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The Density and Distribution of Sitka Spruce and Western Hemlock Seedling Banks in Partially Harvested Stands in Southeast Alaska

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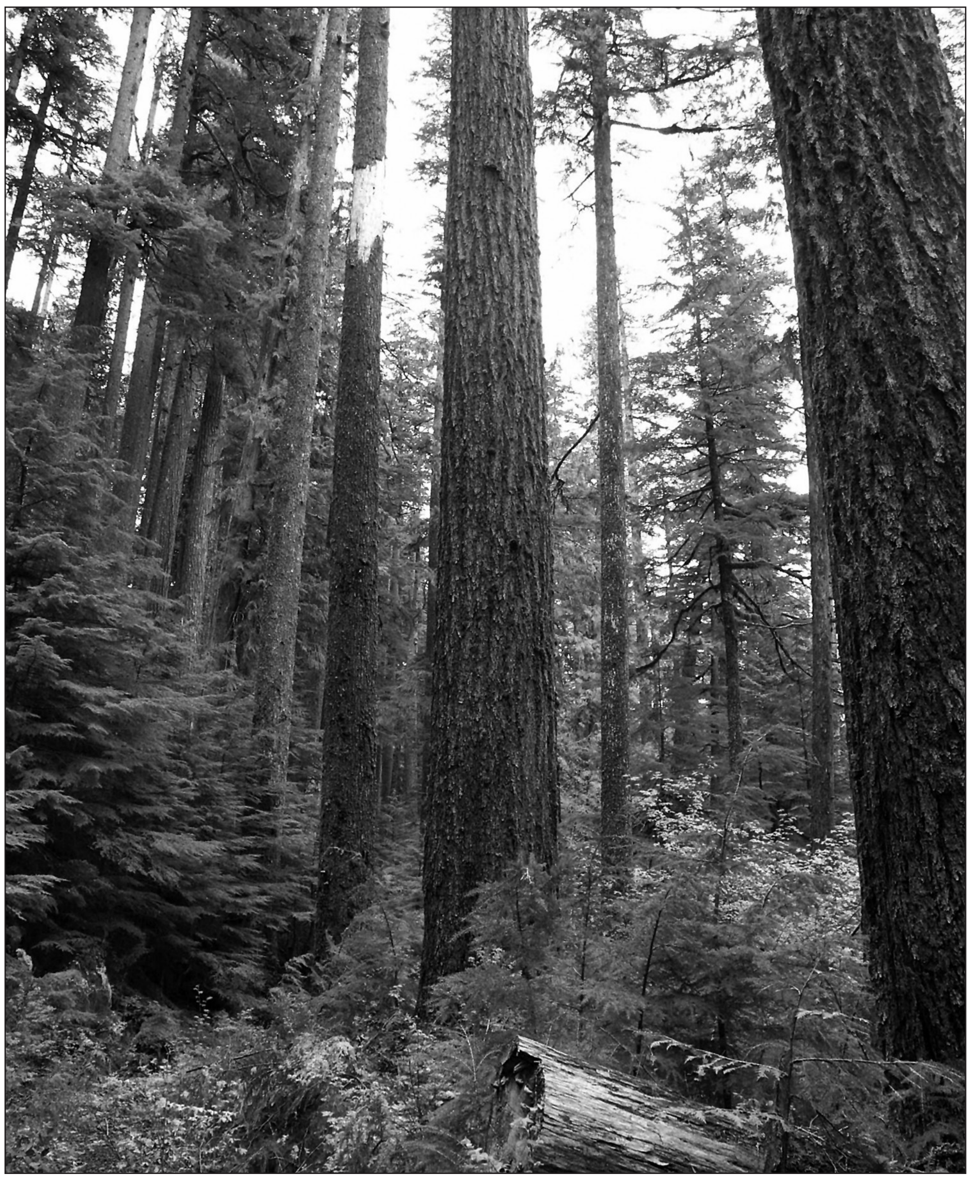

Authors

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Cover photograph by Karen Waddell.

Abstract

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This study's objective was to document and describe the current seedling bank of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) stands in southeast Alaska that were partially cut between 1900 and 1984. We investigated the following: (1) What are seedling bank densities? (2) What are seedling size- and age-class distributions? (3) Do seedbed type, treatment, and understory vegetation affect seedling density and species composition? and (4) What are seedling growth rates?

Density was high for both Sitka spruce (22,000 seedlings/ha) and western hemlock (223,000 seedlings/ha) and varied widely between sites. There were always fewer spruce than hemlock. Ninety-five percent of spruce and 94 percent of hemlock were less than 0.5 m tall. Spruce had a mean age of 8 years (range 1 to 41 years) and hemlock 19 years (range 1 to 110 years). Both species were four times as common on logs as on undisturbed forest floor. Under closed-canopy conditions at the 15 sites harvested between 1900 and 1958, the average annual height growth rate was 2.3 cm for hemlock and 1.7 cm for spruce. At the two open-canopy sites, harvested in 1983 and 1984, annual height growth rates increased to 8.2 cm for hemlock and 10.2 cm for spruce.

Our results suggest that the seedling bank of both species is established and well stocked, thus providing advanced regeneration for the postharvest stand. Because forest managers have increasing concern about effects of clearcut harvesting in Pacific Northwest forest ecosystems and renewed interest in maintaining or restoring biodiversity, other silvicultural methods warrant examination.

Keywords: Natural regeneration, seedling banks, Sitka spruce, western hemlock, southeast Alaska, partial cutting.

