AN ABSTRACT OF THE THESIS OF

Louise Simmons Yount for the degree of Master of Science in Forest Science presented on June 4, 1997. Title: Sitka Spruce and Western Hemlock Regeneration after Selective Harvesting, Tongass National Forest, Southeast Alaska.

Abstract approved: John C Tappeiner II

John C. Tappeiner, II

The objectives of this study were to determine the species composition and density of natural conifer regeneration following selective logging in southeast Alaska. Therefore, we quantified the density and size of new cohort spruce and hemlock and current seedling bank in 17 selectively logged stands. All stands were in mixed hemlock-spruce forests that were logged between 1900 and 1984, located at or near sea level, and not managed after this first logging.

New cohorts included trees that germinated after logging plus advanced regeneration that was shorter than 1.4 m (standard height for diameter measurement - diameter at breast height, d.b.h.) at time of logging. With the exception of one tree, we found new cohort spruce only in plots that had been logged. New cohort hemlock were common in both logged and unlogged plots. New cohort spruce basal area ranged from 2 to 19 m^2 / ha. Individuals were as large as 104 cm d.b.h. but generally ranged between 19 and 55 cm d.b.h. New cohort hemlock basal area ranged from less than 1 to 32 m^2 / ha. The largest tree was 102 cm d.b.h. but most ranged from 11 to 51

cm d.b.h. The absence of new spruce in unlogged plots strongly suggests that disturbance favors spruce recruitment.

The seedling bank included trees 0 to 3 m tall and less than 2.5 cm d.b.h. These seedlings became established after logging. The seedling bank density of both species was high; spruce ranged from 3,000 to 114,000 and hemlock ranged from 47,000 to 723,000 seedlings / ha. Rooting substrate (logs or undisturbed forest floor) was significant for both species (spruce $p = 0.05$, hemlock $p = 0.0001$). There were always more seedlings on logs than on undisturbed forest floor.

By leaving spruce seed trees, judicious soil disturbance, planned entries to regulate overstory density and possibly planting spruce seedlings where the seed source is poor, we believe spruce can be regenerated in these systems. Pre-commercial thinning may be necessary to keep vigorously growing cohorts of spruce and hemlock in these stands, just as it is necessary in young stands regenerated after clearcutting.

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SITKA SPRUCE AND WESTERN HEMLOCK REGENERATION AFTER SELECTIVE HARVESTING, TONGASS NATIONAL FOREST, SOUTHEAST ALASKA

by

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APPROVED:

Major Professor, representing Forest Science

Head of Department of Forest Science

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Louise Simmons Yount, Author

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CONTRIBUTION OF AUTHORS

Dr. John Tappeiner was involved in on-site development of the study design and in the design, analysis, and writing of the manuscript. Robert L. Deal was responsible for leading the research team, preparation of the overstory stand density data, and analysis of tree cores.

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Introduction

Concern about the effects of clearcut harvesting on forest ecosystems in southeast Alaska has led to discussion of alternate methods for timber management. Adverse conditions resulting from clearcut harvesting include the disappearance of understory vegetation after 30 to 80 years, when canopy closure occurs (Alaback 1984). Understory vegetation is an important part of southeast Alaskan forests because it provides a reserve seeding bank of advanced conifer regeneration as well as plants, such as *Vaccinium* spp., that are a food source for wildlife.

With forest managers shifting their emphasis to include biodiversity and ecosystem health, other methods of harvesting and regenerating these stands need to be examined. To justify replacing clearcutting with selective harvest, however, it is necessary to provide evidence of adequate new conifer recruitment, particularly of Sitka spruce, which is of greatest economic value. In this study, we examined the effect of selective harvesting on the regeneration dynamics of Sitka spruce and western hemlock in southeast Alaska.

Timber harvest in southeast Alaska

Historically, timber in southeast Alaska was harvested by individuals or small groups, using hand saws and spring boards to fell trees, which were often the largest diameter Sitka spruce (Rakestraw 1994). Stands typically were accessed from the water and felled trees were usually skidded into the water by steam donkeys. Although clearcutting was already considered the preferable harvest method by the early 1900's, it did not become widely practiced until after World War II, with the development of mechanized equipment for timber harvest and road building and commercial uses for lower grade hemlock and spruce logs (Rakestraw 1994).

Clearcut and selective harvest methods

Clearcut harvesting is defined as removal of the entire stand in one cutting with reproduction obtained either artificially or by natural seeding from adjacent stands or from trees logged in the clearing operation (Nyland 1996, Smith et al. 1997). In the spruce-hemlock forests of southeast Alaska, the effect of clearcutting in the early stages of stand regeneration is an initial increase in understory vegetation, such as *Vaccinium* spp., and an increase in the percentage of spruce compared to regeneration after minor natural disturbance (Ruth and Harris 1979, Alaback and Tappeiner 1991, Deal et al. 1991). Upon canopy closure (30 - to 80 - year old stands) conspicuous understory vegetation, including conifer regeneration, shrubs and ground cover plants such as bryophytes, all but disappears or is greatly diminished until stands reach 120 - 150 years (Alaback 1982, personal observation).

Selective harvest is defined as removing single, scattered or small groups of trees with the deliberate purpose of creating or maintaining an uneven-aged stand that provides a stability of characteristic species composition and structure (Nyland 1996, Smith et al. 1997). To our knowledge there has been no systematic documentation of the effects of selective harvest on overstory or understory stand structure in southeast Alaska.

Natural regeneration

Understanding the conditions necessary for successful natural tree regeneration is an important part of understanding the regeneration niche in forest stands (Grubb 1977, Harper 1977). Seed, adequate light and moisture, suitable germination and establishment substrate, and protection from excessive mortality, are necessary parts of the early regeneration process. With a few exceptions (Taylor 1932, Taylor 1935, Alaback and Tappeiner 1991, Deal et al. 1991, Deal and Farr 1994) natural conifer regeneration has not been investigated in southeast Alaska.

While artificial regeneration is regularly used in the Pacific Northwest, natural regeneration is dominant in southeast Alaska. In coastal forests of the Pacific Northwest, forest managers plant seedlings to assure adequate seedling density after clearcut harvesting (Fowells and Schubert 1951, Gratowski 1958, Gordon 1979, Tesch and Mann 1991). Although southeast Alaska is considered part of the temperate rainforest ecosystem of the Pacific Northwest, it is not subject to some of the factors characteristic of Washington, Oregon and northern California that influence natural tree regeneration, such as summertime moisture stress, highly variable annual temperature fluctuation, and noticeable seed predation (Ruth and Harris 1979).

As a result, although forest managers in southeast Alaska are experimenting with planting seedlings to better control species composition and density (Shaw and Molina 1980), they have successfully relied on adequate seed production and sufficient moisture for establishment of natural Sitka spruce and western hemlock regeneration even in large clearcuts (Ruth and Harris 1979). Both Sitka spruce and western hemlock are prolific seeders, with an average of 463,000 / kg (210,000 / lb) and 573,000 / kg (260,000 / lb) respectively, and their seeds are easily transported by wind (Deal et al. 1991). Cone production for both species usually begins between 20 and 40 years of age, and good cone crops of both species occur every 5 to 8 years in Alaska (Harris 1990, Packee 1990).

In addition to adequate seed, sufficient light is also critical to successful regeneration. Light availability within a forest stand can affect seedlings differently at different developmental stages and is influenced both by understory vegetation and canopy cover. For example, in western Oregon, western hemlock regeneration was practically nil under covers of salmonberry and salal (Huffman and Tappeiner in review) and there was a strong negative correlation between shrub cover and conifer regeneration following thinning (Bailey and Tappeiner in press). Hemlock seedlings in the first few years after germination responded immediately and linearly to an increase in solar radiation caused by windthrow, while *Vaccinium* responded after 3 to 4 years delay (Alaback and Tappeiner 1991). In a coastal Oregon forest, Harmon (1987) found hemlock survived best under closed canopies. In the same study, spruce seedling survival peaked when tree canopy cover ranged from 70% to 80%, with lower survival at either higher or lower values.

Finally, a suitable seedbed is also an important factor affecting successful seedling recruitment (Harper 1977, Gordon 1979) and can be affected by timber removal (Stark 1965, Sidle and Shaw 1983). Exposed mineral soil, often present after harvest activity, appears to be a superior germination substrate for some species, including white spruce, Sitka spruce, red alder, and paper birch (Marquis et al. 1964, Zasada and Gregory 1969, Harris 1990, Packee 1990, Deal et al. 1991, Haeussler et al. 1995). However, other species, such as balsam fir, white cedar, and western hemlock, also regenerate on organic substrates with litter or moss cover (Christy and Mack 1984, Harmon and Franklin 1989, Deal et al. 1991, McLaren and Janke 1996, Cornett et al. 1997).

In the Pacific Northwest and southeast Alaska, western hemlock seedlings in undisturbed stands can be found most often on logs (Minore 1972, Christy and Mack 1984, Harmon 1987), but are often found throughout stands after thinning (Bailey and Tappeiner in press). In the mid 1930's, Taylor (1935) observed preferential establishment of spruce on mineral soil exposed by recent landslides, old Indian garden sites, and recently uncovered glacial out-wash, and a predominance of hemlock regeneration on the moss-covered logs and decaying wood. In stands disturbed by windthrow, Deal et al. (1991) found 80% of western hemlock regeneration on highly organic substrates and 67% of spruce regeneration on mineral and mixed-soil microsites created by windthrow events.

Scope of study

Throughout the Pacific Northwest concern about the effects of clearcutting on the forest ecosystem and loss of late-successional forests has led researchers to study the impact of selective harvest on forest structure (Gray and Spies 1997). This study is part of a larger research project titled "Alternatives to Clearcutting" which was funded by the United States Forest Service. The Alternatives to Clearcutting project is composed of two parts, an experimental and a retrospective study, the latter of which includes the study described in this thesis. Also included in the retrospective study are two other studies, one of which focused on disease and decay and the other on the structure and development of overstory trees and understory vegetation.

Study objectives

Two components of natural regeneration were of interest to us: trees recruited after logging (new cohorts) and the current seedling bank. We defined new cohorts as trees that germinated after logging plus advanced regeneration shorter than 1.4 m (breast height) at the time of logging. Seedlings in the seedling bank were defined as trees 0 to 3 m tall and less than 2.5 cm d.b.h. Within the scope of the Alternatives to Clearcutting project, the specific objectives of this thesis were 1) to quantify the new spruce and hemlock cohort and 2) to document and describe the current seedling bank of conifer regeneration.

Study area

Southeast Alaska lies between latitudes 54° and 60° N. and longitudes 130° and 138° W. This area is characterized by rugged, steeply rising coastal mountains on its border with British Columbia in the east and extends westward over this narrow belt of mainland across numerous islands to the open Pacific (Taylor 1935, Deal et al. 1991). The climate is one of cool, moist summers and mild winters. Annual precipitation ranges between 150 and 500 cm, and extended periods without precipitation are rare. Strong winds from the Pacific are common, particularly during the fall and winter months. The significance of this climate for the forest is that lack of moisture does not limit regeneration, wildfires are rare, and windthrow of trees is common (Harris 1974).

Soils in southeast Alaska are generally less well developed than in the more southerly regions of the Pacific Northwest coast. Particularly immature soils can be found in areas that have undergone recent glacial recession (Ruth and Harris 1979). Soils may be classified by parent material and have developed predominantly from granites and diorites on the mainland and from limestones on the lower slopes of the islands (Taylor 1935, Ruth and Harris 1979). Spodosols are common in this region and have similar chemical properties in their upper horizons regardless of parent material (Ruth and Harris 1979). Soils with well developed spodic and albic horizons have been found in soil surfaces less than 150 years old (Bormann et al. 1995).

Methods

Site selection

We intentionally selected sites throughout the entire area of the Tongass National Forest to examine the impact of selective harvesting on tree regeneration (Fig. 1, Table 1). The 17 sites in this study were selected by using historical records and aerial photographs. The sites were chosen to represent a chronosequence of time since harvest that occurred between 1900 and 1958, except for two sites logged in the mid 1980's. Examination of stumps and residual trees showed that all sites were mixed spruce-hemlock stands before logging. Each site had to be large enough for three logged plots and one unlogged plot, each 0.2-ha (25.2 m radius) in size. Because logging was done using cables to drag the logs from the stand into the water, except at the two sites logged in the mid 1980's, most sites were within 20 to 300 m of water and generally less than 20% slope.

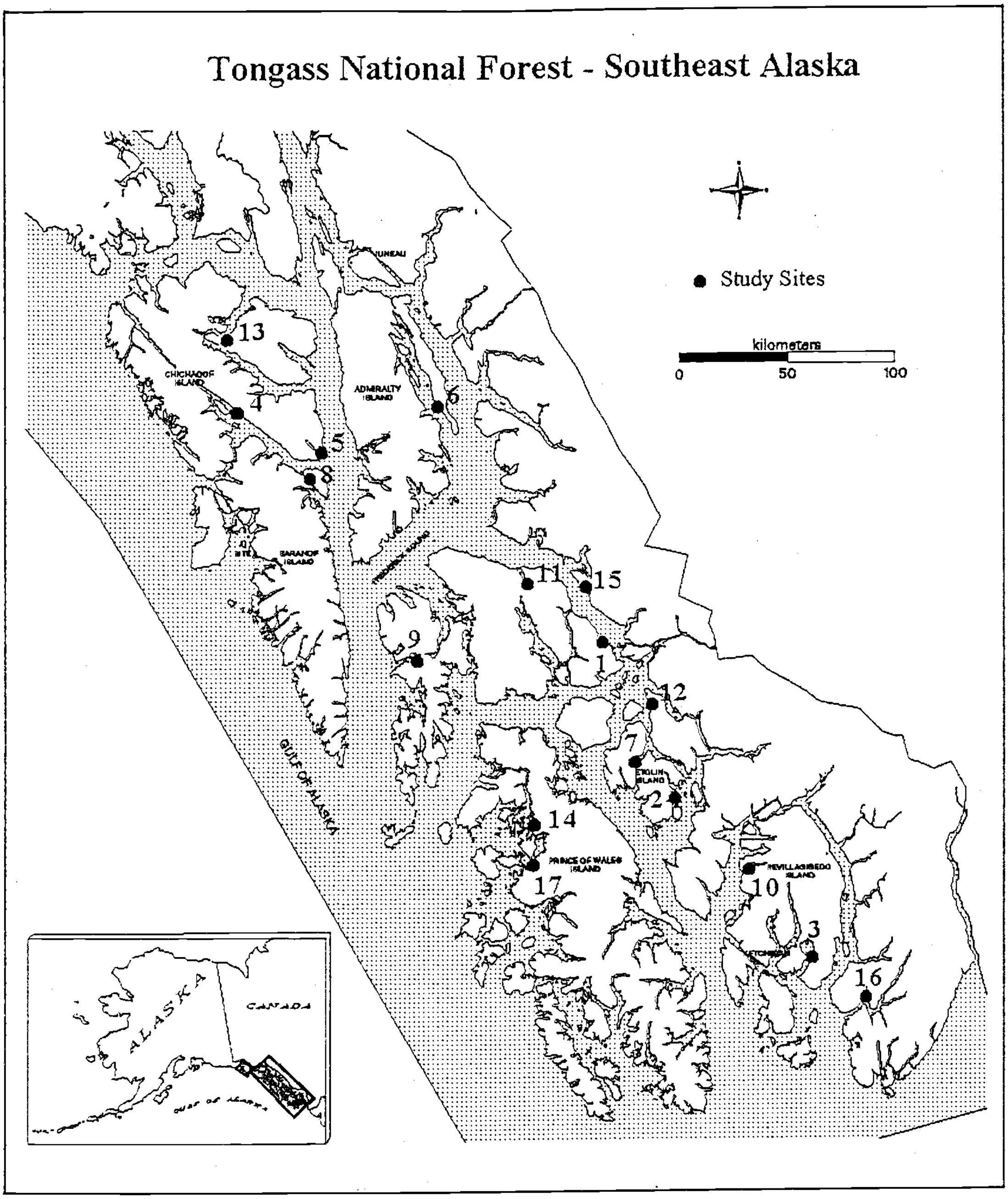


Figure 1. Location of study sites in the Tongass National Forest, southeast Alaska. Numbers refer to sites as listed in Table 1.

