test) than that of the 206 landslide trees, 28.6 cm. In comparisons of height growth of seedlings between individual landslide-clearcut pairs, the five-year growth of trees in clearcuts exceeded that of trees on landslides in all but one pair ($n=16$) (Fig. 1). Five year height growth increased with tree age for both trees in clearcuts ($r=0.8462$, $p<0.005$) and for trees on landslides ($r=0.8077$, $p<0.005$). Between ages 5 and 18 years, trees in clearcuts grew at an average rate significantly greater than that of trees on landslides ($p<0.005$) (Fig. 2). The average height growth per year at each age was added together, from 1 year to 18 years, to yield a projected cumulative height at each age (Fig. 3). At age 18, the projected cumulative height of trees on clearcuts was 853 cm, significantly greater than 533 cm for trees on landslides ($p<0.005$).

The average King (1966) site index as estimated from trees on clearcuts was 120 (site class II (McArdle et al., 1920)); it was 110 (site class III (McArdle et al., 1920)) for trees on landslides ($p<0.10$, paired t test). Average diameter growth measurements taken on 76 trees on clearcuts and 23 trees on landslides were not

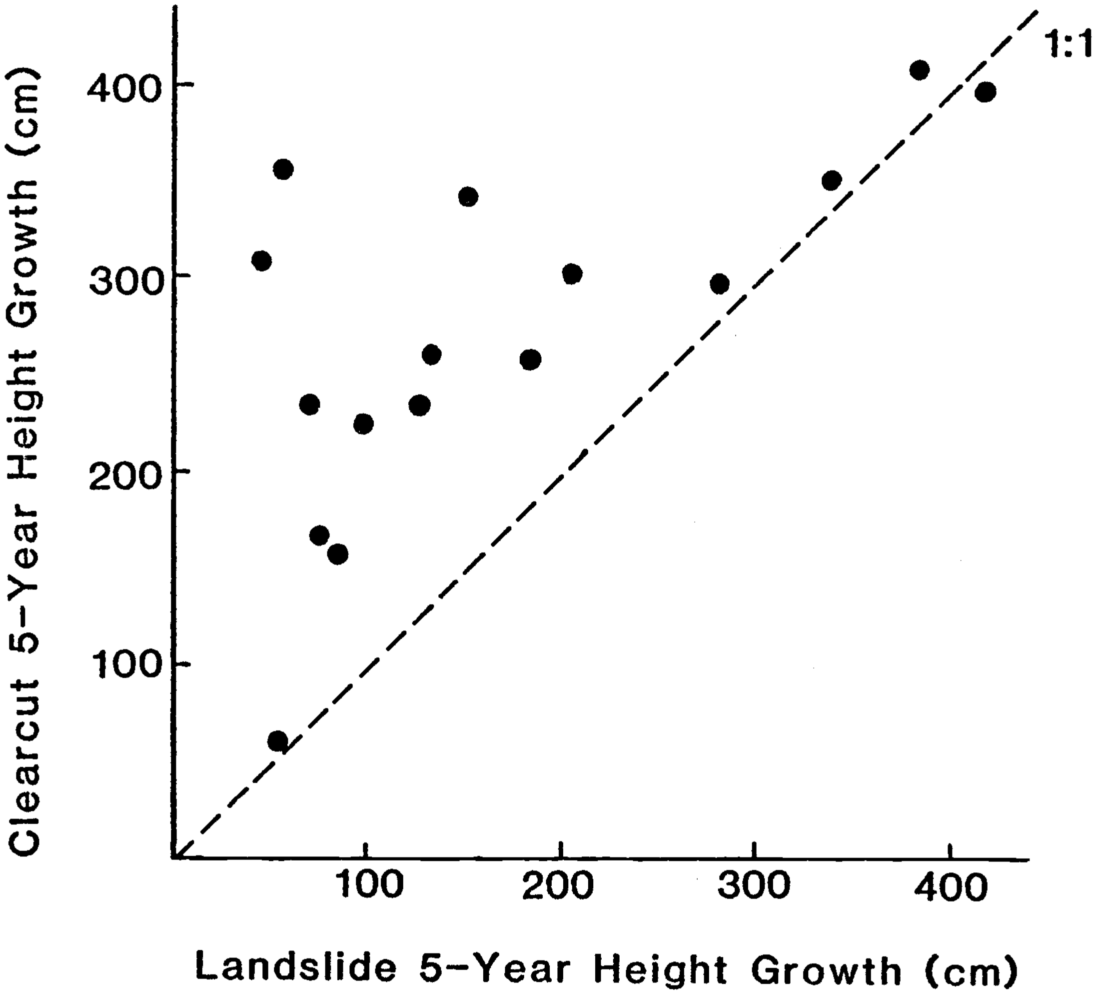

Figure II.1. Comparison of Douglas-fir height growth among landslide-clearcut pairs.

