ROOT STRENGTH CHANGES AFTER LOGGING
IN SOUTHEAST ALASKA

by

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ABSTRACT

A crucial factor in the stability of steep forested slopes is the role of plant roots in maintaining the shear strength of soil mantles. Roots add strength to the soil by vertically anchoring through the soil mass into failures in the bedrock and by laterally tying the slope together across zones of weakness or instability. Once the covering vegetation is removed, these roots deteriorate and much of the soil strength is lost.

Measurements of change in strength of roots remaining in the soil after logging at Staney Creek on Prince of Wales Island, southeast Alaska, indicate that loss of strength in smaller roots occurs rapidly for all species the first 2 years. Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) roots are more resistant to loss of strength than are Sitka spruce *(Picea sitchensis* (Bong.) Carr.) roots. By 10 years, even the largest roots have lost appreciable strength.

KEYWORDS: Root morphology, root damage, soil stability, logging (-forest damage, Alaska (southeast).

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INTRODUCTION

A crucial factor in the stability of steep forested slopes is the role of plant roots in maintaining the shear strength of soil mantles. Roots add strength to the soil by vertically anchoring through the soil mass into fractures in the bedrock and by laterally tying the slope together across zones of weakness or instability.

In Japan, Endo and Tsuruta (1969) reported that soil shear strength increases in proportion to the amount of roots in the soil. Kitamura and Namba (1966, 1968) noted that the resistance of tree stumps to uprooting decreases rapidly as the root systems decay following timber harvest. They concluded, when considering root growth of planted trees, that the forest soil would reach a minimum strength between 5 and 10 years after cutting and replanting.

Bishop and Stevens (1964) and Swanston (1967, 1969) demonstrated the probable effect of roots on the stability of slopes in southeast Alaska and correlated increased landslide activity with time after logging. Wu (1976) measured the contribution of root tensile strength to shear strength of Karta soils at Hollis, Prince of Wales Island, and found it equivalent to at least a cohesion of 120 pounds per square inch (8.44 kg/cm^2) or about 25 percent of the total soil strength available to resist failure. Preliminary measurements of loss in root strength of both Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) by simple penetration tests further indicate a maximum loss of root strength is attained 3 to 5 years after cutting (Swanston 1970).

Similar rates of strength loss are reported for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) roots in coastal British Columbia (O'Loughlin 1974) and in the Oregon Coast Ranges (Burroughs and Thomas 1977). The senior author measured the influence of roots on in-situ shear strength in the Oregon-northern California coastal province and found that the reinforcing effect of the root mass significantly strengthened the soil.

The present study was initiated to quantify these relationships for southeast Alaska and to extend the data base of a much larger investigation to evaluate the interactions of root strength, root biomass, and soil strength in natural forest stands and the influence of logging on these factors. The larger investigation is a portion of a west-wide cooperative inter-Station research program to study mass wasting process and the influence of forest operations on slope stability.