Table 1. Site descriptions for 17 selectively harvested sites in the Tongass National Forest, southeast Alaska. Date is date of harvest.

Site	District	Date	Elevation m	Slope %	Aspect	Plant Association
1) Big Bear Creek	Petersburg	1958	20	10	N	spruce / blueberry / devil's club
2) Canoe Passage	Wrangell	1927	90	25	WNW	hemlock / blueberry
3) Elf Point	Ketchikan	1927	39	35	NW	hemlock-red cedar / blueberry / skunk cabbage
4) Finger Creek	Sitka	1941	6	5	W	hemlock / blueberry / shield fern
5) Florence Bay	Sitka	1914	10	4	S	spruce / blueberry; spruce / devil's club
6) Glass Peninsula	Admiralty	1911	18	15	WNW	spruce / devil's club / skunk cabbage
7) Granite	Wrangell	1983	30	5	NW	hemlock / blueberry/ shield fern
8) Hanus Bay	Sitka	1922	25	20	SW	spruce / devil's club
9) Kutlaku Lake	Petersburg	1920	5	3	N	spruce / devil/s club - salmonberry
10) Margaret Bay	Ketchikan	1958	35	30	NE	spruce / blueberry
11) Portage Bay	Petersburg	1918	36	15	W	hemlock / blueberry / shield fern
12) Rainbow Falls	Wrangell	1942	20	15	SW	spruce / red alder
13) Salt Lake Bay	Hoonah	1928	10	5	NE	spruce / devil's club
14) Sarkar	Thorne Bay	1925	60	20	SSE WNW	hemlock / blueberry
15) Thomas Bay	Petersburg	1984	15	40	NW	hemlock / blueberry/ shield fern
16) Weasel Cove	Misty Fiords	1900	33	41	E	spruce / devil's club
17) Winter Harbor	Thorne Bay	1932	5	2	N	spruce / blueberry

Overstory stand structure

To provide information on current stand structure and density for the three studies within the Alternatives to Clearcutting project, nested subplots were established to survey trees, snags and stumps in different size-classes within each 0.2-ha plot. Tree species, crown position (crown class) and d.b.h. were measured for all live trees. We measured stump diameters 1.4 m from the ground to determine basal area of cut trees. We randomly selected a subsample of trees from each crown class for each tree species to be measured for tree height, live crown and health; hereafter these will be referred to as height trees. In this thesis crown classes 1) dominant, 2) co-dominant, and 3) intermediate, were used to describe cone bearing spruce within the height trees.

New cohorts

We defined new cohorts as trees that had not reached d.b.h. (1.4 m) at the time of harvest. This definition includes advanced regeneration and trees that germinated anytime after timber harvest. Tree increment cores were taken from all the height trees to analyze diameter growth rates and total age, and to determine if they were new cohort trees or if they were taller than 1.4 m when logging occurred. Cores were mounted in wooden blocks, sanded, and xylem rings were counted under a dissecting scope.

When no cores were taken in the 2.5 cm < 15 cm diameter class but new spruce cohorts had been identified in larger classes, we assumed that these smaller spruce also regenerated after timber harvest. The same assumption was not made for hemlock, however, because of its ability to persist in the understory for lengthy periods with little to no growth, and the results from our data on seedling ages. Therefore, it is important to note that diameter classes labeled as new cohort hemlock contain both new and old cohort hemlock. Further analysis of spruce and hemlock recruitment, including growth response of residual spruce and hemlock to overstory removal, is currently being conducted for the stand structure study by Robert L. Deal.

Seedling bank

Substrate

To determine seedbed preference of hemlock and spruce seedlings, we surveyed two substrates, logs and undisturbed forest floor; these will be referred to as substrate plots. In each 0.2-ha plot we located four 1 m^2 plots of each substrate type at the first log in each cardinal direction nearest the center of the 0.2-ha plot. Each forest floor plot was located adjacent to this log. Since disturbed mineral soil is considered ideal substrate for spruce seedling establishment and survival (Ruth and Harris 1979), skid trails were surveyed when present and identifiable. Hereafter this survey will be referred to as the substrate survey.

Areas such as game trails and bare rock were avoided. The decay class of logs was determined according to a classification scheme under development by Patricia Palkovic (Appendix Table A). To determine the percentage of each substrate per 0.2-ha plot, transects were run along plot diameters. Substrate type was recorded at 1 m intervals along the transect, avoiding overlap at the plot center. Fifty points were surveyed in each control plot, and 100 points were divided between the three treatment plots.

Density and size-class distribution

At each substrate plot, all conifer seedlings less than or equal to 3 m tall and less than 2.5 cm d.b.h. were recorded by species and the following size-classes: (1) 0 < 5 cm, (2) 5 < 25 cm, (3) 25 < 50 cm, (4) 50 < 100 cm, (5) 1.0 m < 1.5 m, (6) 1.5 m < 2.0 m, (7) 2.0 < 2.5 m, and (8) 2.5 ≤ 3.0 m. As part of the Alternatives to Clearcutting project, cover for ground and shrub vegetation was determined separately for each species within each 0.2-ha plot. As part of the study on overstory stand structure and understory vegetation, conducted by Robert L. Deal, the density and species of conifer regeneration less than 3 m tall within each 0.2 ha plot was included in a survey of understory vegetation. Data from this survey was then used for additional information on seedling density. Hereafter this survey will be referred to as the vegetation survey.

Ages and growth rates

Height and age measurements were taken on up to two seedlings per size-class per species per substrate plot. Ages were measured on small seedlings by counting whorls on spruce and bud scars on hemlock, or by cutting a disc from the base of the seedling stem. Growth rings were measured in the laboratory with a stereo-microscope.

Light availability: shrub cover and radiation transmission

We measured light availability at each substrate plot by visual estimation of shrub cover (1995 and 1996 field seasons) and instrumental measurement of radiation transmission through the overstory canopy, using a Li-Cor 1000 photometric sensor (1996 field season). Vegetation cover was visualized as a plane covering the $1m^2$ substrate plot and did not take into account layering of foliage.

Within-stand radiation measurements were taken at the center of each substrate plot at the ground, and between 2 and 3 m above the ground when more than 50% of the plot was covered by understory vegetation. With a second data logger, simultaneous measurements were taken 0.5 m above the ground in an open area, as close as possible to each 0.2-ha plot. When possible, these measurements were made between 1000 and 1600 hours each day, but some were made as early as 900 and as late as 1700 hours.

Seed availability

Evidence of reproductively mature Sitka spruce was measured by determining cone density in squirrel middens and presence of cone-bearing spruce within each 0.2-ha plot. We selected as many squirrel middens as were present, up to four, in each 0.2-ha plot. The number of stripped or partially stripped cones were counted within a 1 m^2 plot laid on top of each midden. During the 1996 field season the spruce height trees were inventoried for cones.

Data analysis

All statistical analyses were performed with SAS (1996). Generalized linear models were fit separately for spruce and hemlock. Current seedling bank density was analyzed for each site separately and combined to determine the site-by-site and Tongass-wide response to substrate type, treatment and shrub cover. Because the data had a Poisson distribution with over-dispersion, we used the drop in deviance test in a generalized linear model analysis for the site-by-site analysis of current seedling bank density (McCullagh and Nelder 1989).

When the 17 sites were combined, analysis of variance (ANOVA) was used because the increase in sample size (n), after a square root transformation, normalized the distribution of means (mean number of seedlings per substrate). Predicted values

(95% Confidence Interval) were calculated for the different discrete conditions (e.g. forest floor substrate in logged plots, forest floor substrate in unlogged plots). When shrub cover was significant, representative values of 25% and 75% were used in the calculations since observed shrub cover estimates clustered around these values. Skid trail substrate plots were excluded from the all-site analysis because they were only present at Thomas Bay.

Seedling density per hectare was calculated by using predicted values from the site-by-site regression analysis. Size-class distribution was determined by calculating the number of seedlings in each size-class and the proportion of seedlings found between 0.5 m and 3 m tall. An additional seedling density estimate was made by calculating the ratio of stocked plots (plots with at least one seedling) to unstocked plots using data from the substrate and vegetation survey.

At Granite and Thomas Bay, logged in 1983 and 1984, the overstory canopy on the logged plots had not yet closed. Therefore, seedling size-class distribution was calculated separately for logged and unlogged plots. This provided first-hand information on the early growth rates of new trees In the other 15 sites data from the logged and unlogged plots were pooled together after the Tongass-wide analysis with ANOVA showed that treatment was not significant for either species (hemlock $p = 0.68$, spruce $p = 0.28$).

Substrate (undisturbed forest floor and log) distribution was calculated by determining the area of ground per hectare occupied by each substrate. Because preliminary calculations showed that the area per hectare occupied by the boles of live trees and snags was negligible (< 1%), it was not included in the per hectare calculations of substrate distribution. Forest floor and log cover estimates did not always add up to 1 hectare because stumps, snags and windthrow on the transect were also recorded. Site estimates of substrate distribution from the 1995 field season showed 8.4 times more area occupied by 'other' (825 m^2 of substrate other than logs and forest floor) than estimates from sites visited in 1996 (70 m^2 other than logs and forest floor), even though transect survey methods had not changed appreciably. Because of this discrepancy, the Tongass-wide estimate of substrate distribution was calculated by averaging the 1996 site estimates.

No statistical analyses were done on squirrel midden count or cone presence. This information was used to suggest reasons why seedlings may or may not have been absent or at lower than average densities. Shrub cover was used in the seedling survey analysis. Light availability as the percentage of radiation transmitted through the canopy was calculated by dividing within-stand photosynthetically active radiation (PAR) value by PAR values recorded in the open. These data were not used in the regression analysis because they were only measured during the 1996 field season.

Results

New Cohorts

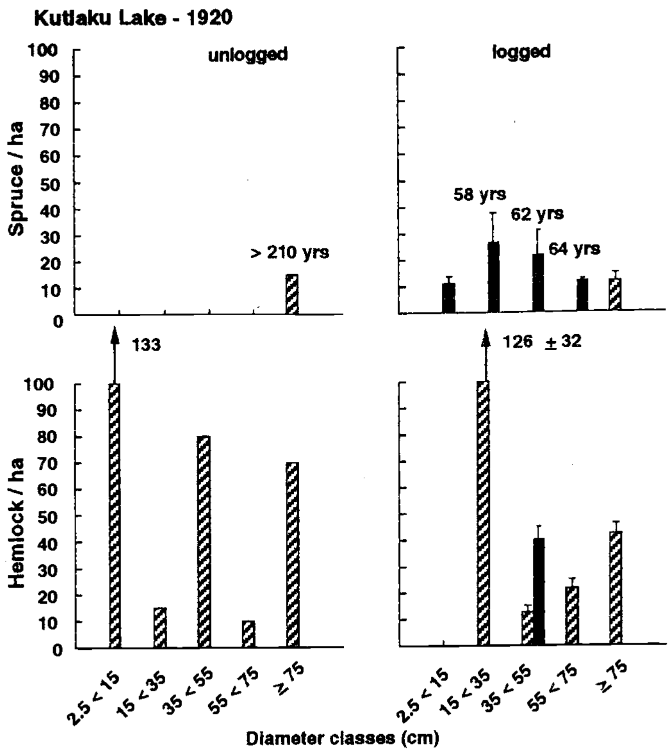
With the exception of one tree, we found no new spruce cohorts in any of the unlogged plots. In contrast, new hemlock cohorts were plentiful in both unlogged and logged plots. Of the 15 sites harvested between 1900 and 1958, new spruce were found at 11 and new hemlock at all of these sites. The new cohort spruce and hemlock at Granite and Thomas were < 2.5 cm d.b.h. and < 3 m tall.

On 9 of the 11 sites where new spruce were found, there were residual spruce that were probably the seed source. For example, at Kutlaku Lake, we found new spruce 2.5 to 75 cm d.b.h. and older spruce > 75 cm d.b.h. (Fig. 2-a). An exception to this was Sarkar (Fig. 2-b). At this site 62% of the harvested basal area was spruce, and the remaining stand was dominated by hemlock (Table 2). In spite of a limited seed source and high hemlock density, spruce regenerated after harvest to 22 stems / ha and a current basal area of 4 m^2 / ha. In contrast, regeneration at Elf Point (Fig. 2-c), typified a site with relatively few new cohort spruce (2 stems / ha, 1 m^2 basal area / ha) despite the presence of residual spruce (Fig. 2-c, Table 2).

The 4 sites at which no new cohort spruce were identified, such as Winter Harbor (Fig. 2-d), generally had a high overall hemlock density (1000 stems / ha, 54 m^2 basal area / ha). At some sites, such as Florence Bay, where new spruce were identified and overall hemlock density was moderate (125 stems / ha, 36 m^2 basal area / ha), the density of new cohort spruce (100 stems / ha, 15 m^2 basal area / ha) was high (Fig. 2-e, Table 2). At others that had a sizable new cohort spruce population, such as Kutlaku Lake, the density of new cohort spruce (75 stems / ha, 9 m^2 basal area / ha) relative to overall hemlock density (290 stems / ha, 58 m^2 basal area / ha) was much lower (Fig. 2-d, Table 2).

We found new cohort spruce as large as 104 cm d.b.h. but most often between 19 and 55 cm d.b.h. New cohort hemlock were found as large as 102 cm d.b.h. but most ranged from 11 to 51 cm d.b.h. In the logged plots, new hemlock were found in all diameter classes; at the five sites where new hemlock were found in the unlogged plots, they were all < 35 cm d.b.h. The results from the overstory stand structure surveys (current stand basal area and stem density, harvested basal area and stems, diameter class distribution of cored height trees, and the density and diameter class distribution of new and old cohorts) are listed in Appendix Tables B - D.

2-a.