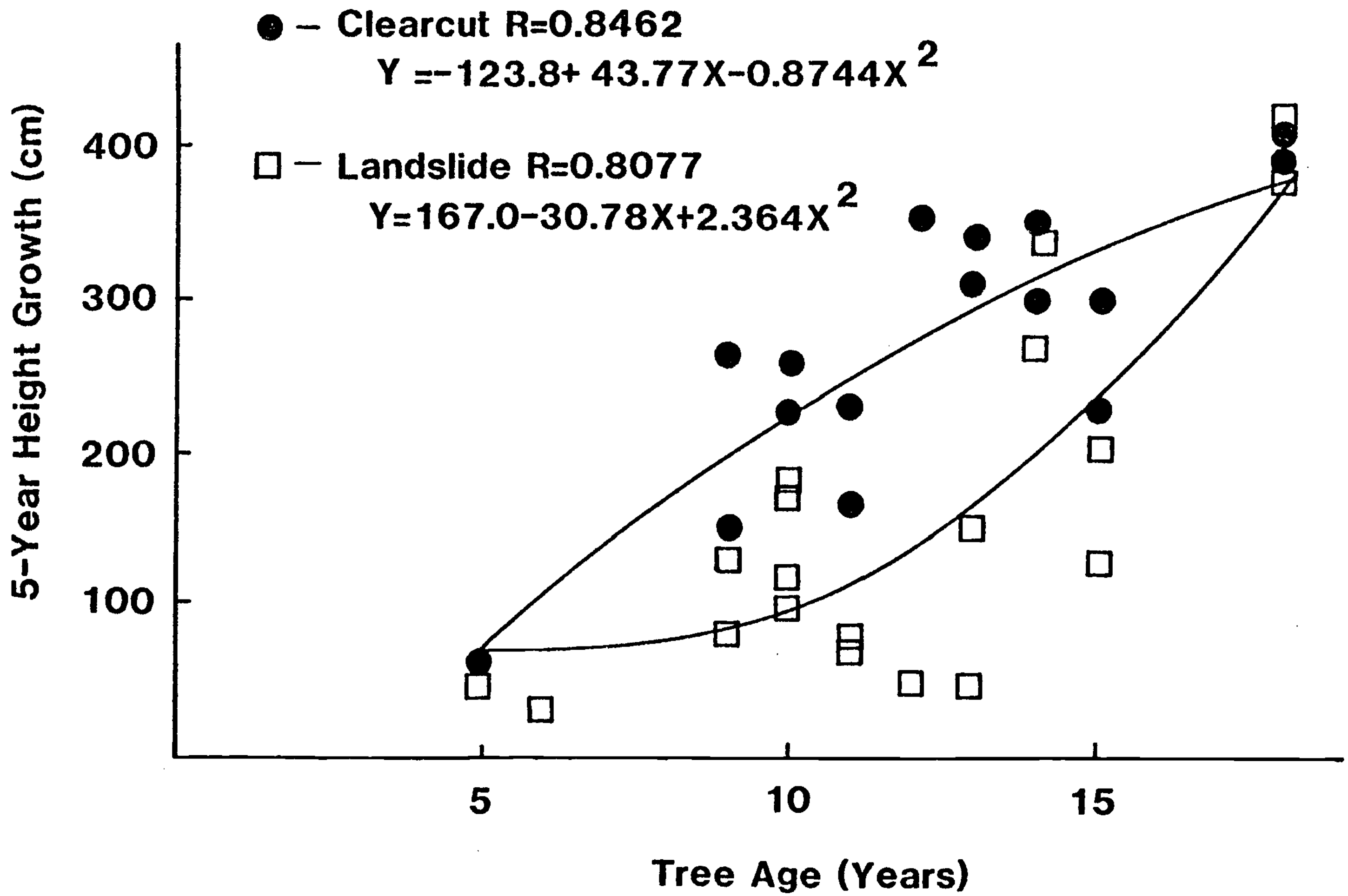

Figure II.2. Relationship between age and height growth for trees on landslides and clearcuts.

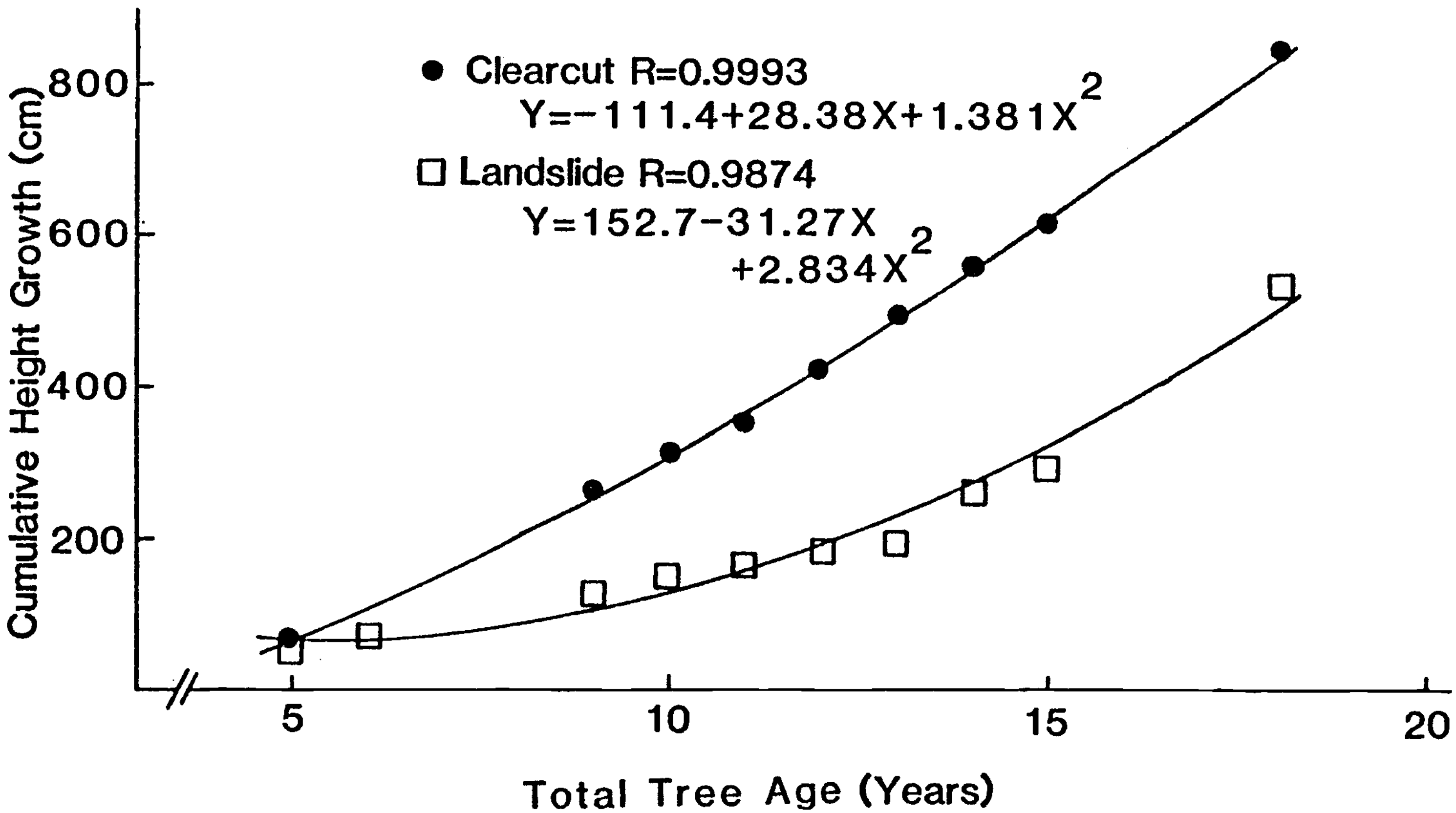

Figure II.3. Increase in cumulative height growth with age for saplings on landslides and clearcuts.

significantly different ($p>0.10$). Possible effects of competition and precommercial thinning on diameter growth were not quantified.