METHODS

Sampling

A prime objective of this study was to measure the change in strength of roots remaining in the soil after logging. To keep the influence of other variables at a minimum, we selected sites having a wide range of cutting ages concentrated within a small geographic area. Staney Creek is one of the very few locations in southeast Alaska having such a wide diversity of cutting ages with
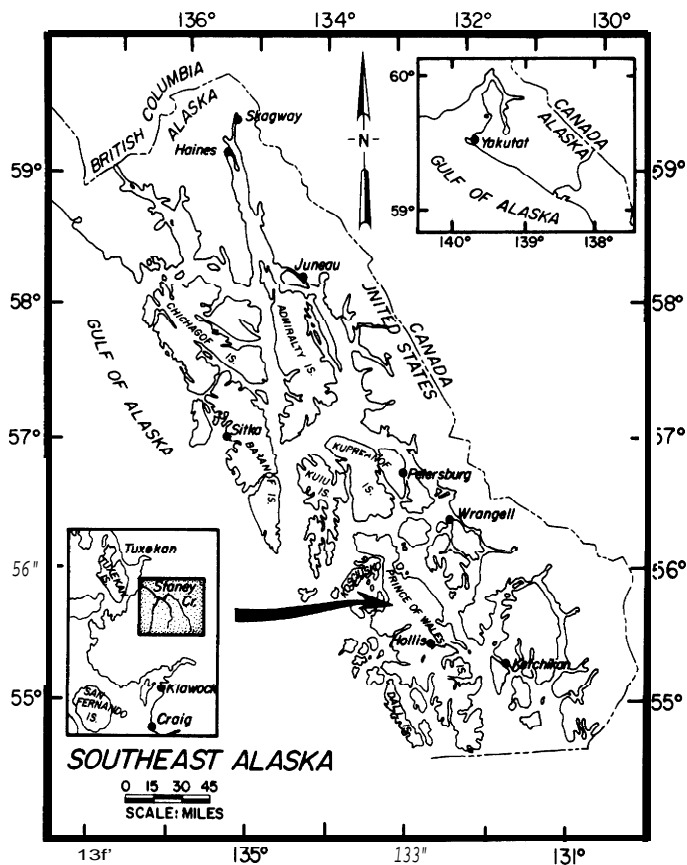
Figure 1.--Planimetric map of southeast Alaska showing location of the Staney Creek study site on the west coast of Prince of Wales Island. (For kilometers, multiply the number of miles by 1.609.)

similar environmental character-istics (fig. 1).

Within the Staney Creek area, five comparable sites, on which the trees had been cut in 1966, 1970, 1972, and 1974, and an uncut stand were found. Within each of the five sites, a western hemlock and a Sitka spruce tree or stump was selected for study. Live huckleberry (*Vaccinium parvifolium* Sm.) roots were also sampled in the clearcut units. Root samples were collected from the subsurface mineral soil rather than from within the extensive surface organic layer.

We planned to collect 15 separate root segments approx-

imately 12 centimeters long for each of the six diameter classes for each species. These were 2-, 5-, 10-, 17-, 25-, and 50-millimeters inside the bark. We were unable to obtain the desired number of roots for some of the large size classes; and, in the areas cut in 1966 and 1970, root decay was so advanced that dead roots in the smaller size classes could not be found.

The selected roots were immediately packed in wet sphagnum, sealed in plastic bags, and air mailed to the laboratory in Arcata, California. At the laboratory, the roots were inventoried and stored at $2^{o}C$. Within 2 weeks, the roots were tested in the shear apparatus.

The results reported here represent data collected from a small geographic area. The slopes were limited to gentle terrain that was characteristic of the Staney Creek area but not generally characteristic of southeastern Alaska. The data are further limited to one tree per species in each of the five cutting age classes selected.

Shearing

Ten of the roots, if available, were prepared for shearing by removing the bark and marking each root into five equally spaced segments. The separation between segments was at least twice the root diameter to prevent one break from in-fluencing subsequent tests. For large roots, only one or two breaks per root sample was possible. The minimum and maximum diameters of each seg-ment were measured. Each root was then sheared at each segment mark.

The shear apparatus (fig. 2) consists of a stationary steel block machined to allow the insertion of hardened steel dies.[1] A hole was drilled in the die to hold a root for each diameter class. A root having a diameter approximately equal to that of the hole was inserted through the die; it protruded at both sides. A movable steel block with a hardened steel V-shaped blade was machined to slide along the surface of the stationary block. The movable block was pushed by a mechanical jack until the protruding root segment failed.

The moving friction of the shear block and the maximum stress applied to each root segment at failure was measured by means of a proving ring and dial gage. Stress was applied to the root at a rate of 3.5 centimeters per minute. Both the moving friction and the maximum stress at failure were converted to kilograms of force.[3] The net maximum stress (shear strength) was obtained by subtraction of the moving friction component from the maximum shearing force component.

In an earlier study, such direct shear strength measurements were found to give an excellent prediction of root tensile strength measured independently with an apparatus designed by Burroughs and Thomas (see footnote 2). A linear regression on paired breaks of the same root yielded the equation:

$$\text{Tensile strength} = -7.555 + 2.227 \; (\text{Shear strength}) \; ;$$

where, the root strengths were expressed in kilograms and the root diameters ranged from 1 to 10 millimeters. The explained variance was 0.972. The direct shear strength measurements were preferred in our study because many more and larger roots could be tested in the limited time availab .