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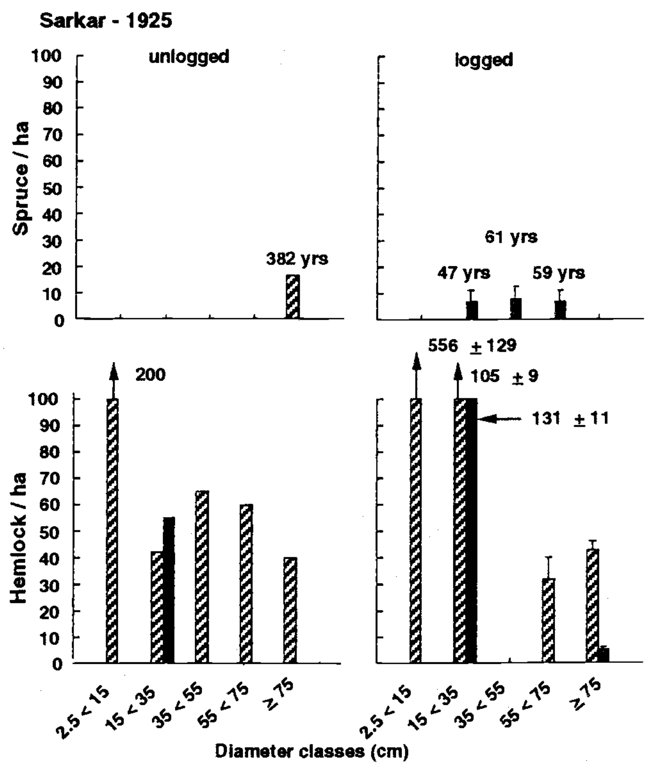
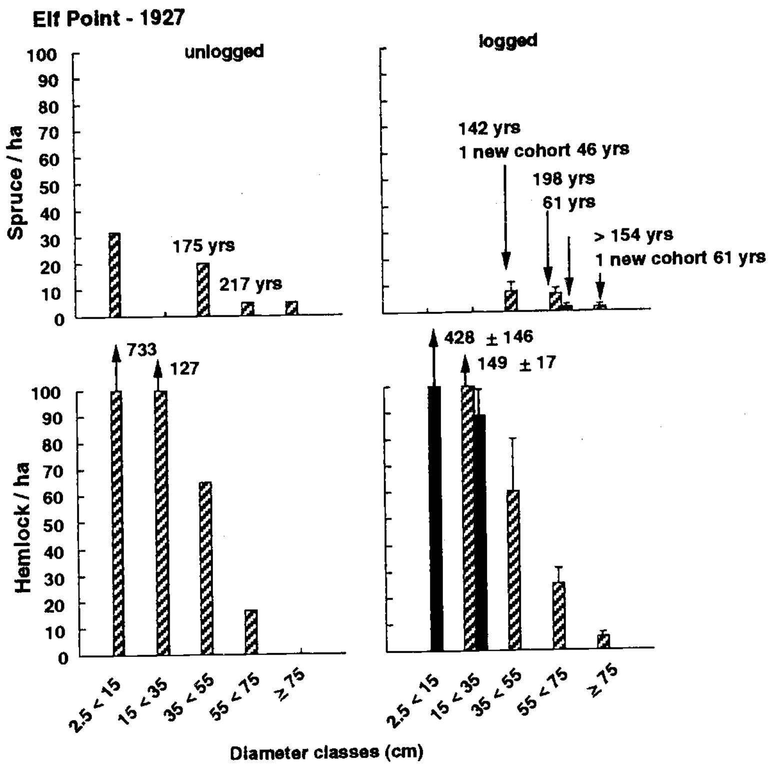


Figure 2. New and old spruce and hemlock cohorts at five sites in the Tongass National Forest, southeast Alaska. These sites were selected to show the range in numbers and sizes of trees. See Appendix Figure for a summary of all 15 sites.

2-c.



2-d.

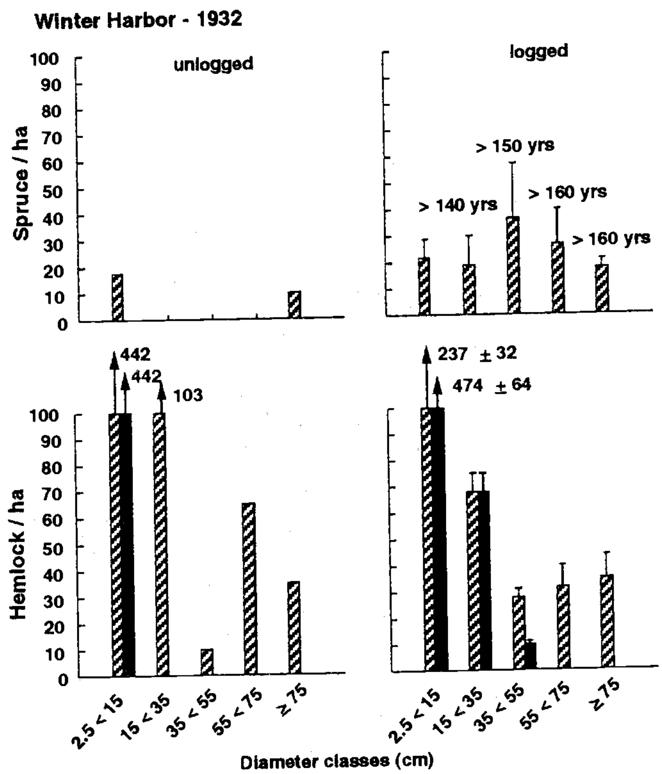


Figure 2, Continued.

2-e.

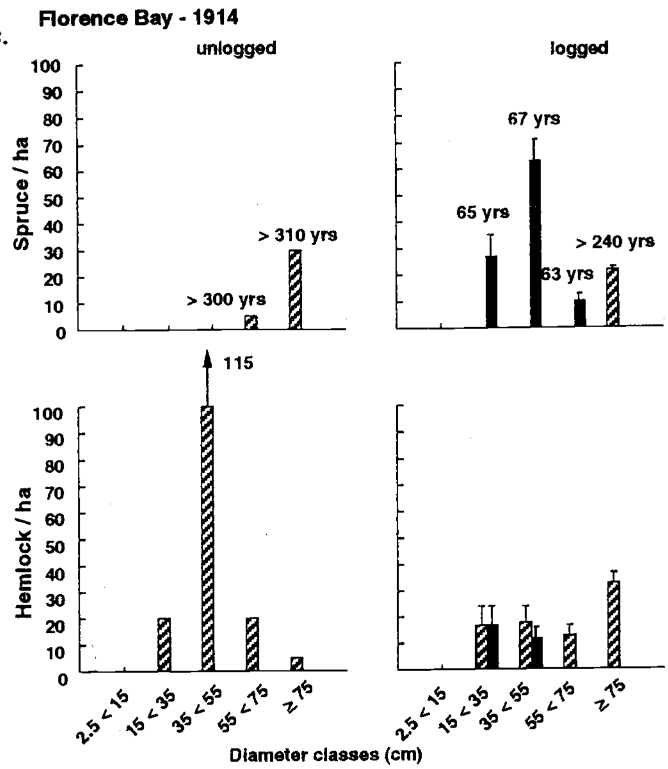


Figure 2, Continued.

Table 2. Basal area, m^2 / ha, of current stand, new cohorts, and harvest volume, for logged and unlogged plots at five selectively harvested sites in the Tongass National Forest, southeast Alaska. These sites were selected to show a range of current and new cohort basal areas. Values for logged plots averaged over three plots.

	Sarkar		Elf Point	
Current basal area	Unlogged	Logged	Unlogged	Logged
Hemlock	61	60 (± 3)	28	33 (± 4)
Spruce	16	4 (± 2)	6	8 (± 2)
New cohort basal area				
Hemlock	3	10	0	7
Spruce	0	4	0	1
Harvested basal area				
Hemlock	0	8 (± 3)	0	3 (± 1)
Spruce	0	13 (± 2)	0	15 (± 3)

	Winter Harbor		Florence Bay	
Current basal area	Unlogged	Logged	Unlogged	Logged
Hemlock	54	54 (± 10)	35	36 (± 5)
Spruce	19	30 (± 10)	28	35 (± 1)
New cohort basal area				
Hemlock	3	6	0	3
Spruce	0	0	0	15
Harvested basal area				
Hemlock	0	1 (± 0.5)	0	1 (± 0.7)
Spruce	0	29 (± 4)	0	1 (± 0.4)

	Kutlaku Lake	
Current basal area	Unlogged	Logged
Hemlock	104	58 (± 6)
Spruce	35	26 (± 3)
New cohort basal area		
Hemlock	0	6
Spruce	0	9
Harvested basal area		
Hemlock	0	0
Spruce	0	19 (± 4)

Seedling bank

Substrate

When data from all 17 sites were combined, substrate was the only significant variable influencing seedling presence for both tree species (ANOVA, hemlock $F = 15.23$ $p = 0.0001$, spruce $F = 3.49$ $p = 0.05$). Mean hemlock seedling density (± SE) was 8 (0.24) per m^2 log and 2 (0.24) per m^2 forest floor; mean spruce seedling density was 0.8 (0.05) per m^2 log and 0.2 (0.05) per m^2 forest floor.

When we analyzed the data separately at each of the 17 sites, the significance of substrate, treatment and shrub cover differed between sites and species (Table 3). Substrate was significant at 7 sites for spruce and at 10 sites for hemlock. At 3 of the 7 sites for spruce and at 7 of the 10 sites for hemlock, substrate alone was significant. In general, there were always more seedlings of both species on logs than on undisturbed forest floor.

Table 3. Significance of three variables on hemlock and spruce seedling density at 17 selectively harvested sites in the Tongass National Forest, southeast Alaska. * indicates $p \leq 0.05$, ** indicates $p \leq 0.01$. Substrate = log or undisturbed forest floor; treatment = logged or unlogged; shrub cover = % shrub cover. There were too few non-zero data points to perform analysis at these sites: "a" (11 seedlings; all ≤ 0.25 m and on logs); "b" (20 seedlings; $15 \leq 0.25$ m in logged plots on logs).

		Variables		
Site	Species	Substrate	Treatment	Shrub cover
Big Bear Creek	hemlock	**		
	spruce	**	**	
Canoe Passage	hemlock			
	spruce			
Elf Point	hemlock	*		
	spruce	*	*	*
Finger Creek	hemlock		*	
	spruce	**	*	
Florence Bay	hemlock			
	spruce			
Glass Peninsula	hemlock	**	**	**
	spruce	**	**	**
Granite	hemlock	**		
	spruce	*		
Hanus Bay	hemlock	**	*	*
	spruce			**
Kutlaku Lake	hemlock	*		
	spruce	*		
Margaret Bay	hemlock	**		
	spruce			
Portage Bay	hemlock	**		
	spruce	a		
Rainbow Falls	hemlock		**	**
	spruce			**
Salt Lake Bay	hemlock			
	spruce	*		
Sarkar	hemlock			
	spruce			
Thomas Bay	hemlock	*	**	*
	spruce			
Weasel Cove	hemlock	**		
	spruce	b		
Winter Harbor	hemlock			*
	spruce			

Treatment, logged vs. unlogged, was significant at 4 sites for spruce and at 5 sites for hemlock. At 2 of the 4 sites for spruce, and at 3 of the 5 sites for hemlock, treatment was significant with substrate. There were generally more seedlings in the unlogged plots than in the logged plots.

Shrub cover was significant at 4 sites for spruce and at 5 sites for hemlock. At 2 of the 4 sites for spruce and 3 of the 5 sites for hemlock, treatment and substrate were also significant. At the other 2 sites for spruce and 1 for hemlock, shrub cover was significant by itself. At all sites where shrub cover was significant, the coefficient was small and negative, indicating that an increase in shrub cover caused a slight decrease in seedling density.

For each discrete combination of significant variables, we calculated the corresponding seedling density (Appendix Table E). An example of the variability in density is shown for Elf Point (Table 4). At this site, substrate was the only significant variable for hemlock. There were 9.5 times more hemlock seedlings on logs than undisturbed forest floor. All three variables were significant for spruce. Spruce seedling density ranged between 3 / ha under 75% shrub cover on undisturbed forest floor in the unlogged plot to 12,000 / ha under 25% shrub cover on logs in the logged plots.

Table 4. Seedling density for discrete microsite conditions at Elf Point, Tongass National Forest, southeast Alaska. 75% and 25% refer to percentage cover of understory vegetation. See Appendix Table E for a summary of all 17 sites.

Hemlock Conditions	Hemlock Density	Spruce Conditions	Spruce Density
forest floor	21,000 (2,000 - 200,000)	forest floor / cut / 75%	60 (0 - 11,000)
		25%	800 (10 - 62,000)
		forest floor / uncut / 75%	3 (0 - 4,000)
		25%	50 (0 - 22,000)
log	200,000 (10,000 - 420,000)	log / cut / 75%	900 (40 - 21,000)
		25%	12,000 (3,000 - 49,000)
		log / uncut / 75%	50 (0 - 10,000)
		25%	700 (8 - 53,000)

Log and forest floor coverage per hectare did not differ significantly between logged and unlogged plots (F=0.63, p=0.44). There was significantly more forest floor than log surface (F=838.61, p=0.0001) in both treatments. The mean coverage of logs was 2,200 m^2 and of forest floor 7,730 m^2 / ha of forest. The remaining area (70 m^2) was green tree stems, stumps or snags. Although consistently more seedlings were found on logs than on forest floor, no pattern emerged for either species when seedling density was compared to percentage log cover per hectare of forest (Fig. 3).

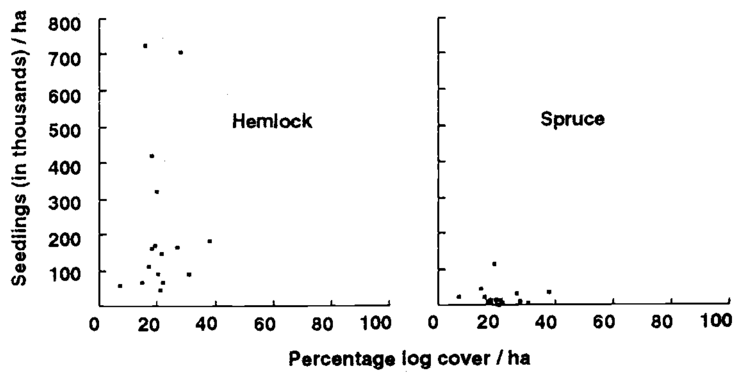


Figure 3. Hemlock and spruce seedling density, seedlings / ha, in thousands, compared to percentage log cover / ha forest floor. See Table 5 for separate densities and 95% CI at each site.

Density and size-class distribution

The density of spruce and hemlock seedlings averaged over the entire stand was generally high and differed widely from site to site (Table 5). There were always more hemlock than spruce seedlings. Hemlock density ranged from 47,000 seedlings per ha at Margaret Bay to 723,000 seedlings per ha at Thomas Bay. Spruce density ranged from zero at Margaret Bay to 114,000 at Big Bear Creek. We did find three spruce seedlings between 0.25 and 0.5 m tall in the vegetation survey at Margaret Bay, but these were not used in the analysis because they were not identified in the substrate survey.

Table 5. Hemlock and spruce seedling density, seedlings / ha, at 17 selectively harvested sites in the Tongass National Forest, southeast Alaska.

Site	Species	Density	95% CI
Big Bear Creek	hemlock	171,000	92,000-317,000
	spruce	114,000	43,000-299,000
Canoe Passage	hemlock	707,000	170,000-2,930,000
	spruce	8,000	4,000-17,000
Elf Point	hemlock	113,000	101,000-322,000
	spruce	9,000	2,000-41,000
Finger Creek	hemlock	181,000	101,000-322,000
	spruce	36,000	15,000-86,000
Florence Bay	hemlock	92,000	52,000-163,000
	spruce	7,000	4,000-14,000
Glass Peninsula	hemlock	67,000	32,000-139,000
	spruce	46,000	20,000-108,000
Granite	hemlock	163,000	88,000-300,000
	spruce	33,000	17,000-64,000
Hanus Bay	hemlock	273,000	151,000-494,000
	spruce	15,000	9,000-27,000
Kutlaku Lake	hemlock	67,000	23,000-191,000
	spruce	4,000	1,000-11,000
Margaret Bay	hemlock	47,000	21,000-107,000
	spruce	0	0
Portage Bay	hemlock	88,000	52,000-147,000
	spruce	3,000	1,000-9,000
Rainbow Falls	hemlock	320,000	162,000-632,000
	spruce	13,000	6,000-26,000
Salt Lake Bay	hemlock	59,000	35,000-100,000
	spruce	23,000	15,000-36,000
Sarkar	hemlock	419,000	268,000-656,000
	spruce	15,000	8,000-26,000
Thomas Bay	hemlock	723,000	398,000-1,315,000
	spruce	24,000	14,000-41,000
Weasel Cove	hemlock	159,000	80,000-314,000
	spruce	6,000	2,000-20,000
Winter Harbor	hemlock	149,000	100,000-223,000
	spruce	13,000	6,000-31,000

The proportion of stocked plots (plots with at least one seedling) ranged from 53% to 100% for hemlock and 0% to 66% for spruce (Table 6). At each site the proportion of plots stocked with hemlock was always greater than the proportion stocked with spruce. The proportion of stocked plots in the substrate survey was always greater than in the vegetation survey, but the trends were similar. There was a general relation between seedling density and proportion of stocked plots: higher seedling density corresponded to a higher proportion of stocked plots (Fig. 4).