Summary

Concern about the effects of clearcut harvesting on forest ecosystems in southeast Alaska has increased interest in alternative methods for regeneration and timber management such as partial cutting or uneven-age management. In this study, spruce and hemlock seedling banks following partial cutting were very dense and compare favorably with naturally regenerated clearcuts in the region. Advance regeneration left after cutting grew rapidly and was a significant and dominant component of the current stand. Thus, the existence of a seedling bank in the partially cut stands provided a new cohort of trees that could easily release and grow following another cutting or disturbance event. This would suggest that partial cutting in this forest type is a sustainable silvicultural system that could maintain current tree species composition and structure on a long-term basis. It is important to remember that the stands we studied were cut to provide specific wood products such as spruce (*Picea sitchensis* (Bong.) Carr.) sawtimber and hemlock (*Tsuga heterophylla* (Raf.) Sarg.) pilings. Cutting occurred without a planned silvicultural system with little effort taken to ensure spruce regeneration. Nevertheless Sitka spruce was maintained in these stands and included both new and advance spruce regeneration. Therefore, well-planned silvicultural systems based on partial cutting will likely provide rapidly growing trees for timber production and maintain stand mixtures of spruce and hemlock trees similar to old-growth forests. Our results show that the establishment of new regeneration and the growth of larger advance regeneration trees of both hemlock and spruce can maintain species composition similar to that of study plots before cutting. The results of this study strongly indicate that silvicultural systems using partial cutting can be successfully applied in western hemlock–Sitka spruce forests in southeast Alaska. By leaving spruce seed-trees, disturbing soil judiciously, planning entries to regulate overstory density to promote seedling establishment, 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 uneven-aged stands.

Partial cutting in the spruce and hemlock forest type is a sustainable silvicultural system that could maintain current tree species composition and structure on a long-term basis.

Introduction

The natural regeneration of trees is a fundamental process for long-term forest growth and development. Natural regeneration plays an important role in a forest's response to disturbances such as windthrow and fire, and it may be part of a silvicultural system for timber management. The success of natural regeneration depends on a variety of factors including plentiful seed, suitable seedbeds for germination and establishment, and a microenvironment that enables early seedling survival and growth.

Climatic conditions are ideal for natural regeneration in southeast Alaska's temperate rain forests. Moisture is plentiful, and temperature extremes are moderate (Harris et al. 1974, Ruth and Harris 1979). In general, despite seed predation by squirrels (Yount 1997), seed availability does not appear to be a limiting factor in this region, as the major tree species—western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.)—are both prolific producers of light seeds that are easily transported by wind (Godman 1952; Harris 1967, 1969, 1990; James and Gregory 1959; Packee 1990).

Since the early 1950s, forest managers in Sitka spruce–western hemlock stands in southeast Alaska almost exclusively have used even-age silvicultural systems (i.e., clearcutting and natural regeneration). However, recent regionwide forest management plans in Alaska (USDA FS 1997) have created guidelines for timber management using alternatives to clearcutting. These plans have sparked interest in assessing the effects of partial cutting in the spruce-hemlock forests of southeast Alaska. Information on the density and species composition of the seedling bank (i.e., advance regeneration) is needed to understand how partial cutting will affect the tree species composition following partial cutting. In particular, it is important to know if Sitka spruce, a moderately shade-tolerant species, has established advance regeneration that might enable forest managers to use partial cutting or uneven-age silvicultural systems to maintain spruce. Sitka spruce is a major component of southeast Alaska forests and historically has been the most economically valuable species. It is important that Sitka spruce continue to be maintained in these forests.

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Successful natural regeneration of western hemlock and Sitka spruce following clearcutting has been well documented in this region (Anderson 1955, Harris and Farr 1974, Ruth and Harris 1979, Zasada and Packee 1995). From other studies (Alaback 1982, Christy and Mack 1984, Deal et al. 1991, Harmon 1987) and personal observation, we knew that Sitka spruce seedlings occur in the understory of coastal Pacific Northwest forests. Deal et al. (1991) documented the presence of Sitka spruce seedlings (< 1.30 m) in three stand-reconstruction plots located in mature and old-growth hemlock-spruce forests in southeast Alaska. In these three stands, he found an average of between 0 and 27,900 seedlings/ha. However, prior to this study, there was no detailed information on the composition of seedling banks of southeastern Alaska forests and how seedling banks might be affected by partial cutting.

The objective of this study was to document and describe the seedling bank of Sitka spruce and western hemlock in partially cut stands in southeast Alaska. We studied the density, size, age, seedbed, and growth rates of Sitka spruce seedlings and compared them to western hemlock seedlings, a species known to be very shade tolerant. Specifically, we investigated the following: (1) What are the densities of established seedling banks? (2) What are the seedling size- and age-class distributions? (3) Are density and species composition affected by seedbed (logs or forest floor), treatment (cut and uncut), and understory shrub cover? and (4) What are the seedling growth rates?

Related Studies

This study was one of three research projects making up the retrospective portion of the USDA Forest Service study "Alternatives to Clearcutting in the Old-Growth Forests of Southeast Alaska." A detailed background description and status report of the Alternatives to Clearcutting project is provided by McClellan (2004). Information and results from the three research projects can be found in Deal (1999, 2001), Deal and Tappeiner (2002), Deal et al. (2002), Palkovic (1998),[1] Yount (1997), and this paper. In particular, note that although this study documents and describes the **current** advance regeneration seedling bank under mostly closed-canopy conditions (15 of 17 sites), Deal and Tappeiner (2002) described the postharvest **response** of Sitka spruce and western hemlock advance and postharvest regeneration in these partially cut stands.

Materials and Methods

Study Area

Our study sites were located throughout the Tongass National Forest in southeast Alaska, which lies between latitudes 54° and 60° N and longitudes 130° and 138° W. This area is characterized by steeply rising coastal mountains and densely forested islands (Harris et al. 1974, Taylor 1935). The climate is maritime. Strong winds from the Pacific are common, particularly during fall and winter. The

[1] Palkovic, P. 1998. Patterns of tree mortality, wounding, and disease in partially harvested stands in southeast Alaska. Unpublished report. On file with: Juneau Forestry Sciences Laboratory, 11305 Glacier Highway, Juneau, AK 99801.