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 50-100%; on landslides stocking ranged from 0-100%, with 36% of the landslides less than 50% stocked (Fig. 4). There was no significant correlation between age of landslides and stocking ($r=-0.1537$, $p>0.10$). In addition to low stocking on some landslides, landslides also had a wider variation in tree densities (0 to 33.1 trees per plot), compared to clearcuts (0.6 to 8.2 trees per plot).

The substrate source and condition groups of the landslide scar area consisted of a larger proportion of the landslide surface (79.7%) than did those of the accumulation and depositional areas (20.3%), and stocking level was much higher in the accumulation and depositional areas (Table 3). Average Douglas-fir height growth on erosional areas, 18 cm/yr, was significantly lower than on depositional areas, 30.7 cm/yr ($p<0.05$), secondary accumulation areas, 33.0 cm/yr ($p<0.10$), and also lower than the average for overall landslide area, 28.6 cm/yr ($p<0.10$). Average height growth of Douglas-fir on depositional areas was not significantly different from that on overall landslide area ($p>0.10$), but was significantly lower than the average height growth on clearcuts, 52.6 cm/yr ($p<0.05$).

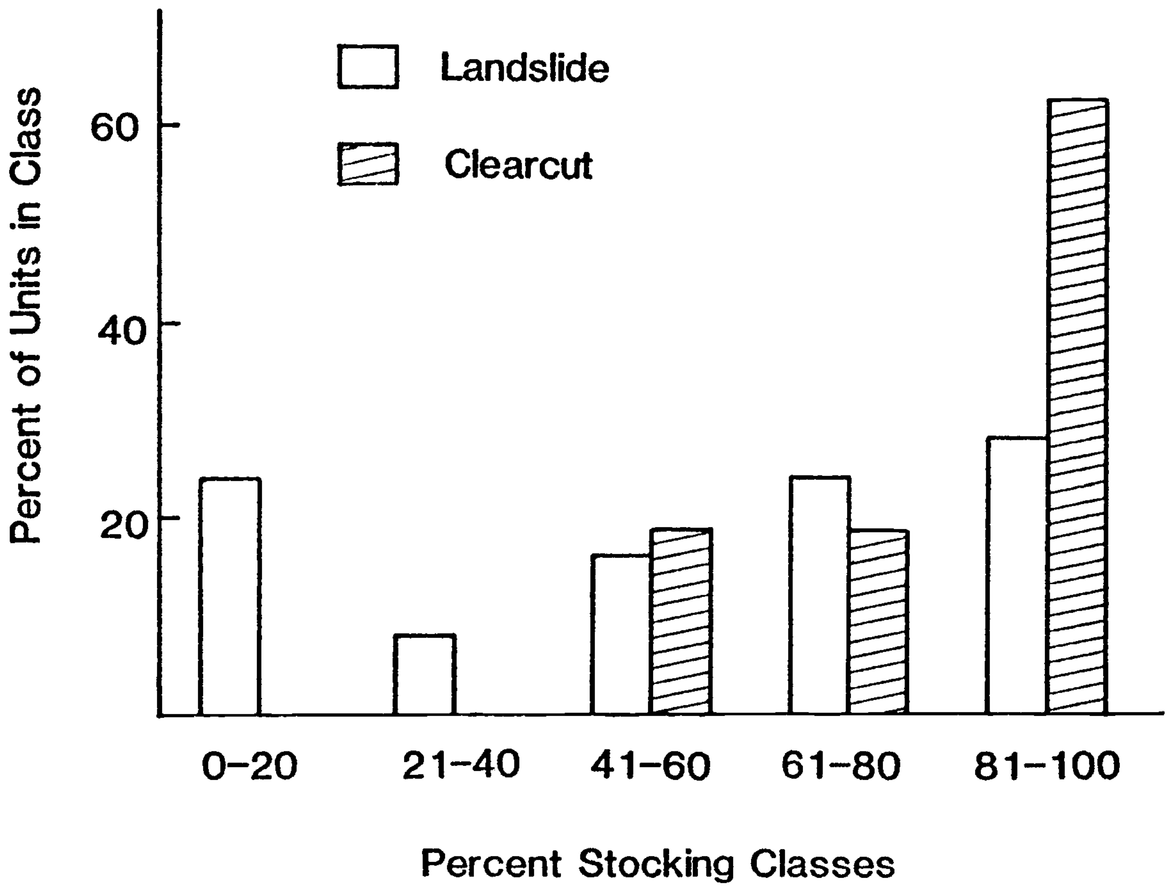

Figure II.4. Proportion of landslide and clearcut units in five stocking classes.

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

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

#n = 262

†n = 472

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

Substrate source and condition group	Area#	Stocking average
	------percent------	
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.

DISCUSSION

Landslides on forest land in the western Cascades of Oregon caused: 1) reduced Douglas-fir height growth rate between the ages of 5 and 18 years, 2) reduced total height of Douglas-fir seedlings from 5 through 18 years old, 3) reduced Douglas-fir site index, 4) decreased stocking levels, and 5) decreased stocking potential.

Reduction in height growth rate appears to be temporary, lasting only until the trees are 18 years old. The recovery of the growth rate at 18 years is apparently balanced by the reduction in total height resulting from the slower growth rate between 5 and 18 years. Total height of 18-year old trees on landslides was 38% less than the height of trees on clearcuts and was equivalent to the height reached 5 years earlier by the trees on clearcuts. These results agree with Wert and Thomas's (1981) work on skid roads which found that trees 14-18 years old were growing at the same rate in skid roads as on undisturbed areas. They suggested that height growth of young seedlings was retarded by physical characteristics of skid roads until a certain age-height combination was reached, when they began to grow at a normal rate. The authors concluded that the reduction in tree volume on skid roads was caused primarily by inadequate seedling survival and delay in seedlings reaching breast height, resulting in low stocking levels and reduced total height.