Table 6. Proportion of stocked plots, plots with at least one seedling, at 17 selectively harvested sites in the Tongass National Forest, southeast Alaska.

		Proportion stocked plots	
Site	Species	substrate survey	vegetation survey
Big Bear Creek	hemlock	72	37
	spruce	66	23
Canoe Passage	hemlock	72	62
	spruce	28	7
Elf Point	hemlock	56	53
	spruce	19	6
Finger Creek	hemlock	53	20
	spruce	28	5
Florence Bay	hemlock	88	31
	spruce	50	9
Glass Peninsula	hemlock	56	50
	spruce	11	4
Granite	hemlock	71 - logged 63 - unlogged	75 - logged 45 - unlogged
	spruce	58 logged 63 unlogged	20 - logged 5 - unlogged
Hanus Bay	hemlock	81	29
	spruce	56	10
Kutlaku Lake	hemlock	66	25
	spruce	13	3
Margaret Bay	hemlock	66	39
	spruce	0	3 unlogged
Portage Bay	hemlock	72	50
	spruce	16	10
Rainbow Falls	hemlock	81	45
	spruce	41	10
Salt Lake Bay	hemlock	69	7
	spruce	56	3
Sarkar	hemlock	97	43
	spruce	41	10
Thomas Bay	hemlock	96 - logged 100 - unlogged	63 - logged 80 - unlogged
	spruce	58 - logged 38 - unlogged	28 - logged 10 unlogged
Weasel Cove	hemlock	81	64
	spruce	16	8
Winter Harbor	hemlock	84	45
	spruce	41	3

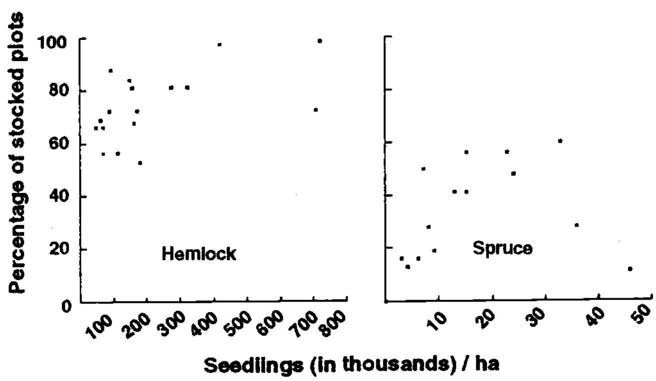


Figure 4. Proportion of stocked plots, plots with at least one seedling, compared to hemlock and spruce seedling density, seedlings / ha, in thousands, in the Tongass National Forest, southeast Alaska.

The size-class distribution of seedlings in the seedling bank at each site roughly followed an inverse-J curve for both spruce and hemlock, with higher seedling density in the smaller size-classes than in the larger ones (Fig. 5). When sites were arranged from oldest to the most recent harvest, as in Figure 5, no clear pattern emerged. Arranging sites north to south showed a general decrease in numbers of spruce seedlings in the two smallest size-classes, but no pattern in hemlock size-class distribution. At 13 of the 17 sites, the proportion of seedlings between 0.5 m and 3.0 m was less than 10% (Table 7). This is generally the case for both spruce and hemlock. Noticeably different from this, however, were the percentages of large seedlings at Granite and Thomas Bay. At these two sites, cut in 1983 and 1984, 19%

and 25% of spruce seedlings were between 0.5 m and 3 m (maximum height: Granite, 2.5 m; Thomas Bay, 2 m). For spruce, this percentage is much higher than at any other site except Weasel Cove (Table 7), where 15% of spruce seedlings were in this height range.

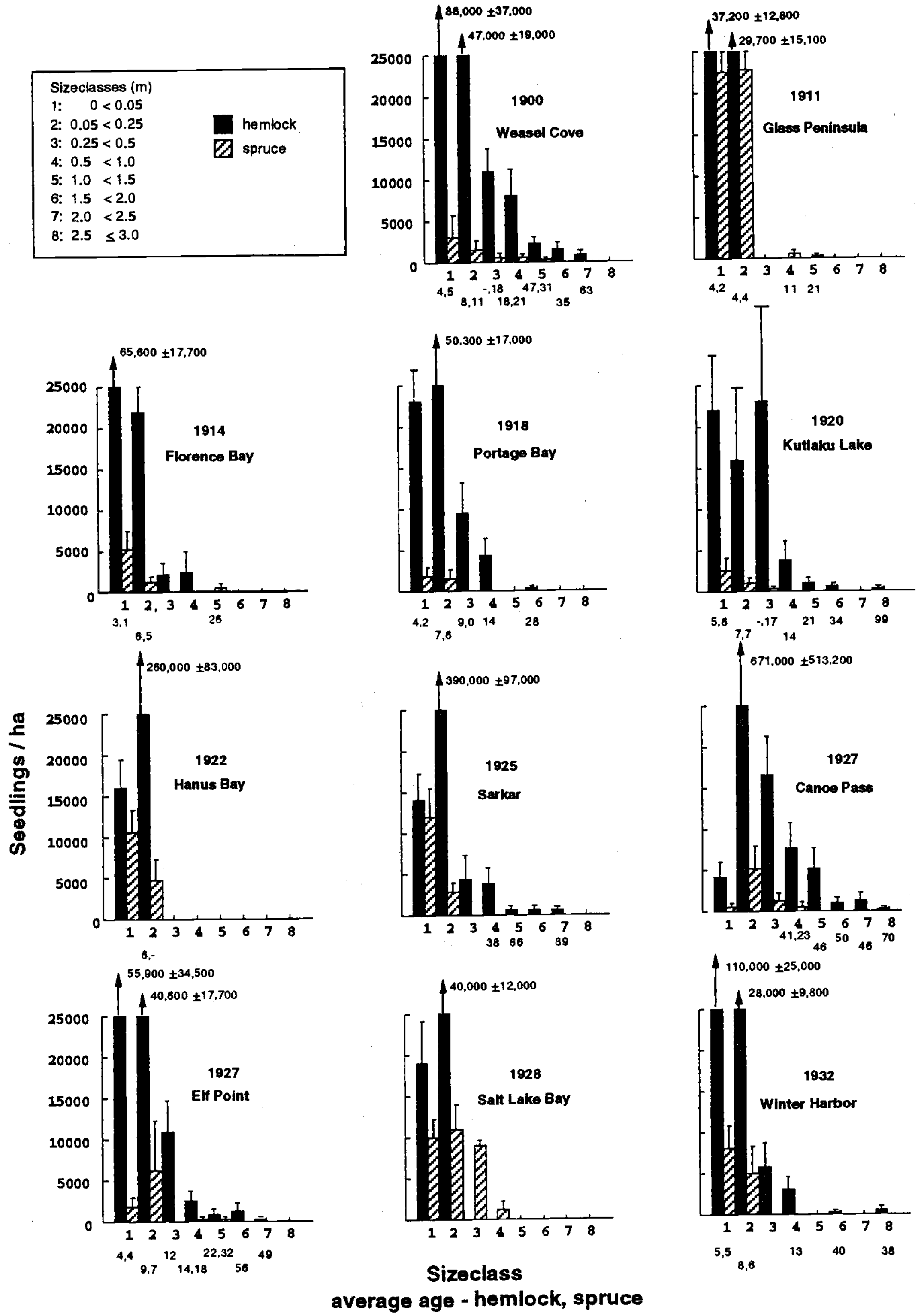


Figure 5. Size-class distribution of hemlock and spruce seedlings at 17 selectively harvested sites in the Tongass National Forest, southeast Alaska. Sites are arranged from oldest to most recent logging date. Numbers below size-classes are the average age of hemlock and spruce seedlings found in that size-class.

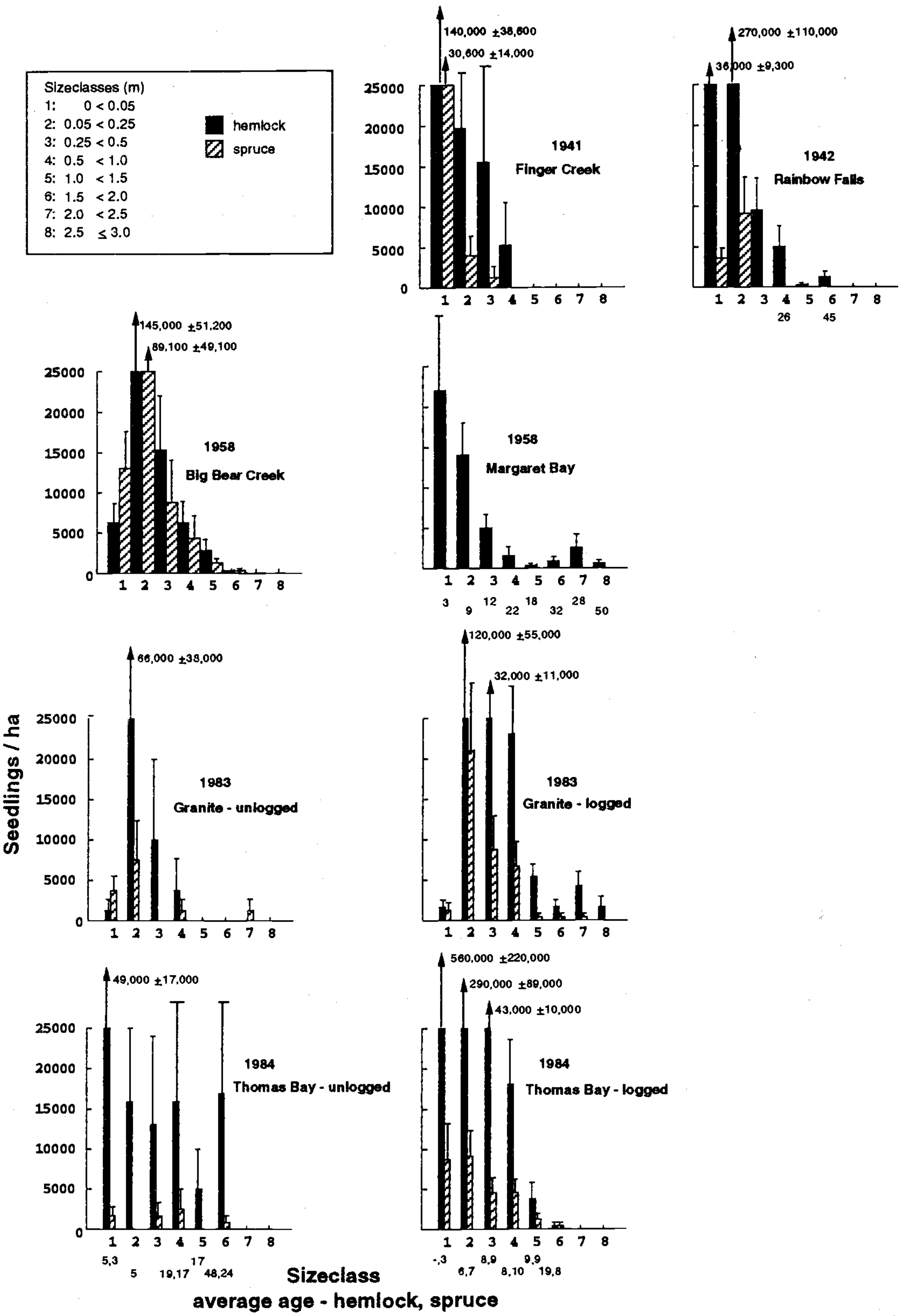


Figure 5, Continued.

Table 7. Percentage of hemlock and spruce seedlings between 0.5 and 3 m tall at 17 selectively harvested sites in the Tongass National Forest, southeast Alaska.

Site	Species	% Seedlings 0.5 - 3 m	Site	Species	% Seedlings 0.5 - 3 m
Big Bear Creek	hemlock	5	Margaret Bay	hemlock	13
	spruce	5		spruce	0
Canoe Passage	hemlock	2	Portage Bay	hemlock	5
	spruce	8		spruce	0
Elf Point	hemlock	4	Rainbow Falls	hemlock	2
	spruce	7		spruce	0
Finger Creek	hemlock	3	Salt Lake Bay	hemlock	0
	spruce	0		spruce	5
Florence Bay	hemlock	3	Sarkar	hemlock	1
	spruce	8		spruce	0
Glass Peninsula	hemlock	0	Thomas Bay	hemlock	3
	spruce	2		spruce	25
Granite	hemlock	17	Weasel Cove	hemlock	9
	spruce	19		spruce	15
Hanus Bay	hemlock	0	Winter Harbor	hemlock	3
	spruce	0		spruce	0
Kutlaku Lake	hemlock	9			
	spruce	0			

Ages and growth rates

The mean age of seedlings was 19 years for hemlock (n = 350) and 8 years for spruce (n = 140). There were only 15 spruce between 1.0 and 3.0 m tall, five of which were at Thomas Bay. The age range for these spruce was 7 to 41 years; the mean height growth rate ranged from 4 to 19 cm / year. There were 57 hemlock between 1.5 and 3.0 m. The age range for these hemlock was 19 to 110 years; the mean height growth rate ranged from 2 to 9 cm / year.

For seedlings 20 years old and younger, height growth was usually greater on logs than on undisturbed forest floor and greater for hemlock than spruce (Table 8). Hemlock seedlings were usually older than spruce and older on logs than forest floor. However, at Thomas Bay, height growth rates were greatest on skid trails for spruce and greatest on undisturbed forest floor for hemlock. On these skid trails, spruce were growing 1.5 times faster than hemlock.

Table 8. Age, year, height, cm, and height growth, cm / year, for spruce and hemlock seedlings ≤ 3m tall and 20 years old or younger, on three substrates, logs, undisturbed forest floor and skid trails, in the Tongass National Forest, southeast Alaska. Values under Tongass were calculated from data collected at 15 selectively harvested sites logged between 1900 and 1958. Thomas Bay was selectively harvested in 1984.

	Log			Forest floor			Skid trail		
Tongass	Mean	SE	*n*	Mean	SE	*n*	Mean	SE	*n*
hemlock									
age	8.0	0.4	134	7.4	0.5	56	-	-	-
height	26.4	2.9	137	15.5	2.8	56			
height growth	2.3	0.2	132	1.7	0.2	56	-	-	-
spruce									
age	7.0	0.6	76	3.8	0.4	27	-	-	-
height	15.7	3.7	74	3.8	0.38	27			
height growth	1.7	0.2	74	1.2	0.2	27	-	-	-
Thomas Bay									
hemlock									
age	8.5	1.3	19	8.2	0.9	10	7.2	0.35	11
height	40.7	9.9	19	70.7	13.4	10	51.5	13.3	11
height growth	4.1	0.57	19	8.2	1.4	10	7.0	1.8	11
spruce									
age	8.1	1.0	12	8.2	1.1	6	6.3	0.92	6
height	23.8	5.6	12	46	14.6	6	77.8	25.1	6
height growth	2.7	0.42	12	5.0	1.0	6	10.2	3.1	6

Light availability: shrub cover and radiation transmission

Shrub cover values at the substrate plots were generally clumped around 25% and 75% cover (Table 9). There was a general pattern of a higher percentage of shrub cover in the unlogged plots than in the logged plots; the difference (% cover unlogged plots - % cover logged plots) generally ranged from - 5 to + 74. Radiation transmission (SE), measured at nine sites, ranged from 1.2% (0.079) to 8.9% (0.40) below shrubs and from 2.8% (0.25) to 17.5% (0.51) above shrubs (Table 9).