[2] Ziemer, R. R. An apparatus to measure the strength of roots. Unpublished report on file at Pacific Southwest Forest and Range Experiment Station, Arcata, Calif.

Figure 2. --Root shearing apparatus.

[3] Here we follow the common engineering practice of expressing force in units of mass. Force is correctly expressed in units of mass-length/time^2 or in newtons. To convert: Newtons = mass (kg) X 9.807 m/sec^2 (gravitational acceleration). We further define the shear strength as the maximum shearing force applied at failure.
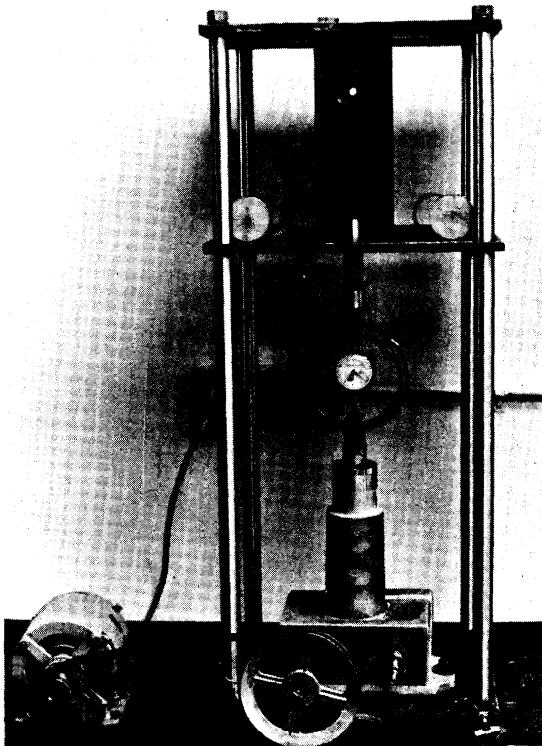
Tensile strength measurements are generally limited to roots less than 10 millimeters in diameter.

Physical and strength characteristics of each root segment were coded for subsequent analysis. The data were initially screened for anomalies such as cracked or dried roots, instrument malfunction, and observer errors. Such data were rejected from subsequent compilation.

The mean shear strength, standard deviation, and number of breaks were calculated for each species, age, and size class (table 1). Further statistical analysis of these data was not justified because the samples were, in no sense, collected at random.

RESULTS

During excavation, tree roots were found to range from resinous roots with a high resistance to decay to nonresinous roots that decayed rapidly. In companion studies, the senior author has observed similar decay resistant roots in coastal Oregon, the Oregon Cascades, and in coast redwood (*Sequoia sempervirens* (D. Don.) Endl.) stands and interior Douglas-fir stands of the northern California Coast Ranges. In the Sierra Nevada and southern California there is such heavy resin in pine roots infected with *Fomes annosus* that larger roots (100- to 200-mm diameter) have not deteriorated, even after 50 years.

[4] Robert Bega, Pathologist, Forest Disease Research, Pacific Southwest Forest and Range Experiment Station, Berkeley, California, personal correspondencc, August 2, 1976. On file at Redwood Sciences Laboratory, Arcata, California.

Table 1 --*Root strength of western hemlock, Sitka spruce, and huckleberry, by size class and time since logging*