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 et al. 1974).

Average annual temperature and precipitation ranges from 8 °C and 145 cm (Juneau) to 11 °C and 384 cm (Ketchikan). Monthly precipitation values range widely, temperatures somewhat less so (table 1). Soils in southeast Alaska are immature Spodosols, developed predominantly from granites, diorites, and limestones, and are typical of areas that have undergone recent glacial recession (Borman et al. 1995, Ruth and Harris 1979, Taylor 1935). The forest floor is typically a mix of undisturbed and disturbed (mineral soil, tip-up mounds) areas, and downed wood in all stages of decay.

Table 1—Monthly rainfall and temperature averages for southeast Alaska

	Precipitation		Temperature	
	Low	**High**	**Low**	**High**
Month	*Centimeters*		*Degrees Celsius*	
January	5.08	29.21	-5.55	1.11
February	3.81	25.40	-3.06	1.94
March	3.81	25.40	-0.56	3.33
April	3.81	20.32	2.50	5.83
May	2.54	22.86	10.30	14.70
June	1.91	17.78	10.80	18.80
July	2.54	20.32	15.30	19.40
August	5.08	29.21	15.70	18.50
September	5.08	45.72	8.89	11.60
October	8.89	53.34	4.72	7.78
November	6.35	38.10	-0.56	9.44
December	5.08	35.56	-3.06	1.67

Source: National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Site Selection

The 17 sites in this study were logged between 1900 and 1958, except for two sites logged in the mid 1980s (table 2). The sites were selected by using both historical records and aerial photographs. Additionally, the sites were chosen with the following goals in mind (table 2, fig. 1):

- Sample a range of time since cutting.
- Sample a range of cutting intensity including an uncut area.
- Have relatively uniform topography, soils, forest type, and plant associations.
- Reflect distribution throughout the Tongass National Forest.

Examination of stumps and residual trees showed that all sites were mixed spruce-hemlock stands before logging. Most sites were within 20 to 300 m of the shoreline, and slopes were less than 20 percent. Each stand was surveyed to find a range of current stand densities and cutting intensities, with number and size of cut stumps and overstory trees noted (Deal and Tappeiner 2002). An uncut control area and three partially cut areas (light, medium, and heavy) were located in a 10-ha treatment area (also referred to as a “stand”). Two examples of the range of cutting intensities within a site are 49 to 96 percent cut (24 m^2/ha to 85 m^2/ha) at Hanus Bay and 17 to 36 percent cut (9 m^2/ha to 26 m^2/ha) at Big Bear Creek.

Because this study was a retrospective not a controlled study, quantification of cutting intensity was determined a posteriori once the range of cutting intensity had been calculated for each site. The cutting intensities are relative and reflect the variability found at each site. For additional detail on cutting intensity, please see Deal et al. (2002) and Deal and Tappeiner (2002). Four randomly located, 0.2-ha

Table 2—Site descriptions for 17 selectively harvested sites in southeast Alaska

Research site	Cutting date[a]	Average shrub cover	Current stand composition		
			Basal area	Spruce	Hemlock
No. of 0.2-ha plots/site		*Percent*	*m^2/ha*	*- - - - Percent - - - -*	
BB, Big Bear Creek (4)	1958	46	53–79	15–47	53–85
CP, Canoe Passage (4)	1927	41	44–66	2–13	74–92
EP, Elf Point (4)	1927	33	42–116	2–4	72–96
FC, Finger Creek (4)	1941	8	58–75	5–60	40–95
FB, Florence Bay (4)	1914	33	56–83	18–75	25–82
GP, Glass Peninsula (4)	1911	25	60–84	11–34	28–83
GR, Granite (4)	1983	58	13–70	0–7	93–100
HB, Hanus Bay (4)	1922	28	56–83	6–62	38–94
KL, Kutlaku Lake (4)	1920	16	58–139	5–49	35–95
MB, Margarita Bay (4)	1958	47	41–63	4–24	76–96
PB, Portage Bay (4)	1918	13	47–56	5–33	67–95
RF, Rainbow Falls (4)	1942	36	44–66	0–28	63–100
SB, Salt Lake Bay (4)	1928	62	63–87	17–73	27–83
SK, Sarkar (4)	1925	24	57–76	0–11	89–100
TB, Thomas Bay (3)	1984	35	49–70	1–17	83–99
WC, Weasel Cove (4)	1900	28	53–75	0–24	67–100
WH, Winter Harbor (4)	1932	21	73–95	2–33	67–98

[a] Cutting date is year of harvest.
Source: Deal et al. 2002, Deal and Tappeiner 2002.

circular overstory plots were installed within each treatment area at each site. The term “overstory plot” is used to distinguish these plots from the seedling bank plots described in this paper. All data were collected between late June and early September in 1995 and 1996.

Seedling Bank Data Collection

For this study we defined seedlings as being < 3 m tall and < 2.5 cm (diameter at breast height). All western hemlock and Sitka spruce seedlings were counted in eight 1-m^2 seedling plots in each overstory plot. The eight seedling plots were divided evenly between two seedbed types—logs and undisturbed forest floor. Surveys on seedbed cover conducted during this study showed the mean forest coverage of logs and forest floor was 2200 m^2/ha and 7730 m^2/ha, respectively. Four seedling plots were located at the first log nearest the center of the overstory plot in the four cardinal directions. Each forest floor seedling plot was adjacent to this log. At the Thomas Bay site, seedlings on mineral soil seedbeds from skid trails were included for comparison. Shrub cover was estimated to the nearest 10 percent by visualizing a horizontal plane covering the seedling plot and did not account for layering of foliage.