Table 9. Percentage shrub cover (SE) and percentage radiation transmission (SE) at 17 selectively harvested sites in the Tongass National Forest, southeast Alaska.

Site	Treatment	Shrub cover	% Radiation transmission below shrubs	% Radiation transmission above shrubs
Big Bear Creek	unlogged	54 (2.9)	.	.
	logged	38(1.6)	.	.
Canoe Passage	unlogged	49 (3.2)	.	.
	logged	33 (1.6)	.	.
Elf Point	unlogged	37 (15.9)	1.6 (0.5)	.
	logged	29 (6.5)	3 (0.4)	7.8 (1.5)
Finger Creek	unlogged	13 (2.9)	.	.
	logged	3 (0.2)	.	.
Florence Bay	unlogged	34 (12.5)	3.3 (0.5)	5.8 (1.3)
	logged	31 (8.7)	5 (3)	10.8 (9.4)
Glass Peninsula	unlogged	29 (13.6)	3.8 (1)	7.2 (1.6)
	logged	21 (6.5)	2.8 (0.2)	4.1 (0.2)
Granite	unlogged	29 (2.7)	.	.
	logged	86 (1.3)	.	.
Hanus Bay	unlogged	29 (2.9)	.	.
	logged	26 (1.6)	.	.
Kutlaku Lake	unlogged	13 (8.2)	4.8 (0.4)	5.1 (0.03)
	logged	18 (6.1)	2 (0.2)	3.3 (0.5)
Margaret Bay	unlogged	84 (2.1)	2.7 (0.1)	9.1 (0.3)
	logged	10 (1.3)	3.3 (0.1)	7.0 (1.0)
Portage Bay	unlogged	15 (1.9)	6.9 (0.7)	.
	logged	11 (1.1)	2.9 (0.1)	.
Rainbow Falls	unlogged	39 (2.9)	.	.
	logged	32 (1.6)	.	.
Salt Lake Bay	unlogged	90 (2.0)	.	.
	logged	33 (1.9)	.	.
Sarkar	unlogged	45 (2.2)	.	.
	logged	3 (0.5)	.	.
Thomas Bay	unlogged	36 (3.1)	3.5 (0.2)	6.5 (0.3)
	logged	34 (2.5)	8.9 (0.4)	17.5 (0.5)
Weasel Cove	unlogged	31 (2.9)	.	.
	logged	24 (1.5)	3.2 (0.2)	5.7 (0.2)
Winter Harbor	unlogged	23 (3.5)	8.5 (1.1)	5.3 (0.8)
	logged	18 (1.8)	1.2 (0.1)	2.8 (0.3)

Seed availability

Squirrel middens of spruce cones were present in 8 of 17 sites. The average number of stripped or partially stripped cones per m^2 of midden ranged from 70 to 300. At sites with middens, the number of middens ranged from 2 to 13 per site. Spruce trees bore cones in 6 of 10 sites where canopy trees were surveyed (Table 10).

Table 10. Availability of Sitka spruce seed in 17 selectively harvested stands in the Tongass National Forest, southeast Alaska, as evidenced by squirrel middens, cone density in the middens (cones / m^2), and presence of cone-bearing spruce (identified by crown class and d.b.h., cm).

			Cone-bearing spruce	
Site	Middens	Cone density	Crown class	d.b.h.
Big Bear Creek	6	70	-	
Canoe Passage	0	0	-	
Elf Point	0	0	1	75.0
			2	64.0
Finger Creek	6	300	-	
Florence Bay	6	100	1	145.1, 134.8, 75.9, 78.6, 145.6, 103.3, 81.4, 98.8
			2	54.2, 53.6, 60.8
			3	51.7
Glass Peninsula	0	0	1	145.6, 103.3, 81.4, 98.8
Granite	3	90	-	
Hanus Bay	13	160	-	
Kutlaku Lake	3	120	1	152.0, 135.8, 182.0, 66.0
Margaret Bay	2	130	-	
Portage Bay	0	0	1	67.5, 165.7
Rainbow Falls	0	0	-	
Salt Lake Bay	0	0	-	
Sarkar	0	0	-	
Thomas Bay	0	0	-	
Weasel Cove	3	160	-	
Winter Harbor	0	0	1	119.0, 75.3
			2	78.8, 49.6
			3	65.1

Discussion

Spruce and hemlock regeneration in new cohorts and the seedling bank

Hemlock and spruce regeneration was plentiful after selective cutting. A number of factors could be suggested to explain this result. In particular is the ability of hemlock to persist in the understory for many years with little growth. We found hemlock less than 3 m tall to persist up to 110 years of age whereas the oldest spruce less than 3 m tall was only 41 years old.

Hemlock readily become established in closed canopy stands as shown by their presence as new cohort trees in both logged and unlogged plots, whereas, with one exception, we found new cohort spruce only in logged plots. It is encouraging, however, that new spruce were identified at 12 sites despite no deliberate management for spruce recruitment. The presence of spruce trees as a seed source at the time of harvest may have been one of the most important factors influencing spruce recruitment at these sites, even though the relationship between residual spruce and amount of new spruce was unclear. Other factors that influence recruitment, such as canopy openness and ground disturbance immediately after harvest, could not be determined in this study.

Granite (logged in 1983) and Thomas Bay (logged in 1984) were the only study sites with open canopy and detectable skid trails, factors which likely caused the difference in size-class distribution between these two locations and the rest of the sites. In the logged plots at both of these sites, spruce seedlings extended into the largest size-classes (1.5 m and taller, Fig. 5). At the other 15 sites, it was rare to find spruce taller than 0.5 m and hemlock taller than 1.5 m. Although the seedling bank size-class distribution differed between sites, both species generally followed the same pattern, inverse-J shape, characterized by 90% or more of the seedlings being smaller than 0.5 m tall (Fig. 5).

While Sitka spruce regenerates well on exposed mineral soil seedbed (Harris 1990, Ruth and Harris 1979), results from other studies (Christy and Mack 1984, Harmon and Franklin 1989, Deal et al. 1991) support our observations that spruce and hemlock seedlings in uneven-aged spruce-hemlock stands are found most often on logs.

Windthrow mounds and pits -- disturbed mineral soil from the root systems of windthrown trees -- are sources of exposed mineral soil, yet we rarely observed either spruce or hemlock seedlings on these microsites that were more than a few years old. Deal et al. (1991), however, found 67% of spruce regeneration on mineral and mixed soil microsites created by windthrow. On the other hand, in recently harvested stands spruce clearly regenerates well on heavily disturbed areas such as skid trails where mineral soil was exposed (Fig. 1 Granite and Thomas Bay, Ruth and Harris 1979). There appears to be a functional difference between the exposed mineral soil created by windthrow and that from logging.

In this study, the observed preference of spruce and hemlock seedlings for woody substrates in naturally regenerated uneven-aged stands may be related to high precipitation and shallow soils. Harmon and Franklin (1989), however, found that freedom from competition with shrubs rather than saturated soil was likely the reason hemlock seedlings in coastal Washington preferentially establish on raised woody substrates. Since the nutrient content of wood is very low (Minore 1972, Sidle and Shaw 1983), compared to mineral soil, the competitive advantage for light that conifer regeneration has over understory vegetation may be an important reason for large numbers of conifer seedlings on woody substrates.

Seedling bank density

Although seedling density varied widely between species and from site to site, numbers of spruce and hemlock seedlings per hectare were generally high. This was not surprising, since both spruce and hemlock are prolific seeders and the seedling density of naturally regenerated clearcuts is usually very high (Ruth and Harris 1979). Since these seedlings represent advanced regeneration, a selective harvest prescription could be designed to retain the most vigorously growing spruce and hemlock in the seedling bank, while also creating microsites (i.e. disturbed forest floor) that promote establishment of new spruce seedlings and the faster growth of this species.

Seed availability, seed predation and light availability are factors that influence seedling density. Big Bear Creek (114,000 seedlings / ha), Glass Peninsula (46,000 seedlings / ha) and Finger Creek (36,000 seedlings / ha) had the three highest densities of spruce seedlings. Of these three sites, Big Bear Creek had a size-class distribution that extended up to 2.0 m with representation in all size-classes. This may be explained by a medium to low amount of shrub cover (54% in the unlogged plot and 38% in the logged plots) and evidence of seed production, i.e. large cone bearing spruce and squirrel middens (Table 10).

In contrast, spruce seedling density at Finger Creek was very high in size-class 1 (0.0 to 0.05 m), but decreased substantially in size-classes 2 and 3. Low shrub cover estimates at the seedling plots (13% in the unlogged plot and 3% in the logged plot) do not explain the absence of spruce seedlings taller than 0.5m and hemlock seedlings taller than 1.0 m. Radiation transmission was not measured at this site, however, perhaps low light limited conifer regeneration to these small sizes (Fig. 5).

Ages and growth rates

The results from this study suggest that growth rates of advanced natural regeneration are uniformly low for spruce and hemlock in stands where canopy conditions more closely resemble old growth than recent clearcuts. Growth rates appear low in stands in which understory vegetation has invaded or the overstory canopies have closed but can be noticeably higher after partial canopy removal and ground disturbance. Because most of the samples for both species were under 1.4 m tall, the growth rate data from our study supply additional information on seedling development.

Harris (1990) reports early spruce height growth is slow in the first few years but increases rapidly thereafter, with the larger spruce trees on average sites reaching a height of 27 m in 50 years. Suppressed hemlock 50 - 60 years old commonly develop into vigorously growing trees after release, but ability to release decreases after age 100 (Packee 1990). If the advanced spruce and hemlock regeneration found at these sites can respond to increased light made available by windthrow or harvest, they should be in a good position to occupy the new growing space. No one knows the response of Sitka spruce advanced regeneration to selective harvesting. We do know that there is a seedling bank of spruce existing in the understory but cannot determine from this study if the new cohort we see in the overstory was released advanced regeneration from the seedling bank or new seedlings established after logging.

Light availability: shrub cover and radiation transmission

We were not able to distinguish a definite relationship between shrub cover and seedling density on all sites in our analyses. After seedlings reach about 25 to 50 cm, however, light seems to become more important to the survival of seedlings. P values from 0.1 to 0.3 on some sites indicate that there may be stronger relationships between seedling growth and low light values beneath shrubs and overstory trees than we were able to determine with our study design. Since radiation transmission was uniformly low, ranging between 1.2% and 18%, and shrub cover estimates ranged from 0 to 100%, with clumps around 25% and 75%, more intensive sampling would likely elucidate the connection between light availability and seedling presence.

In the coastal forests of southeast Alaska, light is considered the primary factor limiting the establishment, survival, and growth of understory vegetation because moisture and temperature extremes are minimized by the northern maritime climate (Ruth and Harris 1979, Tappeiner and Alaback 1989). Since light availability, determined by overstory canopy density, is one of the most important variables affecting understory vegetation density and seedling survival (Harmon 1987, Tappeiner and Alaback 1989, Alaback and Tappeiner 1991, Alaback and Tappeiner in press), additional investigation of specifically directed research of the light regime under forest canopies should be undertaken in future studies of conifer regeneration in southeast Alaska.

Management Implications

Although studies on commercial thinning, similar in effect to selective harvesting, have been conducted in the coastal hemlock-spruce stands at Cascade Head Experimental Forest in Oregon (Graham et al. 1985, Greene and Emmingham 1986), the researchers did not look at the effect of thinning on regeneration. Thus, this study is especially helpful for those people interested in the re-establishment phase of stand development after small-scale disturbance in hemlock-spruce forests.

The results from this study show that hemlock and spruce both regenerated in selectively harvested stands. However, their means of regeneration are apparently quite different from each other. Although new cohorts are generally thought of as having become established after a disturbance, windthrow or harvesting in this case, these new cohorts of spruce and hemlock likely resulted in part from the release of advanced regeneration in the seedling bank

Results from this study and others suggest that hemlock appears better adapted than spruce to regeneration in the understory (Harmon 1987, Packee 1990). New cohort hemlock were found in both the logged and unlogged plots (Fig. 2, Appendix Figure), but new cohort spruce, with one exception, were only in the logged plots. Also, there was always a greater density of hemlock than spruce seedlings at each site (Fig. 5) and hemlock shorter than 3 m tall persisted as long as 110 years. In contrast, there were always fewer spruce seedlings in the seedling bank (Fig. 5), and the oldest spruce seedling was only 41 years old.

The seedling bank growth rates in this study were low because of the density of overstory trees. However, both species grew best after disturbance and spruce grew best on skid trails (Table 8), suggesting that newly established seedlings may be more vigorous and that soil disturbance may favor growth. Generally, the largest seedlings of both species were found at the two sites cut in the mid 1980's, Granite and Thomas Bay. Seedlings may not grow as rapidly with selective cutting as they would in clearcut harvesting. What is important, however, is potential for growth. With subsequent thinnings, growth rates of the advanced regeneration would probably be higher and additional spruce and hemlock might also become established. These seedlings and saplings should not be expected to grow at the maximum rates found in clearcut conditions, but rather maintain their potential for growth should they be released. Preliminary analysis of diameter cores by Robert L. Deal showed rapid growth in many of the new cohort spruce. More work is needed to determine the response of advanced regeneration to release from competition with overstory trees.

It will be informative to follow stand development at Granite and Thomas Bay since new conifer recruitment can still be affected by management. In particular, we recommend that species conversion and growth rates be followed closely at Thomas Bay, noting that the pre-harvest stand was dominated by hemlock and that the early growth rate of spruce on skid trails was higher than the Tongass wide averages on all substrates (Table 8, Appendix Tables B and C).

There was no attempt to obtain regeneration after logging at these sites. However, we observed spruce and hemlock regeneration after only one partial cut and no attempt to regulate overstory density for growth and further seedling establishment. New cohort hemlock cam from both advanced regeneration and newly established seedlings. By leaving spruce seed trees, judicious soil disturbance, planned entries to regulate overstory density and possibly planting spruce seedlings where the seed source is poor, we believe sizable new cohorts of spruce can also be regenerated in these systems while maintaining the attributes of unevenaged stands. It is likely that pre-commercial thinning, may be necessary to keep vigorously growing cohorts of spruce in these stands, just as it is necessary in regenerated clearcuts.

Summary

With the exception of one tree, new cohort spruce were found only in the logged plots, whereas new cohort hemlock were found in both unlogged and logged plots. New cohort spruce had grown as large as 104 cm d.b.h., but generally ranged between 19 and 55 cm d.b.h. New cohort hemlock were as large as 102 cm d.b.h., but most ranged from 11 to 51 cm d.b.h.

Significantly more seedlings of both species were found on logs than on undisturbed forest floor when data from all sites were combined. When sites were analyzed separately, the significance of substrate (logs and undisturbed forest floor), treatment (logged and unlogged), and shrub cover varied from site to site. However, substrate was significant at the most sites, with more seedlings found on logs than on forest floor. The density of both hemlock and spruce seedlings per hectare was generally high throughout our study sites and seedling size-class distribution generally followed an inverse-J shape.