The recovery of height growth rate at age 18 may be due to low vegetation competition and modification of the soil environment. Although landslide areas may be harsh environments for seedling establishment and early growth, older seedlings may be subject to less competition from other tree seedlings, brush, and herbaceous vegetation, than in clearcut units. This is supported by lower average stocking levels, lower percent canopy cover, and shorter stature of vegetation on landslides than in clearcut units. 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 other vegetation development probably increased the rate of stand growth. Nitrogen fixation by symbiotic and free-living organisms can increase the nutrient supply of the site. Vegetation contributes organic matter to soils on landslide scars, increasing the nutrient retention capacity and improving soil physical properties, including bulk density, structure, and aeration. Landslide scars are cut into the surrounding soil mass, allowing sloughing of soil onto the landslide surface, and additions of organic matter from adjacent vegetation. These effects would be more important on the smaller landslides, and Douglas-fir height growth rate appears particularly suppressed on landslides larger than 600 m^2. Another possible effect of landslide size would be the greater thickness of soil removed by larger landslides, exposing more poorly weathered, nutrient-deficient subsoil or bedrock.

The ages of the trees measured (5-18 years old) differ from the ages of the landslides on which they are growing (5-28 years old) because of delay in natural regeneration on some of the landslides. A period of physical stabilization, and possibly erratic production of conifer seed may have caused this delay. The effect of seed source can be eliminated by standard artificial regeneration practices, but landslide stabilization and revegetation is difficult to accelerate artificially. The difference in seed source between the landslides and clearcuts may also confound the height growth and stocking comparisons. Many of the Douglas-fir seedlings in clearcuts have been artificially propagated from selected seed sources, but most landslide seedlings were naturally seeded from nearby sources.

The reduced growth rate of trees on landslides was not found uniformly throughout the landslides, but was lowest on erosional areas of the landslide scars and highest on the primary depositional areas. This agrees with Bugucki's (1976) observation that revegetation was most advanced in the depositional zone. Mark (1964) divided landslides he studied into slip-faces and debris fans, and found vegetation development more advanced and species composition different on debris fans. Average depositional area in this study was 14.2% of the total landslide area. Depositional areas are small primarily because much transported material moves rapidly downslope into stream channels. Areas covered by original landslide deposits may have been underestimated because of large distances between depositional areas and landslide scars, and relatively quick revegetation of the deposits.

The difference in average site index between trees on landslides and trees in clearcuts was probably greatly underestimated. Trees were measured for site index only if they were at least 5 years old at breast height, regardless of their total age. The result was that on many landslides only the trees growing on the most productive parts were measured, while the stunted trees growing elsewhere were not measured. Also, the landslides which were most productive were over-represented, because the landslides without vigorous trees were not measured for site index.

The low measured stocking rates on landslides are the result not only of unfavorable environmental conditions, but are also the result of dependence on natural regeneration. To estimate the stocking that would result from the artificial regeneration of landslide units, 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%. This stockable percent, 80.8%, was then multiplied by the operational stocking rate, for a total potential stocking of the landslides of 66.6%. This reduction in stocking potential may persist at least through one timber rotation, as indicated by the lack of significant increase in stocking levels with increased landslide age.

The reliance on natural regeneration on landslides has also resulted in the wide range of tree densities measured. To obtain maximum production from the landslides, additional expenditures for thinning and interplanting may be required. Hand planting and thinning of landslides is likely to cost more per unit area than on clearcuts, because of generally poor access, small size, and steeper slopes.

ESTIMATED TIMBER RESOURCE IMPACTS

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 combine these two factors into one parameter, an approximation of the total wood volume per unit land area grown was calculated. Average diameters for clearcut and landslide trees were not significantly different, so the overall average diameter, 8 cm at DBH, was used for volume calculations. The average wood volume per tree was calculated (volume of a cone method) using the average cumulative height growth at 18 years for the clearcut and landslide trees (853 cm and 532.5 cm, respectively). The wood volume per tree was then multiplied by the average number of trees per hectare (stocking level multiplied by 618 trees per hectare when 100% stocked, codominant and subdominant trees on plots excluded), to yield a wood volume grown per hectare. The calculated wood volume on the clearcut was 10 m^3/ha and 6 m^3/ha on the landslide when present stocking level was used in the calculation, and 7 m^3/ha when stocking potential was used.

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. Following is an example of such an estimate using this data in a 6,000 ha area of the upper Blue River drainage which has been managed using procedures standard for National Forest lands of the Pacific Northwest. If the rate of growth is assumed to remain the same for the rest of an eighty-year rotation as it was for the first 18 years (for comparison purposes only), total production on clearcuts is 45 m^3/ha. The data indicate that height growth rates of trees on landslides recover at 18 years and are assumed to continue growing at the clearcut rate, but stocking will remain 23% less than the clearcut level. The calculated total wood volume growth for an eighty- year rotation on an average landslide is 33 m^3/ha, a reduction of 27% of wood volume growth on landslides compared to growth on clearcuts. If past rates of landsliding per unit area of road and clearcut continue, with 1.25% of the area clearcut per year for an eighty-year rotation, and assuming accelerated landsliding rates return to undisturbed forest levels 15 years after clearcutting, 1.6% of the watershed will be landslides. The total impact on a watershed basis would be the estimated 27% reduction in wood volume multiplied by the 1.6% area covered by landslides, for a total reduced wood volume production of 0.43%.

The small, but significant, area of landslides (30.8 ha) is likely to increase in the future. By 1980, 19.4% of the Blue River drainage had been clearcut, and 3.3% had been covered by roads. During the period between 1967-1979 an average of 0.9% of the drainage was clearcut each year, and this rate will probably not decrease substantially in the near future. Road building during the period 1968-1979 covered an average 0.06% of the drainage per year. This rate is likely to slow somewhat in the future, as most of the main road network is already established. Marion[3] observed, however, that it is the short local timber access roads that produce the most landslides per unit length. Improved road design, location, and maintenance, and timber harvest techniques will probably produce fewer landslides than did the older methods, but these activities are increasingly being carried out on more inaccessible, steep, and unstable portions of the watershed.