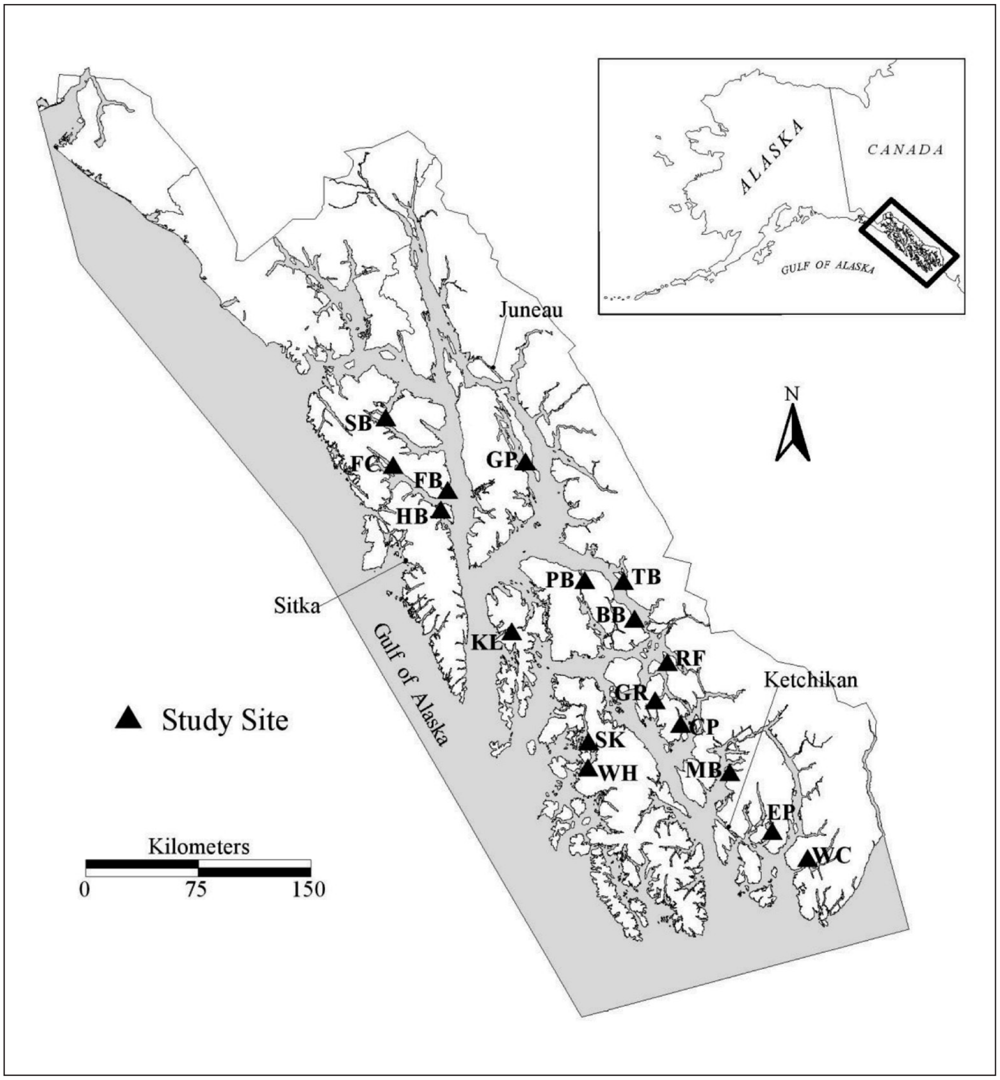

Figure 1—Location of 17 study sites in the Tongass National Forest, southeast Alaska. Site letter codes are referenced from table 2 (from Deal et al. 2002).

Size-class distribution was determined by classifying all counted seedlings into eight height classes (0 to <5 cm, 5 to <25 cm, 25 to <50 cm, 50 to <100 cm, 1.0 to <1.5 m, 1.5 to <2.0 m, 2.0 to <2.5 m, and 2.5 to ≤3.0 m). Ages and heights were measured on a subset of counted seedlings, usually one to two seedlings per size-class per seedling plot. Ages were measured 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 counted in the laboratory with a stereo-microscope.

Data Analysis

All statistical analyses were performed with SAS (1996). Seedling density was analyzed for each site separately to determine between-site variation. Because the data had a Poisson distribution with overdispersion, we used the drop-in-deviance test in a generalized linear model analysis for the individual site analysis of current seedling-bank density (McCullagh and Nelder 1989).

For the 15 sites harvested between 1900 and 1958, seedling density data from cut and uncut plots were pooled for density calculations after analysis of variance (ANOVA) of the sites showed that cutting treatment had no significant impact on seedling bank densities for either species (hemlock $p = 0.68$, spruce $p = 0.28$). That is to say, from the perspective of the current seedling bank, as defined in this study, the canopies of the unharvested control plots and the harvested treatment plots were closed and thus essentially identical in understory conditions. By contrast, in the two recently harvested sites at Granite and Thomas Bay (cut in 1983 and 1984, respectively), tree canopy closure had not yet occurred. Therefore, seedling size-class distribution was calculated separately for the cut and uncut plots to obtain information on the early growth rates of new trees under open canopy. Seedling density per hectare was calculated by using predicted values from the individual site regression analysis.

Seedling bank density was analyzed for response to seedbed (log or forest floor), treatment (cut or uncut 0.2-ha plot) and shrub cover (measured at each seedling plot). Sites were analyzed separately using generalized linear models to determine response variability among sites. When the 17 sites were combined to determine the regional response of seedlings to these variables, ANOVA was used because of the increase in sample size ($n = 17$). A square root transformation was done to normalize the distribution of means (mean number of seedlings per seedbed). Predicted values (95 percent confidence interval) were calculated for each seedbed in cut and uncut plots. On sites where shrub cover was present, representative values of 25 percent cover and 75 percent cover were used in the analysis because estimates of cover clustered around these values.