Height growth rates for hemlock and spruce were uniformly low in closed canopy stands, ranging between 1.2 and 2.3 cm / year, but increased noticeably, to 8.2 cm / yr for hemlock and 10.2 cm / yr for spruce, at the two sites harvested 12 and 13 years before our survey. The oldest hemlock and spruce seedlings less than 3 m tall were 110 years and 41 years old respectively. There was 3 1/2 times more ground surface area covered by forest floor (7,700 m^2 / ha) than by logs (2,200 m^2 / ha).

Radiation transmission was uniformly low, ranging from 1.2% to 18%. Shrub cover ranged between 0% and 100%, with clumps at 25% and 75% cover. Evidence of spruce seed production was present in most stands, either in the form of squirrel middens or cones visible in canopy branches.

Recruitment of new cohort spruce into the overstory did occur after selective harvest. With deliberate management we believe this harvest method can be a viable alternative to clearcutting while still producing sizable new cohorts of spruce. Future studies on conifer regeneration in southeast Alaska should focus on understanding the light regime under all types of forest canopies in southeast Alaska, particularly in relation to overstory tree removal, to evaluate the effects of selective cutting on Sitka spruce and western hemlock regeneration, understory vegetation, and related ecosystem attributes, such as suitability for wildlife, recreation, and timber production.

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Appendices

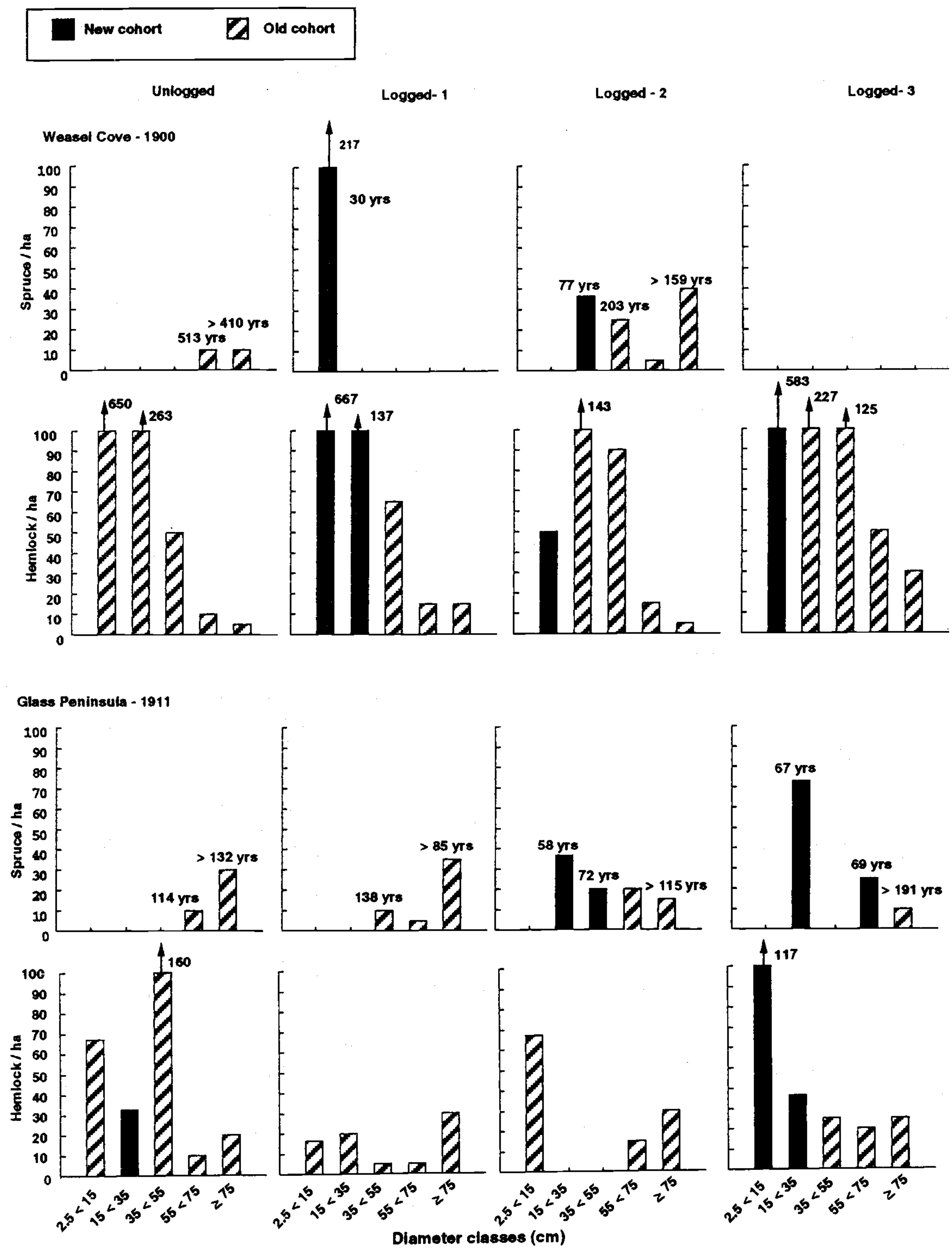
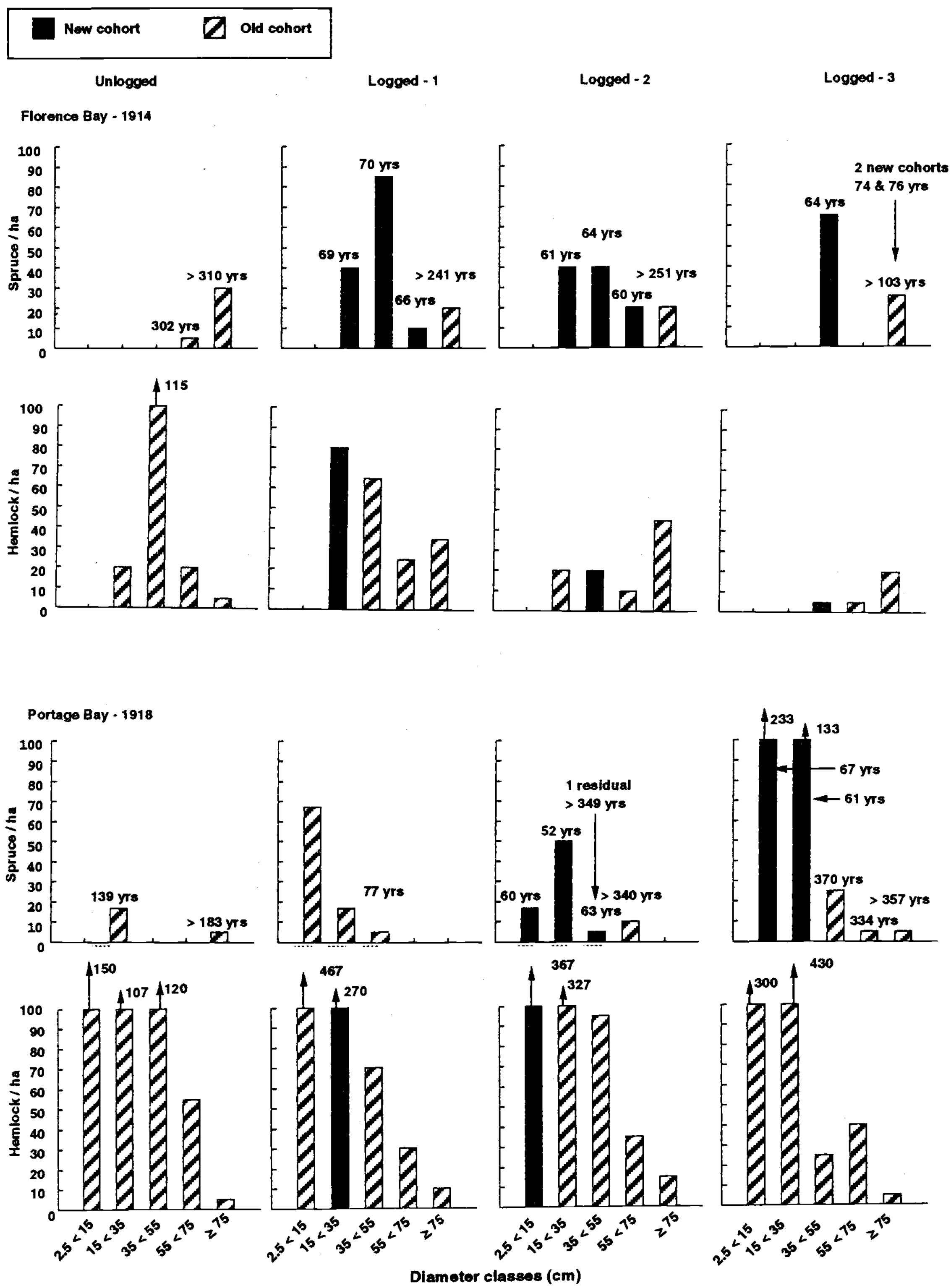


Figure. Density, trees / ha, and diameter class distribution of old and new cohorts of hemlock and spruce at 17 selectively harvested sites in the Tongass National Forest, southeast Alaska.



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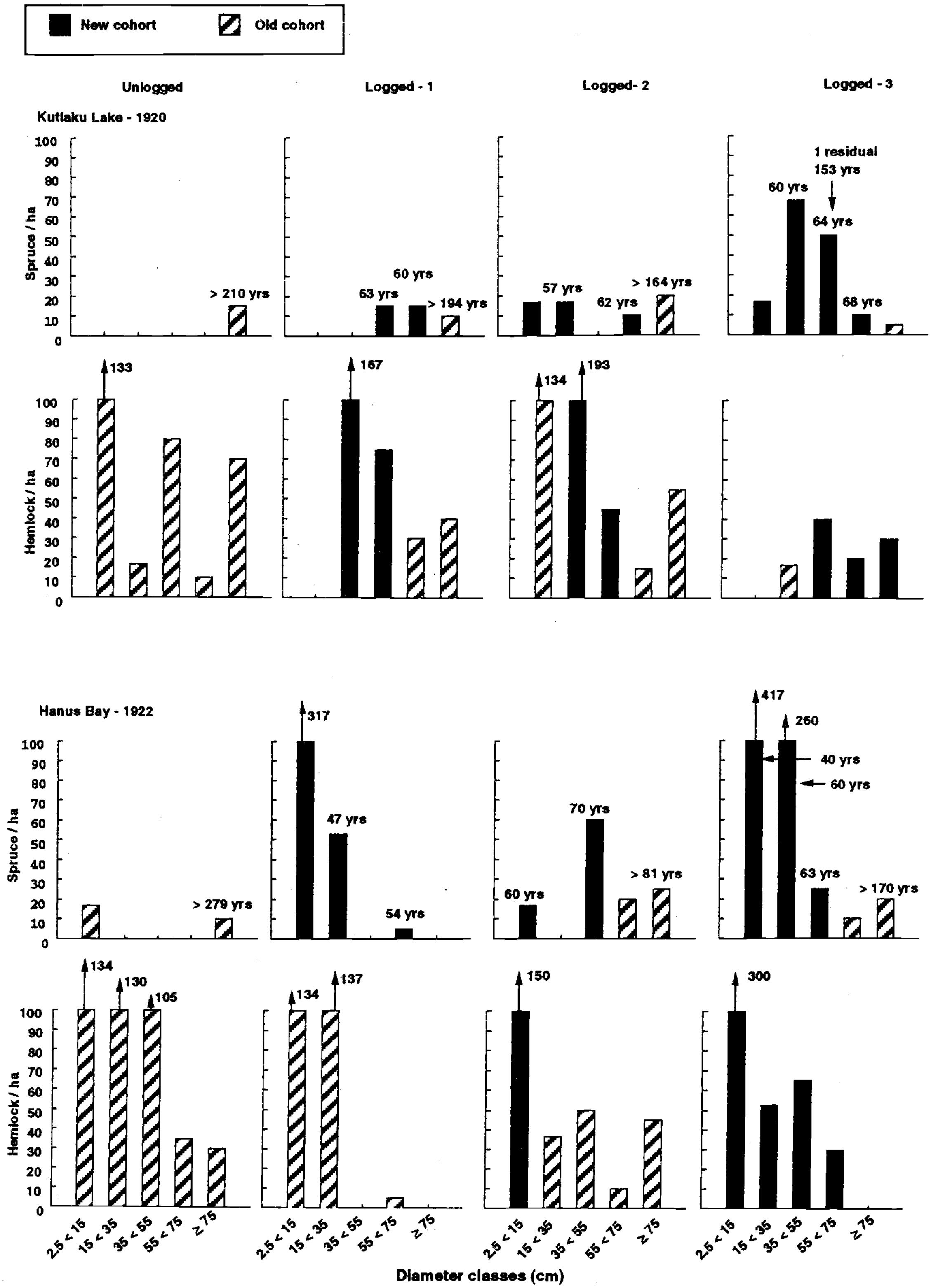

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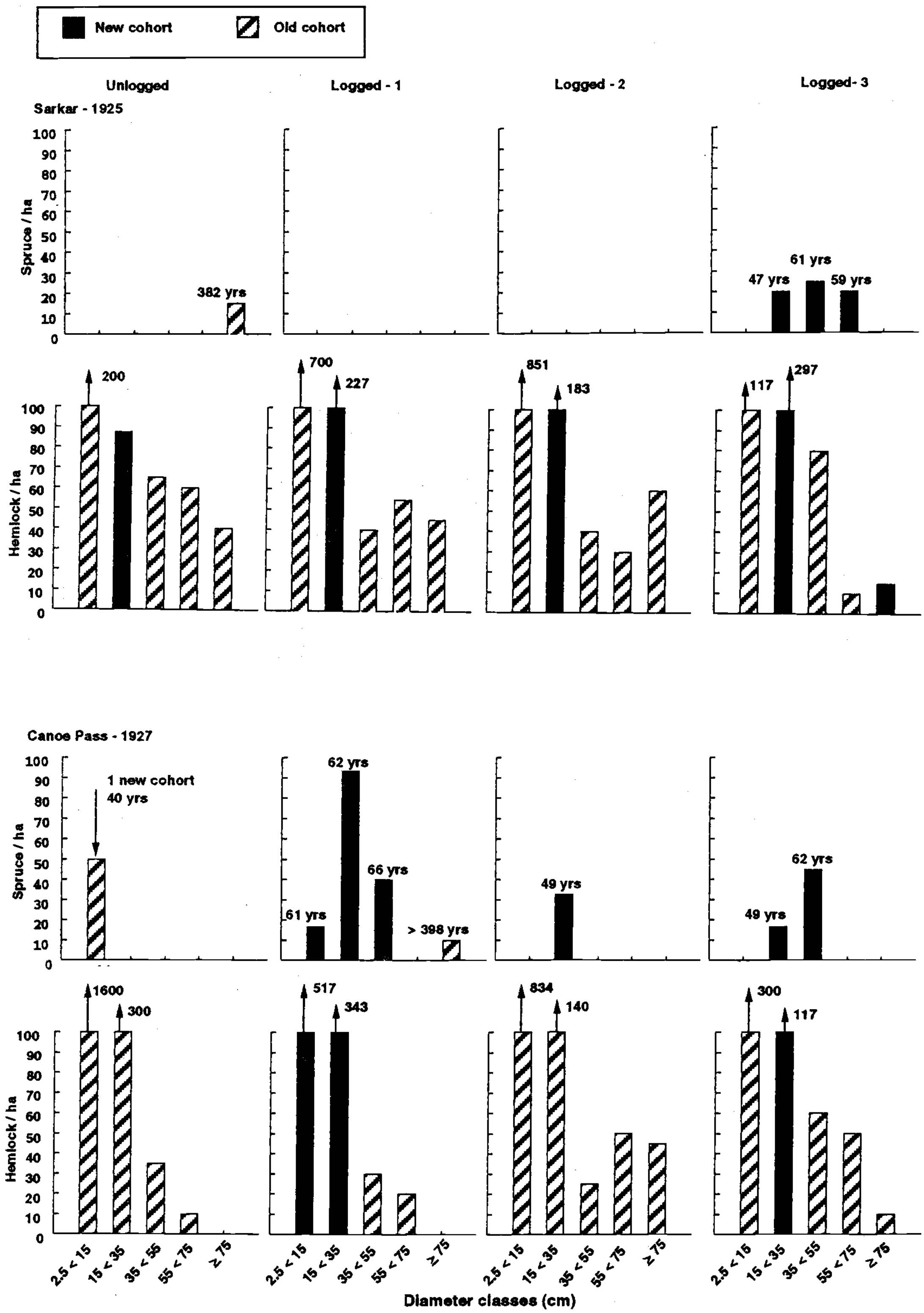