Future landsliding could be estimated more precisely based on management plans for future timber harvest and road building rates, and on soil resource inventory data. Road and clearcut landslide rates per unit area of each soil resource inventory unit could be calculated using extant landslides, and these could be projected into the future, based on harvest and road building plans on those soil resource units.

These results could be extended into 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 of soil sloughing onto edges, organic matter additions and shading from adjacent vegetation, and the size effect on depth of sliding. 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 landslide scars. Landslide frequency combined with size determines the proportion of the broad landscape area affected by landsliding. Soil depth and bedrock characteristics affect the suitability of the material remaining after landsliding for support of tree growth. Interactions between soils, bedrock, and climate determine long-term stability of landslide sites, which affects the reestablishment of vegetation. Tree species characteristics influence potential for reforestation on landslide disturbed sites. Douglas-fir was the leading pioneer species on landslides examined 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.

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CHAPTER III

VEGETATION DEVELOPMENT ON LANDSLIDES IN THE WESTERN OREGON CASCADES[1]

D. W. R. Miles[2]

ABSTRACT

Shallow, rapid soil mass movements are common events in the Pacific Northwest, and the resulting persistent, poorly vegetated landslide scars and debris deposits are subject to continuous erosion. The persistence of unvegetated landslide scars and deposits was examined by sampling vegetation on a chronosequence of landslides 6-28 years old in the western Oregon Cascades. Average vegetation cover for all landslides was 51%, ranging from 7-88%. No discernible trend in vegetation cover or species composition over time was detected. Variations in landslide distribution and topography resulted in a wide range of plant microhabitats, with 140 species identified. The combination of wet-site, bare mineral soil, and droughty bedrock habitats disguised trends in overall landslide vegetation recovery.

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INTRODUCTION

Shallow, rapid soil mass movements remove soil and vegetation from hillslope positions and deposit the debris downslope and in stream channels. The resulting landslide scars and deposits are vulnerable to surface erosion, dry ravel, and further mass wasting. Removal or redeposition of surface soil and organic matter by landsliding alters nutrient supplies and rooting medium available for forest vegetation, temporarily or permanently reducing forest productivity. Landslides are common events and primary sources of sediment in steep terrain of the Pacific Northwest, and land management activities, especially road building and clearcutting, can significantly accelerate their rate of occurrence (Swanston and Swanson, 1976; Megahan et al., 1978). The effect of landsliding on forest and watershed resources is a result not only of initial landslide events, but also of the persistence of unvegetated scars and deposits. Vegetation establishment on landslides can retard further erosion through development of protective canopy, litter layer, and soil-binding root mass.

The purpose of this study was to examine the rate and species composition of revegetation, and site conditions, on landslide scars and deposits 6-28 years old. The site for the study was the H.J. Andrews Experimental Forest and the adjacent upper Blue River drainage in the western Oregon Cascades, approximately 80 km east of Eugene, Oregon. The elevation ranges between 450 and 1630 m, and the sites are in the western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) zone of the Douglas-fir (*pseudotsuga menziesii* (Mirb.) Franco) region (Franklin and Dyrness, 1973). The overstory of mature forests is dominated by Douglas-fir, with varying amounts of western hemlock and western red cedar (*Thuja plicata* Donn.).

METHODS

A chronosequence of 25 landslide areas 6 to 28 years old was sampled randomly from an inventory of 257 landslides occurring in the 12,300 ha area since 1946 (Dyrness, 1967; Swanson and Dyrness, 1975; Marion, 1981). Twenty plots per landslide were sampled for vegetation cover and species composition. The sampling system and plot size (radius 2.27 m) was determined in another part of the study (Miles et al., 1983) which used the stocked-quadrat sampling method (Haig, 1931). Where 20 plots would not fit on the landslide without overlap, the number of plots was reduced accordingly.

Ocular estimates of percent cover were made of every plant species or plant species group to the nearest 5% (except for 1-5 and 99%), with plants less than 1% cover given a 1% value. Percent litter cover, percent cover for all vegetation, and average litter depth were estimated. Landslide sites were described with respect to slope, aspect, elevation, and landslide type, age, and size (Table 1).

Table III.1. Age, site, vegetation cover, litter cover, and litter depth data for landslide areas in western Oregon.

Landslide age	Site type#	Slope	Aspect	Landslide area	Elevation	Vegetation cover	(S)	Litter cover	Litter depth
years		%	degrees	m^2		%		%	mm
6	RF	74	335	105	850	25.6	(20.0)	23.9	1.6
9	RF	80	000	312	550	38.5	(21.9)	24.4	0.9
10	FO	100	350	237	790	76.4	(24.5)	80.5	20.7
11	FO	173	350	36	760	27.2	(32.2)	25.8	0.2
11	FO	70	190	858	790	84.5	(16.3)	80.5	14.5
11	CC	70	15	550	730	24.8	(31.6)	15.0	0.8
11	RF	52	180	177	1100	35.6	(32.5)	30.8	4.6
11	RF	67	335	942	730	47.8	(33.3)	27.0	1.2
11	RF	75	165	193	670	9.2	(11.0)	2.0	0.1
12	CC	79	10	79	820	38.3	(40.2)	48.9	6.3
14	RF	85	150	318	750	82.4	(20.2)	70.5	7.3
16	FO	57	100	325	760	66.7	(25.8)	60.4	6.1
16	FO	80	235	145	670	57.2	(44.6)	54.5	8.9
16	RF	50	170	500	760	65.9	(28.1)	67.2	6.3
16	RF	82	010	563	720	77.8	(23.2)	61.4	9.4
16	RF	85	130	1115	580	7.1	(8.3)	0.2	0.0
17	CC	78	245	512	760	58.2	(30.8)	49.5	5.6
17	CC	50	130	236	910	76.9	(13.8)	73.4	11.4
17	RC	40	130	452	730	50.0	(31.9)	35.1	3.7
18	RC	50	240	373	560	58.0	(28.2)	52.0	4.9
19	RF	70	090	1065	490	53.8	(31.4)	35.5	4.5
24	CC	80	280	1287	690	11.2	(12.8)	2.4	0.3
24	RF	70	20	307	760	86.8	(16.6)	75.6	9.3
26	CC	85	105	192	690	59.3	(19.6)	39.3	5.4
28	RF	70	110	586	460	42.4	(28.9)	42.4	4.4

#RF = roadfill, FO = forest, CC = clearcut, RC = roadcut.