Size-class distribution was determined by calculating the number of seedlings in each size class and the proportion of seedlings found between 0.5 and 3 m tall. Size-class distribution was calculated by using predicted values from the site-by-site regression analysis and was analyzed for each site separately and then combined. Age-class distribution was determined by calculating the ages of sampled seedlings for each height class.

Results

Spruce and hemlock seedling banks are generously stocked.

Our most important results are as follows:

- Spruce and hemlock seedling banks are generously stocked.
- There are more spruce and hemlock seedlings on logs than on the forest floor.
- A higher percentage of understory vegetation cover results in a lower density of spruce and hemlock seedlings.
- Seedling bank density declines dramatically after seedlings reach 25 cm in height; however, some spruce and hemlock up to 3 m tall persist in the understory.

Seedling Density

Seedling density for both Sitka spruce and western hemlock was high and differed widely among sites, and there were always fewer spruce than hemlock seedlings (table 3). Mean spruce seedling density ranged from 3,000 to 46,000 seedlings/ha, on 15 of 17 sites, with the lowest and greatest mean density found at Margaret Bay and Big Bear Creek (0 and 114,000/ha, respectively). Mean hemlock seedling density at all sites was extremely high, ranging between 47,000/ha and 419,000/ha, on 15 of 17 sites; two sites averaged more than 700,000/ha. Although hemlock seedlings at Margaret Bay were plentiful (47,000/ha) this site had the lowest seedling density for hemlock as well as for spruce.

Table 3—Seedling density size class data for hemlock and spruce seedlings at 17 sites in southeast Alaska

	Spruce		Hemlock	
Site	Density	Seedlings 0.5 to 3.0 m	Density	Seedlings 0.5 to 3.0 m
	Thousand seedlings/ha	*Percent*	*Thousand seedlings/ha*	*Percent*
Big Bear Creek	114 (43–299)	5	171 (92–317)	5
Canoe Passage	8 (4–17)	8	707 (170–2,930)	2
Elf Point	9 (2–41)	7	113 (101–322)	4
Finger Creek	36 (15–86)	0	181 (101–322)	3
Florence Bay	7 (4–14)	8	92 (52–163)	3
Glass Peninsula	46 (20–108)	2	67 (32–139)	0
Granite	33 (17–64)	19	163 (88–300)	17
Hanus Bay	15 (9–27)	0	273 (151–494)	0
Kutlaku Lake	4 (1–11)	0	67 (23–191)	9
Margarita Bay	0 (0)	0	47 (21–107)	13
Portage Bay	3 (1–9)	0	88 (52–147)	5
Rainbow Falls	13 (6–26)	0	320 (162–632)	2
Salt Lake Bay	23 (15–36)	5	59 (35–100)	0
Sarkar	15 (8–26)	0	419 (268–656)	1
Thomas Bay	24 (14–41)	3	723 (398–1,315)	25
Weasel Cove	6 (2–20)	15	159 (80–314)	9
Winter Harbor	13 (6–31)		149 (100–223)	3

Note: Values are means with range in parentheses.

Size- and Age-Class Distribution

Size-class distribution of the conifer seedling banks roughly followed an "inverse-j" curve (fig. 2). The overwhelming majority of spruce (95 percent) and hemlock (94 percent) seedlings were ≤0.5 m tall. The proportion of the total seedlings taller than 0.5 m was less than 10 percent for all but two sites for spruce and three sites for hemlock (table 3).

The mean age was 19 years (range 1 to 110 years) for hemlock seedlings (n = 350) and 8 years (range 1 to 41 years) for spruce seedlings (n = 140) (table 4). In the three smallest size classes (0 to < 0.5 m), the age range was about the same for both species (1 to 19 years for spruce and 1 to 15 years for hemlock). In the larger size classes, between 0.5 m and 3.0 m, however, the age ranges in each size class were more variable in general, especially for hemlock. For example, ages of western hemlock in size class 6 ranged from 14 to 110 years, whereas ages for Sitka spruce ranged from 8 to 31 years (table 4).

Table 4—Average age of Sitka spruce and western hemlock seedlings in eight size classes in southeast Alaska

	Spruce			Hemlock		
Height size class	Mean, SE (n)	Min.	Max.	Mean, SE (n)	Min.	Max.
1 (0 < 5 cm)	4 ± 0.2 (61)	1	10	4 ± 0.2 (60)	1	10
2 (5 < 25 cm)	7 ± 0.3 (48)	4	15	7 ± 0.2 (112)	3	14
3 (25 < 50 cm)	13 ± 1.1 (15)	6	19	10 ± 0.9 (11)	6	15
4 (50 < 100 cm)	17 ± 1.4 (20)	6	32	18 ± 1.2 (66)	5	48
5 (1.0 < 1.5 m)	21 ± 2.3 (15)	7	33	34 ± 3.4 (38)	7	95
6 (1.5 < 2.0 m)	22 ± 4.4 (5)	8	31	40 ± 3.5 (37)	14	110
7 (2.0 < 2.5 m)	19 ± 0.9 (3)	18	21	41 ± 5.3 (22)	14	99
8 (2.5 ≤ 3.0 m)	35 ± 6.0 (2)	29	41	50 ± 7.0 (11)	30	99

SE = Standard error.

Seedling Bank Microsites

The combined data set (all 17 sites) showed no significant difference in seedling density between the cut and uncut plots for either species. Seedbed was the only variable that affected hemlock and spruce seedling density (ANOVA, hemlock $F = 15.23$ $p = 0.0001$, spruce $F = 3.49$ $p = 0.05$). Seedlings of both species occurred four times as often on logs as on the forest floor. Although consistently more seedlings occurred on logs than on the forest floor, no pattern emerged for either species when seedling density was compared to percentage of log cover per hectare of forest. At a given percentage of log cover, seedling density for both species ranged widely. For example, at three sites with an average log cover of 2150 m^2/ha, average spruce density ranged from 4,000 to 15,000 seedlings/ha and hemlock density ranged from 67,000 to 419,000 seedlings/ha.