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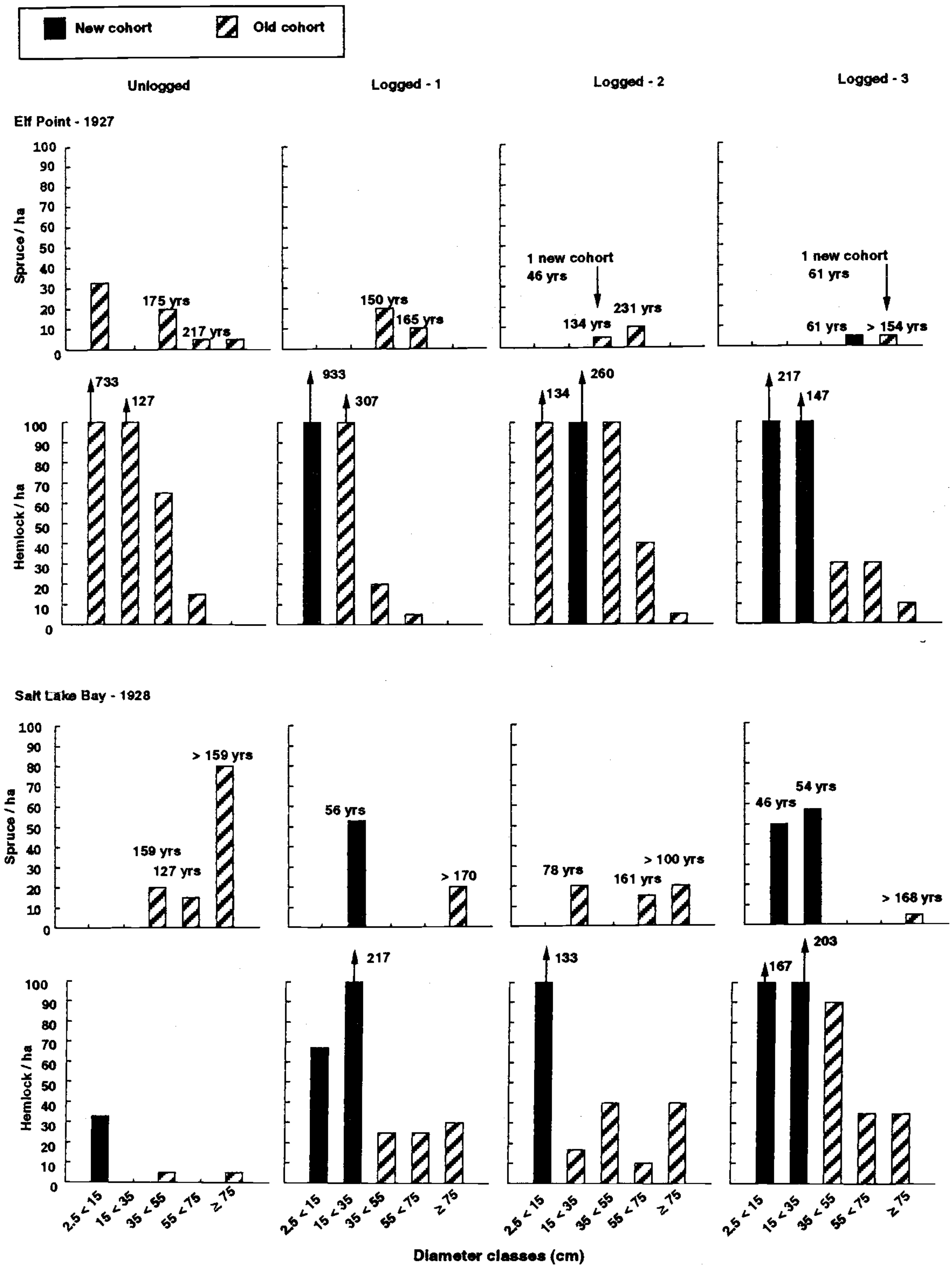

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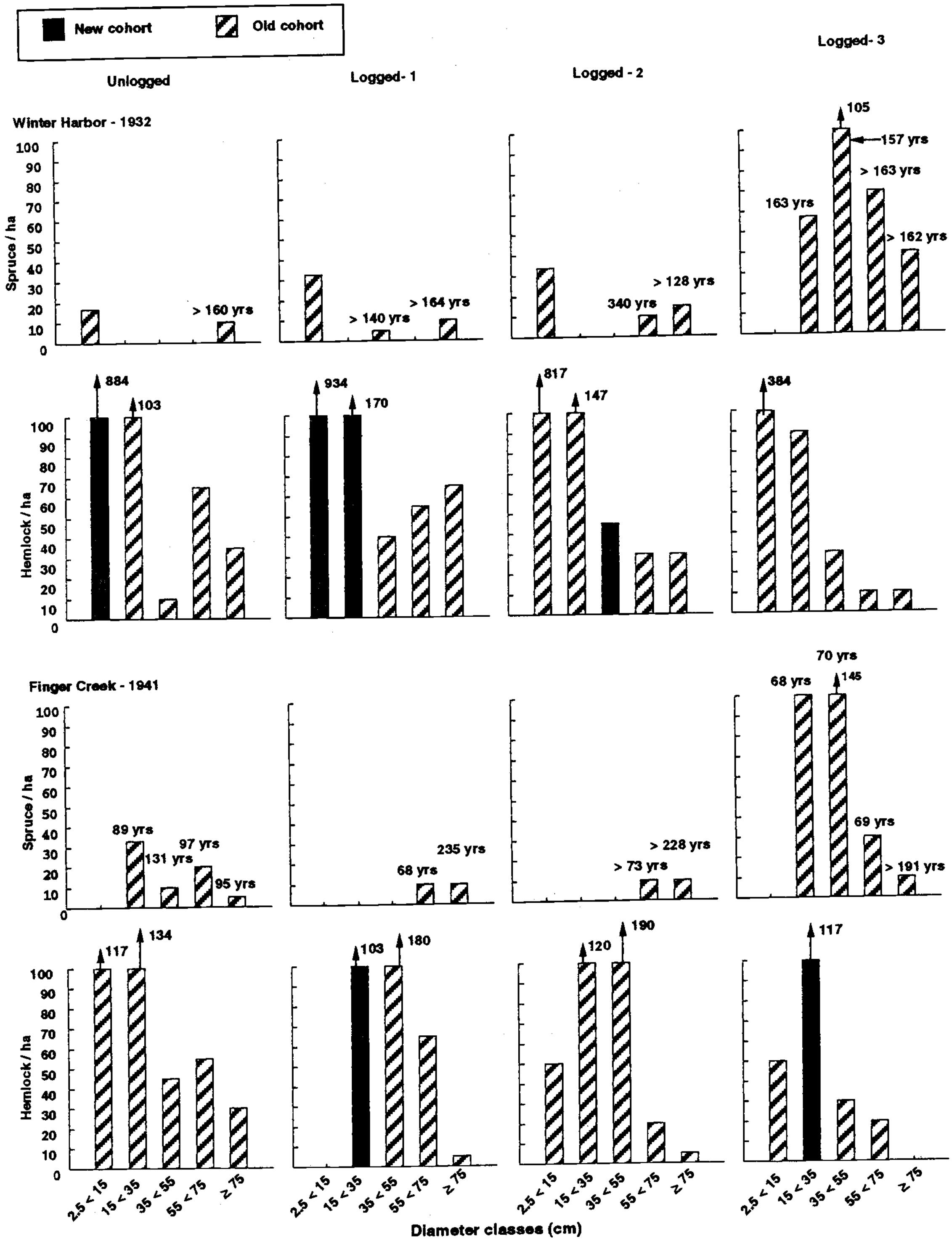

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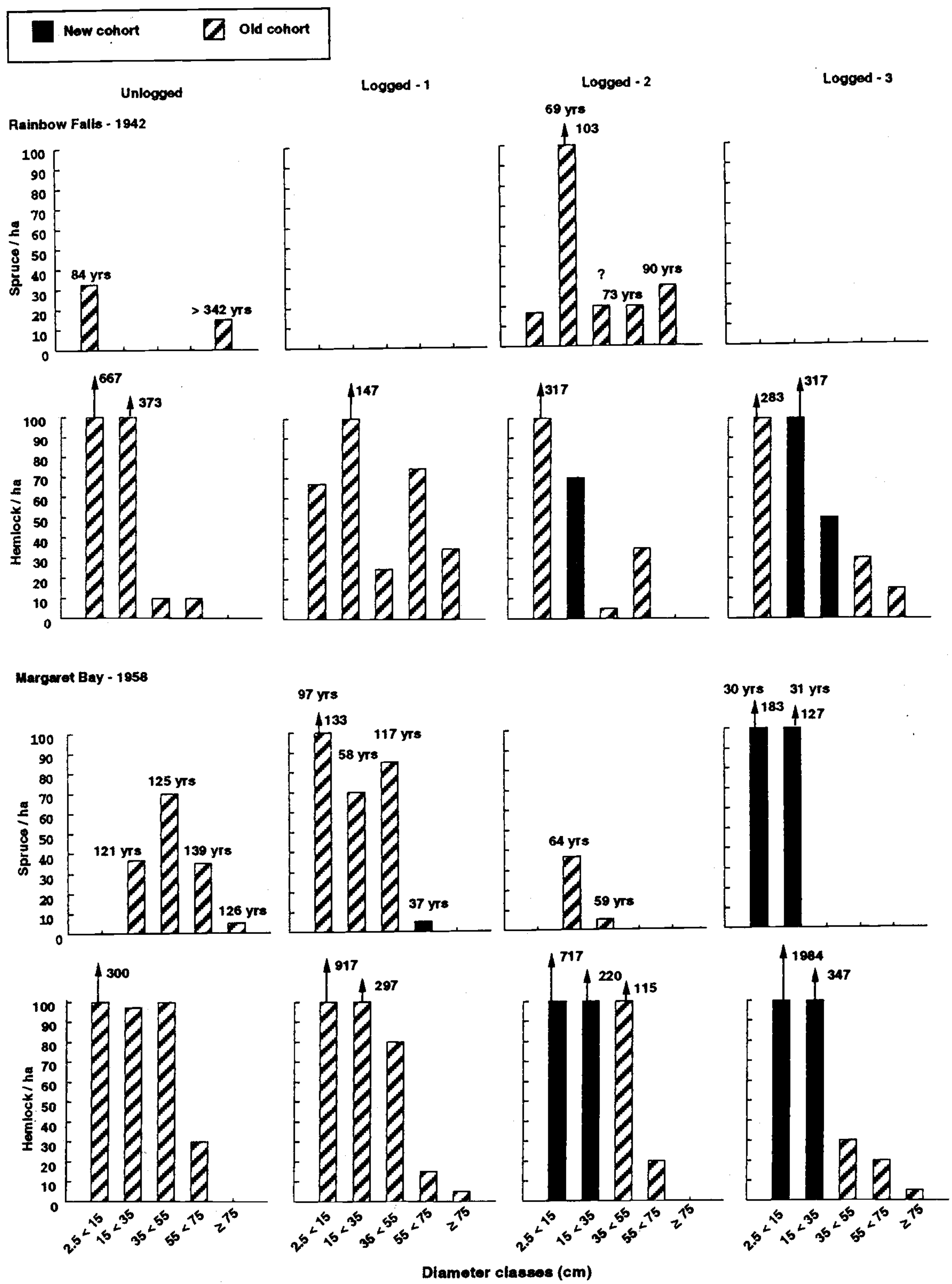

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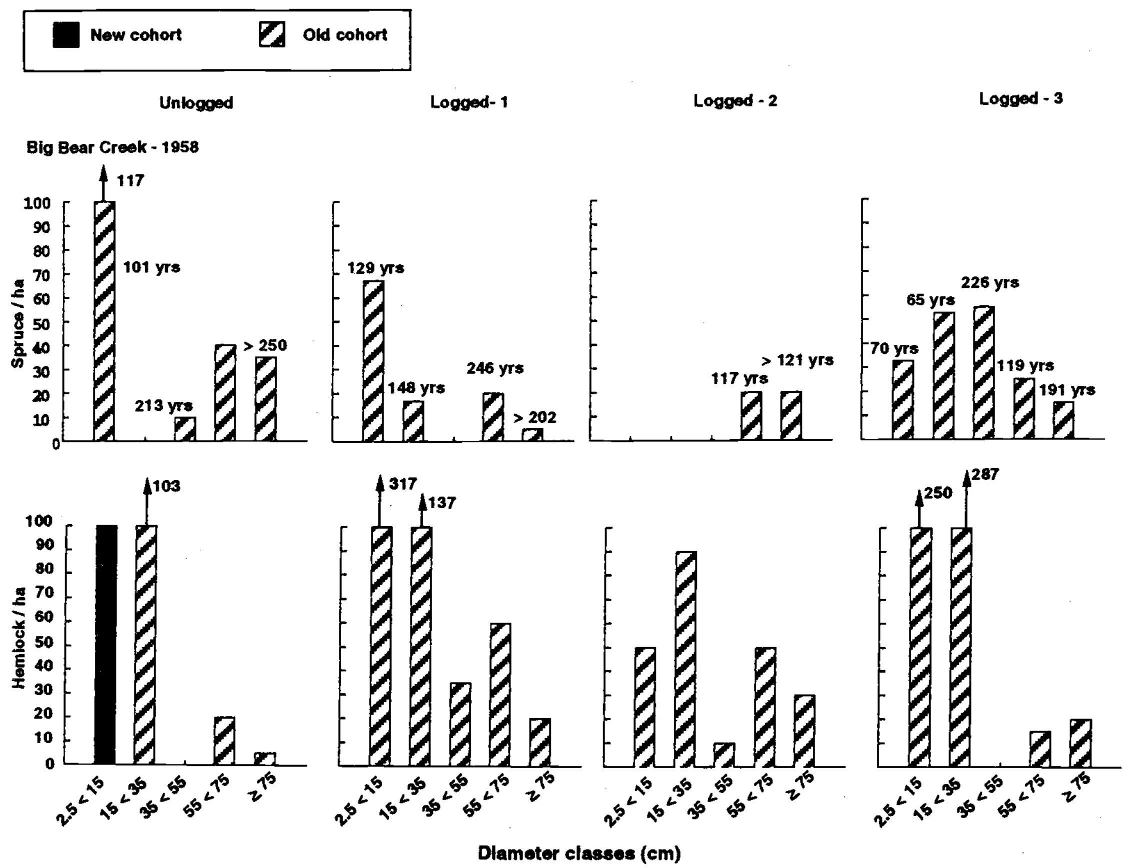

Figure, Continued.