Root diameter	Statistical measure[1]	Live roots			Dead roots — Years since logging							
					2		4		6		10	
		Huckle-berry	Western hemlock	Sitka spruce	Western hemlock	Sitka spruce	Western hemlock	Sitka spruce	Western hemlock	Sitka spruce	Western hemlock	Sitka spruce
mm												
2	X̄	3.58	9.72	5.65	5.68	2.55	4.00	4.85	2.77	3.44	3.26	--
	σ	1.80	3.06	.60	1.41	.83	2.11	3.19	2.19	90	2.02	--
	n	50.	50.	45.	50.	50.	45.	50.	50.	20:	20.	--
5	X̄	30.38	42.73	25.35	28.09	20.44	21.87	38.42	21.48	13.09	17.96	13.10
	σ	8.28	11.63	7.54	7.02	7.79	9.53	16.23	11.58	2.17	5.18	6.72
	n	50.	50.	50.	50.	50.	55.	50.	50.	50.	50.	14.
10	X̄	146.91	128.98	106.11	101.41	70.54	78.16	99.09	157.28	87.90	68.29	50.50
	σ	30.37	40.63	45.41	32.47	25.03	18.57	51.80	50.41	39.02	37.56	30.31
	n	44.	50.	49.	50.	50.	50.	49.	47.	49.	50.	47.
17	X̄	442.5	454.4	501.4	318.6	149.4	255.6	319.0	551.2	303.1	409.6	153.9
	σ	194.8	120.5	164.9	193.8	23.0	74.6	162.5	130.2	141.3	181.5	82.6
	n	23.	36.	27.	50.	30.	30.	46.	48.	49.	45.	35.
25	X̄	--	757.8	811.2	518.0	420.6	707.7	937.8	800.9	530.4	507.9	438.7
	σ	--	194.1	337.4	190.8	104.4	290.5	294.6	207.8	145.6	170.8	176.8
	n	-	23.	23.	32.	30.	37.	19.	49,	39.	46.	24.
50	X̄	--	2884.	2427,	2806.	2257.	2581.	2705.	2984.	2608.	1391.	314.
	σ	--	124.	588.	265.	556.	679.	174.	80.	273.	387.	177.
	n	__	10.	10.	14.	5.	8.	7.	6.	11.	8.	6.

[1] X̄ = mean shear strength in kilograms; σ = standard deviation in kilograms; n = number of breaks.

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LIVE ROOTS

There is a linear relationship between the logarithm of root strength and the logarithm of root diameter for live roots of the three southeast Alaska species tested (fig. 3).
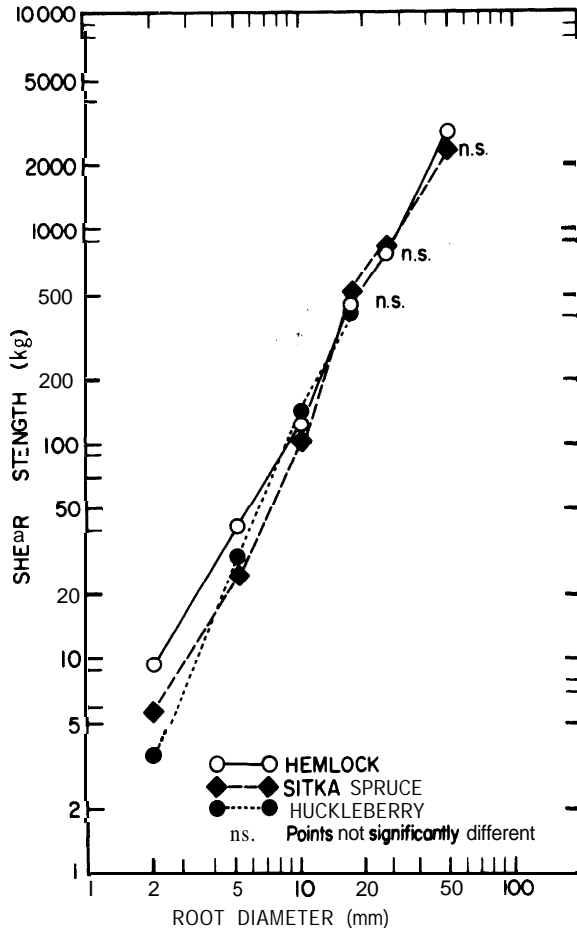

Figure 3. --Root shear strength vs. root diameter for live western hemlock, Sitka spruce, and huckleberry.