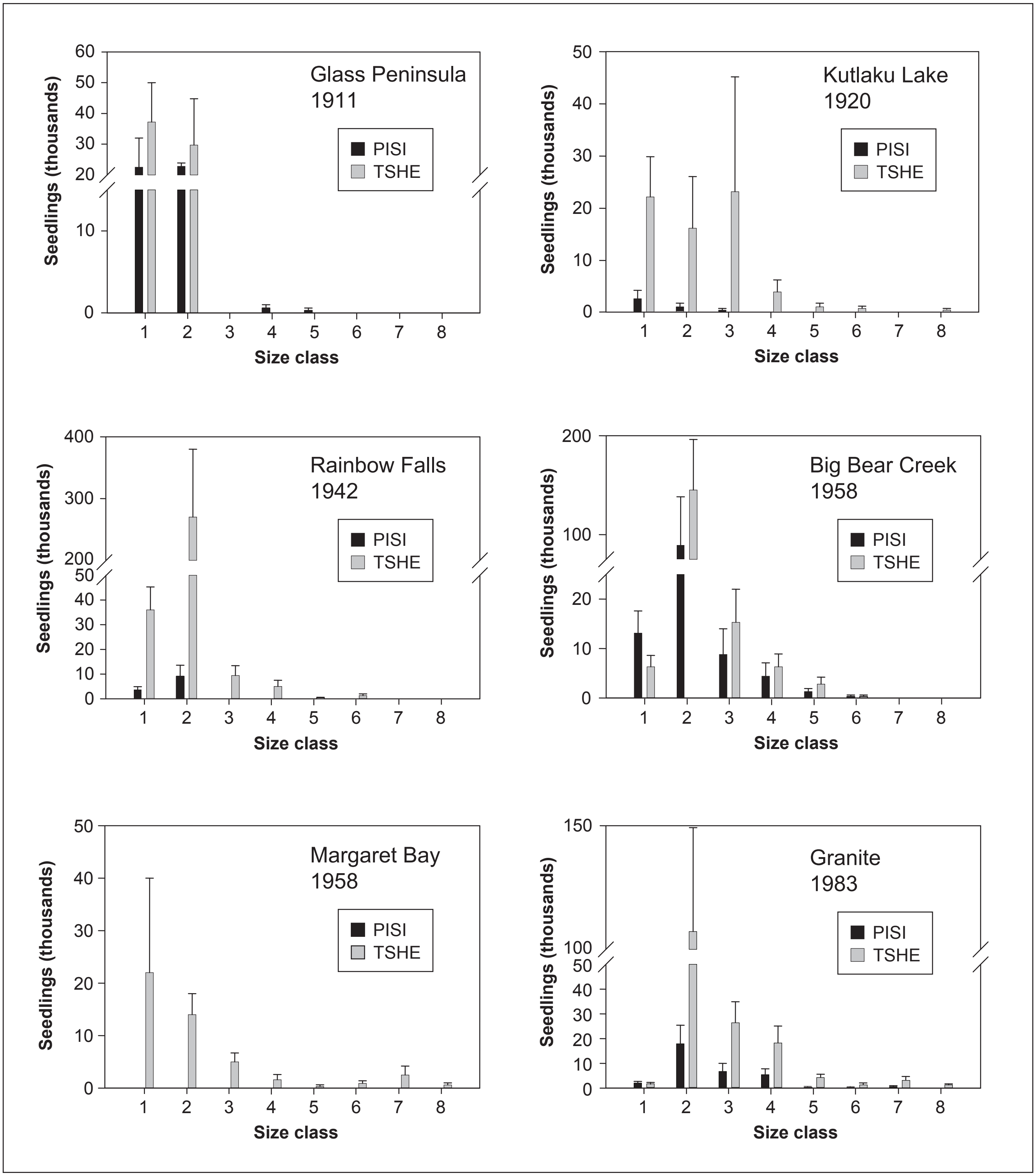

Figure 2—Size-class distribution and standard error of western hemlock (TSHE) and Sitka spruce (PISI) seedlings at six selectively harvested sites in southeast Alaska. The year below the site name is the cutting date and sites are arranged from oldest to most recently cut. These sites represent the range of size-class distributions found in this study. The eight size classes are defined as follows: 0 to <5 cm, 5 to <25 cm, 25 to <50 cm, 50 to <100 cm, 1.0 to <1.5 m, 1.5 to <2.0 m, 2.0 to <2.5 m, and 2.5 to <3.0 m.

The most common variable affecting seedling densities was seedbed, but treatment and shrub cover were also significant at some sites (table 5). The significance of these three variables differed between both species and sites. Seedbed alone was significant at 3 of the 7 sites for spruce and at 7 of the 10 sites for hemlock, but at sites where treatment or shrub cover was significant, another variable was almost always also significant.

Table 5—Significance of seedbed, treatment, and shrub cover on spruce and hemlock seedling density at 17 sites in southeast Alaska

Site		Seedbed[a]	Treatment[b]	Shrub cover[c]
Big Bear Creek	Spruce	**	**	
	Hemlock	**		
Canoe Passage	Spruce			
	Hemlock			
Elf Point	Spruce	*	*	*
	Hemlock	*		
Finger Creek	Spruce	**	*	
	Hemlock		*	
Florence Bay	Spruce			
	Hemlock			
Glass Peninsula	Spruce	**	**	**
	Hemlock	**	**	**
Granite	Spruce	*		
	Hemlock	**		
Hanus Bay	Spruce			**
	Hemlock	**	*	*
Kutlaku Lake	Spruce	*		
	Hemlock	*		
Margarita Bay	Spruce			
	Hemlock	**		
Portage Bay	Spruce			
	Hemlock	**		
Rainbow Falls	Spruce			**
	Hemlock		**	**
Salt Lake Bay	Spruce	*		
	Hemlock			
Sarkar	Spruce			
	Hemlock			
Thomas Bay	Spruce			
	Hemlock	*	**	**
Weasel Cove	Spruce			
	Hemlock	**		
Winter Harbor	Spruce			
	Hemlock			*

* Indicates $p \leq 0.05$, ** indicates $p \leq 0.01$, sites with no asterisk are where none of the variables significantly influenced seedling density.
[a] Seedbed = log or undisturbed forest floor.
[b] Treatment = cut or uncut.
[c] Shrub cover = percentage shrub cover.