Table A. Snag and log classification guidelines for southeast Alaska. These guidelines are currently under development by Patricia Palkovic, Juneau Forestry Sciences Lab, 2770 Sherwood Lane, Juneau, Alaska, 99801-8545.

SNAG and LOG DECAY CLASSES (1-5)

Use presence/absence of twigs and 1 and 2 branches of snag or log for classification, then move on to other features. Note that trees in any class can be broken off (and have heart rot), so look for the top on the ground. Ignore the oldest rounded-off stumplike structures that look like mounds (e.g. > class 5). To identify species, examine bark and use the hatchet-sniff test.

1 Some twigs retained, most bark intact; logs with little outer decay.

2 Twigs gone, some secondary branches retained, bark beginning to slough, top usually broken (non-cedars) or intact (Cedars); sapwood decaying.

3 ***Non-cedars***: Secondary branches gone, but primaries or stubs present, height decreasing, most bark gone; logs decaying but can support themselves;
Cedars: Primary branches retained, top usually intact, bark mainly gone, sapwood decaying, heartwood sound but beginning to check.

4 ***Non-cedars***: Branch stubs mainly gone, height decreasing, most bark gone, considerable decay of heartwood at base, logs slumping and colonized by moss or other vegetation;
Cedars: Primary branches mainly gone, bole usually intact coming to point, surface deeply checked, bark and sapwood mainly gone.

5 ***Non-cedars***: broken stumplike appearance, top portion with branch stubs gone, bark almost completely gone, wood decaying and sloughing away, colonized by vegetation, log can't support itself, becoming oval as it slumps into forest floor; log sometimes unrecognizable.
Cedars: Bole broken often with jagged top, downed portion covered by vegetation or unrecognizable.

Table B. Current stand density, stems and basal area, m^2 / ha, at 17 selectively harvested sites in the Tongass National Forest, southeast Alaska.

	Big Bear Creek				Canoe Passage			
# stems	Uncut	Cut 1	Cut 2	Cut 3	Uncut	Cut 1	Cut 2	Cut 3
hemlock	228	572	568	230	1945	910	1083	703
spruce	202	182	108	40	50	160	33	62
basal area								
hemlock	15	31	42	42	27	28	55	38
spruce	39	30	10	37	0.3	16	1	6
	Elf Point				Finger Creek			
# stems	Uncut	Cut 1	Cut 2	Cut 3	Uncut	Cut 1	Cut 2	Cut 3
hemlock	1040	1265	568	433	263	353	385	207
spruce	63	30	15	20	68	20	20	315
basal area								
hemlock	28	24	46	29	46	53	48	17
spruce	6	6	4	14	13	13	11	58
	Florence Bay				Glass Peninsula			
# stems	Uncut	Cut 1	Cut 2	Cut 3	Uncut	Cut 1	Cut 2	Cut 3
hemlock	160	238	212	30	290	77	112	223
spruce	35	172	203	123	40	50	92	108
basal area								
hemlock	35	48	40	21	44	31	27	33
spruce	28	36	34	35	37	50	27	27
	Granite				Hanus Bay			
# stems	Uncut	Cut 1	Cut 2	Cut 3	Uncut	Cut 1	Cut 2	Cut 3
hemlock	363	1440	1970	1590	433	385	292	448
spruce	25	0	0	60	27	375	122	732
basal area								
hemlock	67	13	58	20	61	50	51	24
spruce	3	0	0	2	22	6	33	42

Table B, Continued.

	Kutlaku Lake				Margaret Bay			
# stems	Uncut	Cut 1	Cut 2	Cut 3	Uncut	Cut 1	Cut 2	Cut 3
hemlock	310	312	442	107	527	1313	2385	1073
spruce	15	40	63	148	147	293	310	42
basal area								
hemlock	104	63	71	39	31	37	38	38
spruce	35	26	35	17	25	17	7	3

	Portage Bay				Rainbow Falls			
# stems	Uncut	Cut 1	Cut 2	Cut 3	Uncut	Cut 1	Cut 2	Cut 3
hemlock	437	847	838	800	1060	348	427	695
spruce	22	88	82	402	48	0	190	0
basal area								
hemlock	45	45	48	39	27	58	17	41
spruce	11	2	6	13	17	0	41	0

	Salt Lake Bay				Sarkar			
# stems	Uncut	Cut 1	Cut 2	Cut 3	Uncut	Cut 1	Cut 2	Cut 3
hemlock	43	363	240	530	452	1067	1163	523
spruce	115	73	55	112	15	0	0	65
basal area								
hemlock	4	47	43	62	61	69	64	49
spruce	83	16	26	6	16	0	0	12

	Thomas Bay				Weasel Cove			
# stems	Uncut	Cut 1	Cut 2		Uncut	Cut 1	Cut 2	Cut 3
hemlock	383	633	232		978	898	1015	303
spruce	0	133	5		20	217	0	107
basal area								
hemlock	70	49	63		30	30	63	27
spruce	0	0.3	6		10	1	0	38

	Winter Harbor			
# stems	Uncut	Cut 1	Cut 2	Cut 3
hemlock	1097	1263	1068	523
spruce	27	48	58	262
basal area				
hemlock	54	83	59	21
spruce	19	12	15	63

Table C. Harvested volume, stems and basal area, m^2 / ha, at 17 selectively harvested sites in the Tongass National Forest, southeast Alaska.

	Big Bear Creek			Canoe Passage		
# stems	Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3
hemlock	0	0	0	5	0	20
spruce	40	15	15	30	35	55
basal area						
hemlock	0	0	0	1	0	5
spruce	13	8	20	16	28	39
	Elf Point			Finger Creek		
# stems	Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3
hemlock	0	5	10	0	20	0
spruce	10	15	15	15	35	5
basal area						
hemlock	0	2	6	0	1	0
spruce	6	26	13	11	27	6
	Florence Bay			Glass Peninsula		
# stems	Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3
hemlock	10	0	0	0	0	0
spruce	5	0	0	15	5	0
basal area						
hemlock	4	0	0	0	0	0
spruce	2	0	0	14	5	0
	Granite			Hanus Bay		
# stems	Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3
hemlock	200	40	30	0	0	40
spruce	0	0	10	55	20	65
basal area						
hemlock	51	11	5	0	0	20
spruce	0	0	4	54	22	39

Table C, Continued.

	Kutlaku Lake			Margaret Bay		
# stems	Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3
hemlock	0	0	0	5	30	50
spruce	5	10	20	10	55	15
basal area						
hemlock	0	0	0	2	12	24
spruce	9	17	30	5	15	13

	Portage Bay			Rainbow Falls		
# stems	Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3
hemlock	15	35	45	60	25	15
spruce	5	40	15	10	30	25
basal area						
hemlock	5	2	12	11	2	6
spruce	2	15	6	3	15	18

	Salt Lake Bay			Sarkar		
# stems	Cut 1	Cut 2	Cut 3	Cut 1	Cut 2	Cut 3
hemlock	0	0	5	5	0	40
spruce	85	40	95	15	30	20
basal area						
hemlock	0	0	2	5	0	19
spruce	22	28	28	9	21	9

	Thomas Bay			Weasel Cove		
# stems	Cut 1	Cut 2		Cut 1	Cut 2	Cut 3
hemlock	35	20		0	5	0
spruce	0	5		5	15	5
basal area						
hemlock	18	14		0	1	0
spruce	0	5		3	11	3

	Winter Harbor		
# stems	Cut 1	Cut 2	Cut 3
hemlock	10	5	0
spruce	5	40	100
basal area			
hemlock	3	1	0
spruce	16	38	34

Table D. Diameter class distribution of cored trees at 17 selectively harvested sites in the Tongass National Forest, southeast Alaska.

Site	Species	Diameter Class (cm) 2.5 < 15	15 < 35	35 < 55	55 < 75	≥ 75
Big Bear Creek	hemlock	1	7	1	8	6
	spruce	5	3	3	5	9
Canoe Pass	hemlock	2	5	7	6	4
	spruce	1	6	2	0	2
Elf Point	hemlock	2	10	5	6	3
	spruce	1	1	6	6	5
Finger Creek	hemlock	1	7	9	9	3
	spruce	0	3	8	8	7
Florence Bay	hemlock	1	3	9	5	8
	spruce	0	5	10	6	10
Glass Peninsula	hemlock	4	3	5	6	6
	spruce	0	5	4	6	8
Hanus Bay	hemlock	3	3	5	6	6
	spruce	3	6	4	1	8
Kutlaku Lake	hemlock	0	2	3	3	7
	spruce	0	3	5	3	4
Margaret Bay	hemlock	6	9	10	4	0
	spruce	2	9	5	3	1
Portage Bay	hemlock	4	9	8	8	4
	spruce	2	7	7	3	3
Rainbow Falls	hemlock	3	7	5	5	4
	spruce	1	2	0	2	4
Salt Lake Bay	hemlock	4	13	2	4	10
	spruce	3	8	5	2	9
Sarkar	hemlock	0	9	0	6	12
	spruce	0	2	3	4	3
Weasel Cove	hemlock	4	4	8	6	6
	spruce	3	3	4	2	4
Winter Harbor	hemlock	4	4	4	4	11
	spruce	1	5	3	3	10

Table E. Spruce and hemlock seedling density, seedlings / ha, for discrete microsite conditions at 17 selectively harvested sites in the Tongass National Forest, southeast Alaska. 75% and 25% indicate percentage cover of understory vegetation. Too few non-zero data points to perform analysis at these sites: "a" (11 seedlings, all $\leq$ 0.25 m and on logs); "b" 20 seedlings; 15 $\leq$ 0.25 m in logged plots on logs).

	Hemlock		Spruce	
Site	Conditions	Density (CI)	Conditions	Density (CI)
Big Bear Creek	floor	6,000 (1,500 - 24,000)	floor/cut	300 (30 - 4,000)
			floor/uncut	5,000 (600 - 43,000)
	log	38,000 (22,000 - 66,000)	log/cut	7,000 (2,000 - 21,000)
			log/uncut	91,000 (53,000 - 160,000)
Canoe Pass	-	710,000 (170,000 - 2,900,000)	-	8,000 (4,000 - 17,000)
Elf Point	floor	21,000 (2,000 - 200,000)	floor/cut/75 %	60 (0 - 11,000)
			25 %	800 (10 - 62,000)
			floor/uncut/75 %	3 (0 - 4,000)
			25 %	50 (0 - 22,000)
	log	200,000 (10,000 - 42,000)	log/cut/75 %	900 (40 - 21,000)

Table E, Continued.

Site	Hemlock Conditions	Hemlock Density (CI)	Spruce Conditions	Spruce Density (CI)
Elf Point, cont.			log/cut/25 %	12,000 (3,000 - 49,000)
			log/uncut/75 %	50 (0 - 10,000)
			25 %	700 (8 - 53,000)
Finger Creek	cut	91,000 (41,000 - 200,000)	floor/cut	5,000 (1,000 - 18,000)
			floor/uncut	58,000 (23,000 - 150,000)
	uncut	45,000 (240,000 - 840,000)	log/cut	14,000 (5,000 - 41,000)
			log/uncut	170,000 (97,000 - 310,000)
Florence Bay	-	92,000 (52,000 - 160,000)	-	7,000 (4,000 - 14,000)
Glass Peninsula	floor/cut/75 %	800 (100 - 5,000)	floor/cut/75 %	300 (70 - 2,000)
	25 %	4,000 (1,000 - 12,000)	25 %	1,000 (300 - 4,000)
	floor/uncut/75 %	5,000 (900 - 30,000)	floor/uncut/75 %	5,000 (1,000 - 22,000)
	25 %	25,000 (9,000 - 74,000)	25 %	16,000 (5,000 - 50,000)

Table E, Continued.

Site	Hemlock Conditions	Hemlock Density (CI)	Spruce Conditions	Spruce Density (CI)
Glass Peninsula, cont.	log/cut/75 %	6,000 (1,000 - 32,000)	log/cut/75 %	4,000 (1,000 - 15,000)
	25%	30,000 (15,000 - 60,000)	25%	14,000 (7,000 - 27,000)
	log/uncut/75 %	44,000 (9,000 - 200,000)	log/uncut/75 %	65,000 (22,000 - 200,000)
	25%	210,000 (120,000 - 360,000)	25%	210,000 (140,000 - 310,000)
Granite	floor	26,000 (6,000 - 110,000)	floor	14,000 (4,000 - 49,000)
	log	300,000 (190,000 - 460,000)	log	52,000 (27,000 - 100,000)
Hanus Bay	floor/cut/75 %	15,000 (2,000 - 98,000)	75 %	2,000 (300 - 16,000)
	25 %	51,000 (17,000 - 160,000)		
	floor/uncut/75 %	36,000 (5,000 - 240,000)		
	25 %	130,000 (39,000 - 400,000)		
	log/cut/75 %	66,000 (9,000 - 460,000)	25 %	11,000 (6,000 - 22,000)

Table E, Continued.

	Hemlock		Spruce	
Site	Conditions	Density (CI)	Conditions	Density (CI)
Hanus Bay, cont.	log/cut/25 %	230,000 (110,000 - 480,000)		
	log/uncut/75 %	160,000 (24,000 - 1,100,000)		
	25 %	570,000 (270,000 - 1,200,000)		
Kutlaku Lake	floor	11,000 (700 - 170,000)	floor	600 (30 - 12,000)
	log	120,000 (55,000 - 270,000)	log	7,000 (3,000 - 17,000)
Margaret Bay	floor	6,000 (600 - 62,000)		0
	log	88,000 (47,000 - 160,000)		
Portage Bay	floor	31,000 (11,000 - 85,000)	a	
	log	140,000 (90,000 - 230,000)		
Rainbow Falls	cut/75 %	51,000 (13,000 - 210,000)	75 %	
	25 %	190,000 (92,000 - 380,000)		

Table E, Continued.

Site	Hemlock		Spruce	
	Conditions	Density (CI)	Conditions	Density (CI)
Rainbow Fall, cont.	uncut/75 %	190,000 (51,000 - 740,000)	25 %	10,000 (5,000 - 22,000)
	25 %	700,000 (360,000 - 140,000)		
Salt Lake Bay	-	59,000 (35,000 - 100,000)	floor	13,000 (6,000 - 26,000)
			log	34,000 (21,000 - 53,000)
Sarkar	-	420,000 (270,000 - 660,000)	-	15,000 (8,000 - 26,000)
Thomas Bay	floor/cut/75 %	130,000 (36,000 - 460,000)	-	24,000 (14,000 - 41,000)
	25 %	330,000 (120,000 - 920,000)		
	floor/uncut/75 %	26,000 (5,000 - 130,000)		
	25 %	65,000 (14,000 - 310,000)		
	skid/cut/75 %	250,000 (90,000 - 640,000)		
	25 %	620,000 (240,000 - 1,600,000)		

Table E, Continued.

Site	Hemlock Conditions	Hemlock Density (CI)	Spruce Conditions	Spruce Density (CI)
Thomas Bay, cont.	log/cut/75 %	570,000 (170,000 - 1,900,000)		
	25 %	1,500,000 (890,000 - 2,400,000)		
	log/uncut/75 %	110,000 (23,000 - 560,000)		
	25 %	290,000 (77,000 - 1,100,000)		
Weasel Cove	floor	23,000 (4,000 - 130,000)	b	
	log	300,000 (180,000 - 480,000)		
Winter Harbor	75 %	44,000 (11,000 - 180,000)	-	13,000 (6,000 - 31,000)
	25 %	110,000 (670,000 - 190,000)		