RESULTS AND DISCUSSION

The 25 landslides sampled ranged in elevation from 460 to 1100 m, with all aspects represented (Table 1). Landslides ranged in slope from 40 to 173%, in map area from 36 m^2 to 1287 m^2, and in age from 6 to 28 years before sampling in 1981. The average vegetation cover for all landslides was 51%, litter cover 45%, and litter depth 6 mm. Individual landslides ranged in average vegetation cover between 7 and 88% (Table 1).

Reestablishment of vegetation on landslide scars and deposits over time should return vegetation cover to levels of surrounding mature forests, which typically approach 100% cover. Vegetation cover on landslides was not significantly related to landslide age ($r=0.1705$, $p>0.10$), or to slope, aspect, elevation or landslide size (stepwise multiple regression maximum $r^2=0.1465$, $p>0.10$). Individual species cover did not increase regularly with landslide age; the occurrence of the five tree and shrub species with the highest average cover at various landslide ages is presented in Figure 1 and Figure 2.

The trend in vegetation development over time may not emerge from the relatively short age span of landslides sampled. Additionally, large within and between landslide variation in unmeasured site characteristics may confound the relationship between landslide age and vegetation cover. A variety of topographic positions and landslide features result in a wide range of microhabitats. Individual landslides may have conditions ranging from persistent wet areas where groundwater emerges at soil surface-bedrock contacts to very droughty sites where coarse fragments accumulate or soil is shallow.

Wide ranges of microhabitat conditions resulted in a large array of plant species established on landslides. Vegetation developed on landslides included 140 species and species groups (for example perennial fireweeds, Table 2). Fifty-four plant species averaged at least 0.10% cover for all landslides (Table 2); the remaining, unlisted species contributed 2% cover. Total species cover is 68%,

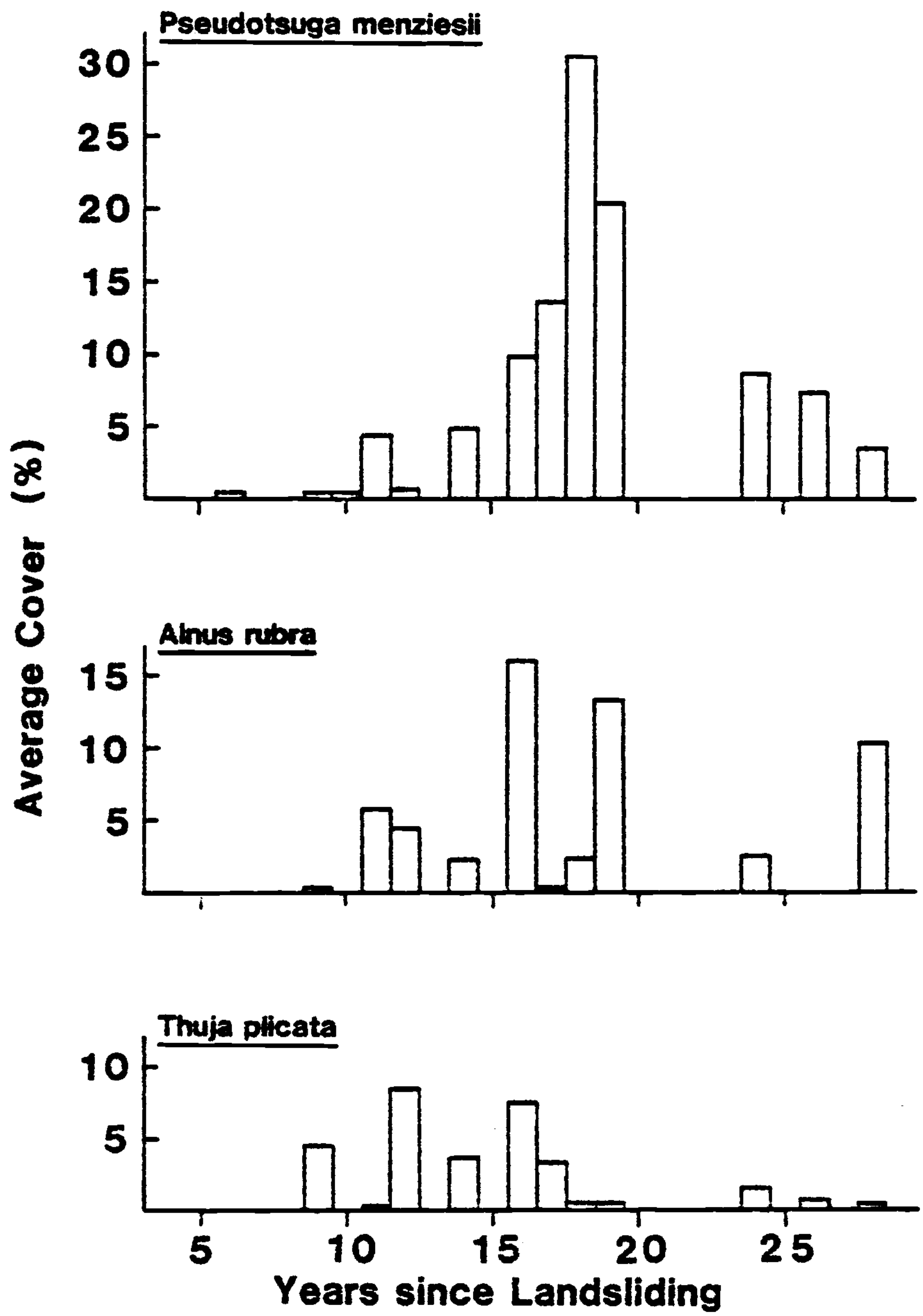

Figure III.1. Vegetation cover for three tree species found on various aged landslides in western Oregon.