At four sites for each species, treatment, combined with either or both seedbed and shrub cover, had a significant effect on seedling densities. At one of these four sites, Glass Peninsula, all three variables (seedbed, treatment, and shrub cover) were significant for both species. At one site, Finger Creek, treatment was the only significant variable affecting hemlock seedling density.

Analysis of each site showed shrub cover, combined with either or both seedbed or treatment, significantly affected seedling density for spruce at two sites and for hemlock at four sites. At Glass Peninsula, all three variables were significant for both species (46,000 spruce and 67,000 hemlock seedlings/ha). At two sites for spruce (15,000 seedlings/ha at Hanus Bay and 13,000 seedlings/ha at Rainbow Falls) and one site for hemlock (149,000 seedlings/ha at Winter Harbor) shrub cover was the only variable significantly affecting seedling density (table 5).

High levels of shrub cover were associated with decreased seedling density. For example, at Hanus Bay, the seedling density model predicted seedling density ranging from 2,000 to 11,000 seedlings/ha for spruce and from 36,000 to 130,000 seedlings/ha for hemlock (seedlings under 75 percent or 25 percent shrub cover).

An example of the variability in seedling density at each site is illustrated here for Elf Point (table 6). At this site, seedbed was the only significant variable for hemlock. There were 9.5 times as many hemlock seedlings on logs (200,000 seedlings/ha) than on undisturbed forest floor (21,000 seedlings/ha). All three variables were significant for spruce at this site. Spruce density ranged between 3,000 seedlings/ha under 75 percent shrub cover on undisturbed forest floor in the uncut plot to 12 million seedlings/ha under 25 percent shrub cover in the cut plots. At eight sites for spruce and four sites for hemlock, there were no significant variables explaining seedling densities. These sites (table 5) were located throughout the study area.

Table 6—Seedling density for specific microsite conditions, harvest treatment, and shrub cover, at the Elf Point installation[a]

Hemlock		Spruce	
Conditions[b]	**Density (95% CI)**	**Conditions**	**Density (95% CI)**
	Thousand seedlings/ha		*Thousand seedlings/ha*
Forest floor	21,000 (2,000–200,000)	Forest floor / cut / 75%	60 (0–11,000)
		Forest floor / cut / 25%	800 (10–62,000)
		Forest floor / uncut / 75%	3 (0–4,000)
		Forest floor / uncut / 25%	50 (0–22,000)
Log	200,000 (10,000–420,000)	Log / cut / 75%	900 (40–21,000)
		Log / cut / 25%	12,000 (3,000–49,000)
		Log / uncut / 75%	50 (0–10,000)
		Log / uncut / 25%	700 (8–53,000)

[a] This site was chosen to represent the variability in seedling density under different conditions.
[b] Microsite conditions are forest floor and logs; harvest treatments are cut or uncut; 75 percent and 25 percent refer to percentage cover of understory vegetation.

Seedling Growth Rates

Growth rates were uniformly low for spruce and hemlock seedlings in multiaged, closed-canopy stands.

Growth rates were uniformly low for spruce and hemlock seedlings in multiaged, closed-canopy stands ("All sites," table 7). These stands were harvested between 38 and 96 years prior to being surveyed for this study, and crown expansion had closed the canopy. In these closed-canopy stands, both species grew faster on logs than on undisturbed forest floor, and hemlock grew slightly faster than spruce. Hemlock seedlings in the understory of closed-canopy stands maintained a growth rate comparable to spruce seedlings in size classes between 0 and 0.25 m (table 4); however, height growth slowed down in taller size classes.

Table 7—Age, height, and annual height growth for spruce and hemlock seedlings ≤ 3 m tall and ≤ 20 years old, on logs, undisturbed forest floor, and skid trails, in southeast Alaska

	Log			Forest floor			Skid trail		
	Mean	SE	n	Mean	SE	n	Mean	SE	n
All sites[a]									
Hemlock									
Age (yr)	8.0	0.40	134	7.4	0.50	56	—	—	—
Height (cm)	26.4	2.90	137	15.5	2.80	56			
Height growth (cm/yr)	2.3	0.20	132	1.7	0.20	56	—	—	—
Spruce									
Age (yr)	7.0	0.60	76	3.8	0.40	27	—	—	—
Height (cm)	15.7	3.70	74	3.8	0.38	27			
Height growth (cm/yr)	1.7	0.20	74	1.2	0.20	27	—	—	—
Thomas Bay[b]									
Hemlock									
Age (yr)	8.5	1.30	19	8.2	0.90	10	7.2	0.35	11
Height (cm)	40.7	9.90	19	70.7	13.40	10	51.5	13.30	11
Height growth (cm/yr)	4.1	0.57	19	8.2	1.40	10	7.0	1.80	11
Spruce									
Age (yr)	8.1	1.00	12	8.2	1.10	6	6.3	0.92	6
Height (cm)	23.8	5.60	12	46	14.60	6	77.8	25.10	6
Height growth (cm/yr)	2.7	0.42	12	5.0	1.00	6	10.2	3.10	6

[a] Values under "All sites" were calculated from data collected at 15 sites partially logged between 1900 and 1958. These sites were multiaged, closed-canopy stands.
[b] Thomas Bay was partially harvested in 1984 and was used as a comparison to the 15 multiaged, closed-canopy sites.