Sitka spruce -roots are weaker than hemlock roots (fig. 3, table l), particularly the smaller roots. For example, Sitka spruce roots, 2 to 5 mm in diameter, are about 40 percent weaker than similar size hemlock roots. This difference is less in 10-mm Sitka spruce roots, which are about. 18 percent weaker than 10-mm hemlock roots There is little difference in strength of live roots larger than 17 mm.

After logging, red huckleberry commonly invades the site. Very small huckleberry roots have substantially less strength than either hemlock or Sitka spruce roots of comparable size. For example, 2-mm roots of huckleberry are about 63 percent weaker than hemlock roots and about 40 percent weaker than Sitka spruce roots. This difference vanishes in roots with larger diameters, and there is little difference between the three species at 17 mm.

DEAD ROOTS

The contribution of tree roots to the strength of the soil is a function of the individual root strengths and the number of roots per unit volume of soil. Within the first few years after logging, there is a decrease in the average strength of the roots in the soil (fig. 4). Then, 4 to 6 years after logging, the strength of residual roots is at least as great as the average strength of live roots. By this time, however, most of the nonresinous roots have completely decayed and only resinous roots in the residual root biomass are left. Resinous roots are only a small fraction of the total root mass in the original live forest stand.

Several important differences between hemlock and Sitka spruce roots are related to size and change in strength with time after cutting.
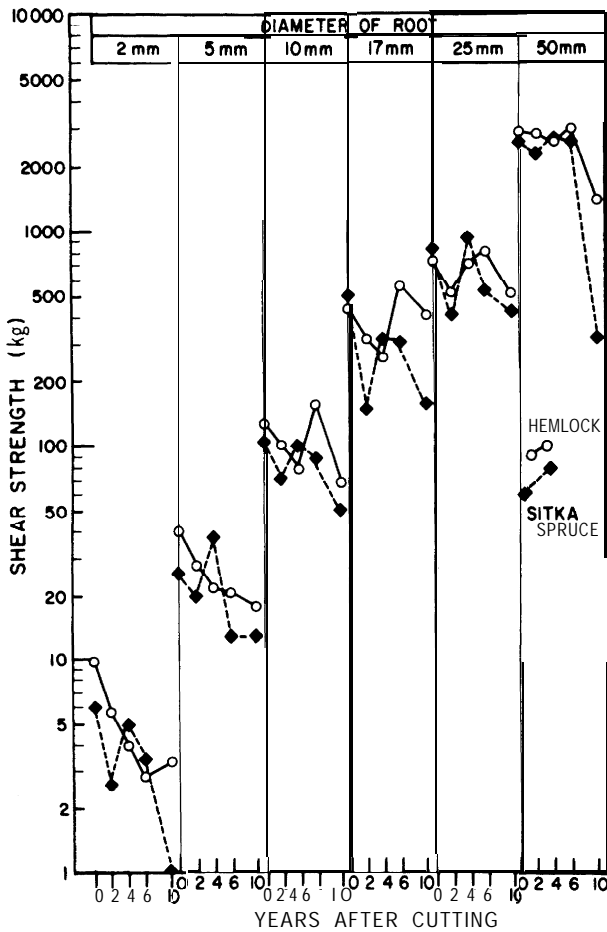
Figure 4. --Change in root shear
strength, in years after cutting,
for different root diameters of
western hemlock and Sitka spruce,

Hemlock Roots

There is a continual loss
in average strength of residual
hemlock roots less than 25 mm in
diameter with time after logging
with about 32 percent of the
strength lost during the first
2 years (Table 1, fig. 4).   For
example, for 2-mm diameter roots,
there is a 42-percent loss in
strength the first 2 years after
logging.   Within 4 years, there
is a 59-percent loss.   By 6 years,
70 percent of the strength of
the residual roots is lost.
Residual roots having a diameter
of 5 mm show a 34-percent loss
in strength the first 2 years.
Within 4 years, half the strength
is lost.   By 10 years after cut-
ting, 58 percent is lost.