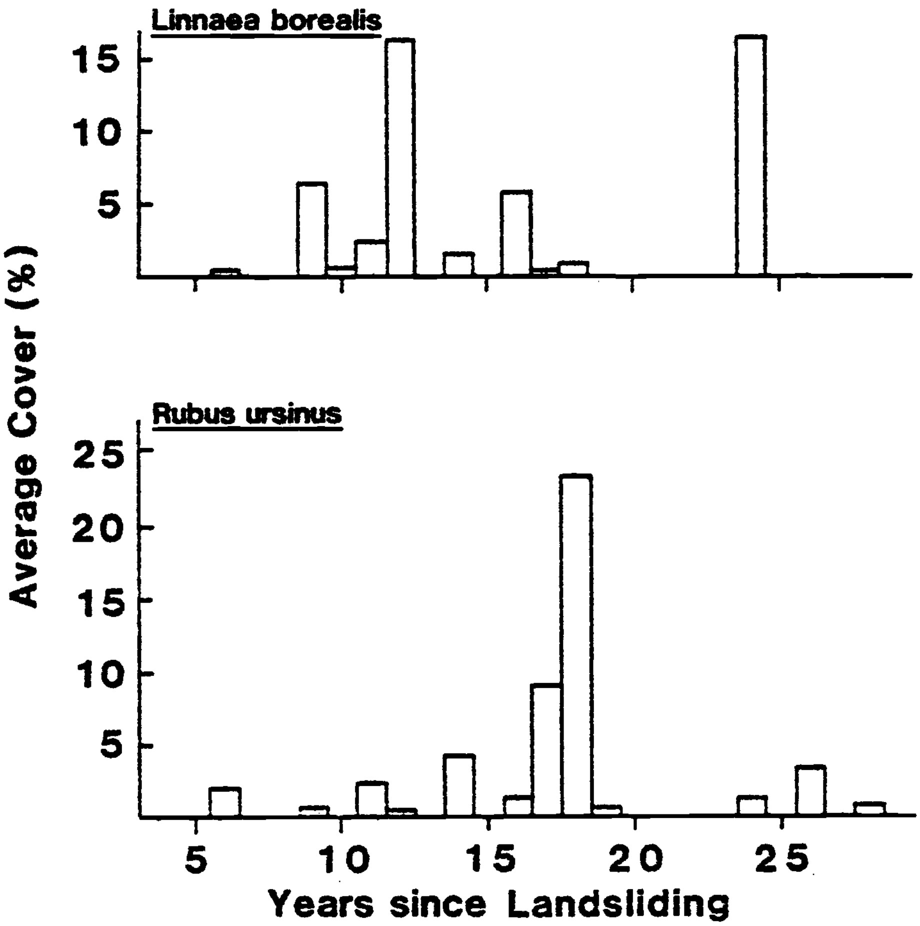

Figure III.2. Vegetation cover for two shrub species found on various aged landslides in western Oregon.

Table III.2. Plant species average cover, frequency, and maximum cover for landslide areas in western Oregon.

Scientific name	Common name	Average cover	Fre-# quency	Maximum cover†
		%	%	%
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir	8.40	96	90
Alnus rubra Bong.	red alder	7.77	64	99
Linnaea borealis L.	twinflower	3.96	68	80
Rubus ursinus Cham. & Schlecht.	blackberry	3.46	96	75
Thuja plicata Donn	western red cedar	2.87	64	80
Ceanothus velutinus Dougl.	snowbrush	2.46	36	90
Petasites frigidus (L.) Fries	coltsfoot	2.30	60	75
Acer circinatum Pursh	vine maple	2.03	64	90
Agrostis tenuis Sibth.	highland bentgrass	1.95	64	60
Equisetum L. sp.	horsetail	1.86	48	90
Tsuga heterophylla (Raf.) Sarg.	western hemlock	1.67	80	80
Lotus purshianus (Benth.) Clements & Clements and L. micranthus Dougl.	annual lotus	1.65	52	70
Acer macrophyllum Pursh	bigleaf maple	1.61	72	99
Gaultheria shallon Pursh	salal	1.45	56	70
Salix L. sp.	willow	1.10	60	70
Adiantum pedatum L.	five-finger fern	1.07	32	60
Anaphalis margaritacea (L.) B.&H.	pearly-everlasting	1.00	88	30
Rubus parviflorus Nutt.	thimbleberry	0.99	64	40
Whipplea modesta Torr.	whipplevine	0.98	68	40
Lotus crassifolius (Benth.)Greene	big lotus	0.84	24	60
Aruncus sylvester Kostel.	goatsbeard	0.76	24	50
Ceanothus integerrimus H.& A.	deerbrush	0.73	40	50
Polystichum munitum (Kaulf.)Presl.	swordfern	0.66	92	40
Festuca arundinacea Schreb.	alta fescue	0.66	36	40
Pteridium aquilinum (L.) Kuhn.	brackenfern	0.63	48	80
Trientalis latifolia Hook.	star flower	0.59	96	5