A reduction in residual
strength of intermediate size
hemlock roots (l0-25 mm) during
the first 4 years after logging
is followed by an apparent in-
crease in strength as a result
of dominance of resinous roots
in the residual biomass,   This
increase reaches a peak about
6 years after cutting, then
declines as the resinous roots
begin to decay.   The root strength
at 6 years is at least as great
as that of the original live roots.
This does not imply that the
strength of the soil-root matrix
is increasing, because the total
number of roots continually
becomes smaller and the roots
remaining in the soil are the
decay resistant resinous roots
which represent a small fraction
of the original root biomass.
By 10 years after cutting, even
these resinous roots have begun
to lose their strength.

There is no loss in strength
of large hemlock roots (50 mm)
during the first 6 years after
cutting.   Within the next 4
years, however, 50 percent of
the strength is lost.

Sitka Spruce Roots

There is a decrease of about
50 percent in strength of Sitka
spruce roots less than 25 mm in
diameter within the first 2 years
after logging, followed by an
increase in the 4th year to a
strength approximating that of
live roots.   This apparent in-
crease is also due to the
dominance of resinous roots in
the biomass.   After this 4-year
peak, there is a continual

reduction in root strength as the resinous roots decay. By the 10th year, no roots less than 2 mm in diameter remain in the soil and few roots smaller than 5 mm. Therefore, essentially all strength from these smaller roots is gone. The remaining resinous roots, from 10 to 25 mm in diameter, lose about 50 percent of their strength between the 4th and 10th year,

There is no loss in strength of 50-mm roots for the first 6 years, but between 6 and 10 years, these large roots lose 87 percent of their strength.

Comparison of Roots of Hemlock and Sitka Spruce

In general, there were fewer residual Sitka spruce roots per age class, which suggested that they are less resistant to decay. Because the nonresinous fraction of the Sitka spruce roots decays more rapidly than the resinous fraction, the resinous roots dominate the residual biomass 2 years earlier than do the resinous roots of hemlock. As the proportion of nondecayed resinous roots rises, the average residual strength also rises. Therefore, this observed increase in strength of the Sitka spruce roots 4 years after logging and of the hemlock roots 6 years after logging reflects the rate of total decay of the nonresinous root fraction. This does not imply that the strength of the soil through the binding action of roots increases after logging since the total number of roots or biomass of roots continues to decline.

There appears to be no resinosis of hemlock roots less than 5 mm diameter, whereas resinosis is apparent in small Sitka spruce roots.

The average strength of residual Sitka spruce roots is consistently less than that of hemlock roots until 4 years after logging when the impact of resinosis is observed in Sitka spruce.

SUMMARY AND CONCLUSIONS

1. There is a linear relationship between the logarithm of root strength and the logarithm of root diameter for the live roots of Sitka spruce, western hemlock, and red huckleberry.

2. In uncut stands hemlock roots are stronger than Sitka spruce roots,

3. Very small huckleberry roots have substantially less strength than either hemlock or Sitka spruce, but strength rapidly increases with diameter and closely approximates the strength of the tree roots above 10 mm diameter.

4. Sitka spruce roots decay more rapidly than do hemlock roots.

5. As tree roots decay with time after logging, residual hemlock roots continue to be stronger than residual Sitka spruce roots until 4 years after cutting.

6. Hemlock loses about one-third of the average strength of its roots smaller than 25 mm in diameter within 2 years after logging.

7. Sitka spruce loses about one-half the average strength of its roots smaller than 25 mm in diameter within 2 years after logging.

8. Within 2 years after logging, most of the original roots larger than 1 mm of the three species can still be found

in the soil. By 4 years, many of the roots have totally decayed, and a proportionately larger number of decay resistant, resinous roots are left. By 10 years after cutting, even these resinous roots have lost appreciable strength.

9. Since this study was exploratory and designed to provide data for a more regional evaluation of root strength, several limitations should be mentioned:

   a. We studied a specific geographic area, namely Staney Creek, Prince of Wales Island.

   b. We selected only one site for each age class,

   c. We selected only one tree per species for each age class

   d. We located sites on relatively gentle terrain.

Subsequent studies and papers will evaluate the significance of these factors on root strength and its rate of reduction after logging. A more definitive measure of the rate of root biomass loss after logging in southeast Alaska is also needed.

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