Epilobium angustifolium L. and other perennial fireweeds	perennial fireweed	0.50	80	10
Galium aparine L.	bedstraw	0.46	88	10
Hieracium albiflorum Hook.	hawkweed	0.44	100	2
Aralia californica Wats.	California aralia	0.40	36	55
Festuca occidentalis Hook.	western fescue	0.39	60	20
Castanopsis chrysophylla (Dougl.) DC.	chinquapin	0.36	28	70
Oplopanax horridum (Smith) Miq.	devil's club	0.36	8	70
Epilobium minutum Lindl. and other annual fireweeds	annual fireweed	0.35	84	2
Boykinia elata (Nutt.) Greene	boykinia	0.34	52	50
Vancouveria hexandra (Hook) Morr. & Dec.	inside-out flower	0.30	56	15
Frageria L. sp.	strawberry	0.27	40	40
Gnaphalium L. sp.	cudweed	0.26	28	60
Blechnum spicant (L.) Roth.	deerfern	0.24	24	25
Symphoricarpos Duhamel sp.	snowberry	0.23	8	80
Madia Mol. sp.	tarweed	0.22	24	15
Berberis nervosa Pursh	Oregon grape	0.21	68	20
Athyrium filix-femina (L.) Roth.	ladyfern	0.20	32	20
Viola sempervirens Greene	evergreen violet	0.18	64	2
Rhododendron macrophyllum G. Don	rhododendron	0.18	44	15
Cirsium Mill. sp.	thistle	0.18	48	25
Populus trichocarpa T. & G.	black cottonwood	0.17	12	50
Vaccinium parvifolium Smith	red huckleberry	0.16	64	30
Corylus cornuta Marsh.	hazelnut	0.14	32	40
Taxus brevifolia Nutt.	Pacific yew	0.14	16	60
Collomia heterophylla Hook.	collomia	0.12	40	1
Campanula scouleri Hook.	harebell	0.12	52	1
Carex L. sp.	sedge	0.11	36	20
Achlys triphylla (Smith) DC	vanilla leaf	0.11	32	10

#Frequency = percent of landslides (n=25) on which species was found.

†Maximum of 472 plots on 25 landslides.

and differs from the 51% total vegetation cover because of multi-storied canopies. A frequency of occurrence was calculated for each species, as the percent of landslides on which the species was found (Table 2). [The maximum cover of each species on any individual plot is also listed in Table 2.]

Landslides expose large areas of bare mineral soil, opening them for revegetation. Douglas-fir and red alder, well adapted for establishment on mineral soil, are the most important early colonizers of landslides in the study area. Douglas-fir is also the most important timber species in western Oregon, and those portions of landslides revegetated with Douglas-fir rapidly return to timber production, although at reduced growth rates (Miles et al., 1983).

Nitrogen-fixing plants are favored on nutrient-deficient subsoil exposed by landslides, and both leguminous and non-leguminous nitrogen fixers were found on landslides. These species, including *Alnus rubra*, *Ceanothus velutinus*, *Lotus purshianus*, *Lotus crassifolius*, and *Ceanothus integerrimus* totalled 13.4% vegetation cover.

Landslide areas characterized by wet-site conditions, such as seeps and intermittent channels are favorable habitats for quick revegetation. In the western Cascades of Oregon, *Alnus rubra* is generally confined to wet areas. Other characteristic wet-site species include *Petasites frigidus*, *Equisetum* sp., *Salix* sp., *Adiantum pedatum*, *Aruncus sylvester*, *Aralia californica*, *Oplopanax horridum*, *Boykinia elata*, *Athyrium felix-femina*, *Populus trichocarpa*, and *Carex* sp. These wet-site species totalled 16.4% cover, and are an indicator of the total landslide area in wet-site conditions.

Past management of the forest environment has also affected the species composition of landslides. Douglas-fir was artificially planted on clearcuts and occasionally on roadsides in the area, but only one landslide was planted. Species composition of roadfill and roadcut landslides are affected by seeding of roadsides for erosion control. Hydromulch seeding of *Agrostis tenuis*, *Festuca arundinacea*, *Dactlis glomerata*, and *Lolium* sp. has occurred; however, only

Agrostis tenuis and Festuca arundinacea still persist as major components of the vegetation.

Landslide scars and deposits consist of a heterogeneous mixture of bare mineral soil, wet spots, and severely droughty unstable material, which revegetate at very different rates. Twelve to ninety-three percent of the area within landslides had not been reclaimed by vegetation when sampled 6-28 years after sliding. These areas are subject to continuing surface erosion, dry ravelling, and mass movement. This erosion inhibits future revegetation, and headward erosion of landslide scars can damage additional areas. Vegetation develops most quickly at landslide edges, where soil and organic matter are added from adjacent areas, and bottoms, where debris are deposited and moisture collects. These areas may collect sediment from unvegetated areas upslope, thereby reducing the amount reaching streams. The distribution of microhabitats within and between landslides makes overall revegetation rates difficult to discern.

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CHAPTER IV

CONCLUSION

Shallow, rapid soil mass movements have been a major management problem in steep forest land of the Pacific Northwest. Considerable work has been published on the frequency, distribution, processes, causes, and impacts of landsliding. Although loss of site productivity due to landslides has been assumed, little quantitative work has been done in this area. This study was designed to determine the magnitude and duration of forest productivity losses due to landslides in the western Oregon Cascades.

Landslides are highly variable in their characteristics and distribution, and are consequently variable in their effects on forest productivity. Overall, this study has shown that the primary effect of landslides is to reduce the area suitable for plant growth. Conifer stocking levels on landslides ranged from 0 to 100%, with 36% of the landslides less than 50% stocked, and an average stocking of 62%. Present management techniques depend on natural regeneration for landslides, resulting in poor stocking and wide ranges of tree densities. While artificial regeneration would improve stocking on landslides, 31% of the total landslide area was estimated to be unstockable or only marginally stockable. Stocking was highest on accumulation and depositional areas which, though covering only 20% of the landslide area, accounted for 30% of total landslide stocking.

Timber productivity is further reduced by low seedling growth rates compared to growth rates on nearby clearcuts. Cumulative height growth of Douglas-fir trees 18 years old on landslides was reduced

38% compared to trees on clearcuts, and calculations combining height growth and stocking level at that age estimated a 40% reduction in wood volume grown on landslides compared to clearcuts. Total average vegetation cover is 51%, compared to nearly 100% cover expected in undisturbed forests or clearcuts of similar ages. The most important colonizers of landslides was Douglas-fir and red alder. Vegetation cover did not significantly progress within the 22 years age span of landslides studied. These unvegetated areas are exposed to erosion, which further reduces or maintains low productivity.

A variable of primary importance for determining the impact of landslides on overall productivity is the areal extent of land-sliding. In this study, an estimated 1.6% of the area would be in landslides over an 80 year rotation.

These data should be useful for land managers in different areas, after it is adjusted for local landslide size, frequency and depth, soil characteristics, climate, geology, and revegetation tree species. The information can assist in the evaluation of the impacts of landslides on resources and property, and the cost-effectiveness of land management activities which alter the rate of occurrence of landslides.

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