Owing to recent logging, crown closure at two of our study sites (Thomas Bay and Granite) had not yet occurred at the time of our survey; thus they were removed from the "All sites" analysis and assessed separately. At Thomas Bay, seedlings of both species on all seedbeds grew faster (min. annual growth rate 2.7 cm for spruce seedlings on logs) than seedlings in closed-canopy stands (max. annual growth rate 1.7 cm for hemlock seedlings on undisturbed forest floor and spruce seedlings on logs) (table 7). Mean annual growth on undisturbed forest floor (8.2 cm for hemlock and 5.0 cm for spruce) was almost twice that on logs (4.1 cm for hemlock and 2.7 cm for spruce) for both species. However, the fastest average annual growth rate found in this study was for spruce seedlings on disturbed soil (10.2 cm).

Sites at which we found the tallest seedlings (where more than 10 percent were taller than 0.5 m), had, in some cases, a higher percentage of shrub cover than sites with no seedlings taller than 0.5 m (table 8). At seven sites there were more spruce than hemlock between 0.5 m and 3.0 m. The average shrub cover at those seven sites was 40 percent, compared to 27 percent at the other 10 sites. At 8 of the 10 sites with 27 percent average shrub cover, there were no spruce seedlings taller than 0.5 m.

Table 8—Percentage of spruce and hemlock seedlings between 0.5 and 3 m, and percentage shrub cover at 17 sites in southeast Alaska

Site	Seedlings 0.5–3.0 m		Average shrub cover
	Spruce	Hemlock	
		Percent	
Finger Creek	0	3	8
Portage Bay	0	5	13
Kutlaku Lake	0	9	16
Winter Harbor	0	3	21
Sarkar	0	1	24
Glass Peninsula	2	0	25
Hanus Bay	0	0	28
Weasel Cove	15	9	28
Elf Point	7	4	33
Florence Bay	8	3	33
Thomas Bay	3	25	35
Rainbow Falls	0	2	36
Canoe Pasage	8	2	41
Big Bear Creek	5	5	46
Margarita Bay	0	13	47
Granite	19	17	58
Salt Lake Bay	5	0	62

Discussion

Seedling Density

Both spruce and hemlock seedling banks were very dense, even overstocked by management standards, and compare favorably with naturally regenerated clearcuts in the same region (U.S. Forest Service regeneration survey data on file at Forestry Sciences Laboratory, Juneau, Alaska). The one exception was at Margarita Bay where there were no spruce seedlings in any of the four treatment plots (one uncut and three cut), although overstory, cone-producing spruce trees were present in all four plots. Hemlock seedling density at this site was also the lowest in our study (table 3).

Margarita Bay was logged about 40 years earlier, and on the cut plots, there was a dense second canopy layer of hemlock and spruce, but no ground vegetation (including no seedling bank) beneath the seed trees. This site was a heavily cut, hemlock-dominated stand and is currently densely stocked. In contrast, the uncut plot had a multilayered vertical structure including thick understory vegetation. With time, we expect that there will be canopy openings in the cut plots from windthrow or timber harvest and that a spruce-hemlock seedling bank will develop.

It is unclear why seedling density differed so much among sites. Seed source and overstory species composition do not explain the variation. For example, Big Bear Creek (114,000 spruce seedlings/ha [table 3] and 15–47 percent current spruce basal area [table 2]) had 2.5 times the spruce density of Glass Peninsula (46,000 spruce seedlings/ha [table 3] and 11–34 percent current spruce basal area [table 2]). Thomas Bay and Granite, harvested in 1984 and 1983, respectively, had the lowest spruce basal area of any of the sites (table 2), while also having some of the highest spruce seedling densities (table 3). These two sites still exhibited characteristics of recently harvested stands, open canopy and disturbed mineral soil from skid trails, which may explain why the spruce seedling density was so high relative to the number of spruce seed trees in the overstory.

Size- and Age-Class Distribution

Sitka spruce is considered moderately tolerant to tolerant of shade, and our study documented that spruce can persist as long as 30 years and even up to 41 years of age.

The “inverse-j” curve distribution of both spruce and hemlock seedling banks is typical of tree seedling population dynamics in all-aged (uneven-aged) forests (Smith 1986). It was not surprising that hemlock seedlings should persist in the understory of these closed-canopy stands, as hemlock is shade tolerant, and its persistence in the understory for more than 100 years is not uncommon (Packee 1990). Sitka spruce is considered moderately tolerant to tolerant of shade (Harris 1990, Minore 1972), and our study documented that spruce can persist as long as 30 years and even up to 41 years of age.

Ott (1997) reported that spruce’s ability to maintain itself in mature stands was substantially less than that of hemlock. For example, Ott (1997) found that although western hemlock seedlings (< 2.5 cm d.b.h.) occurred on 46 to 92.3 percent of his understory vegetation plots at each of three study sites, Sitka spruce seedlings only occurred on 2 to 21 percent of understory vegetation plots. By comparison, we found many spruce seedlings at our sites although most of them were < 0.5 m tall. Little information is available on the growth of advance regeneration spruce. However, Ott (1997) documented that mean and median heights for both western hemlock and Sitka spruce were greater in gaps than under closed-canopy forest. Our results are similar to his.

Seedling Bank Microsites

Seedlings of both species can occur on a range of microsites, although it appears that logs are microsites that favor seedling establishment (Christy and Mack 1984, Deal et al. 1991, Harmon and Franklin 1989, McKee et al. 1982, this study). It is not clear why this is so. The more frequent occurrence of spruce and hemlock seedlings on woody seedbeds in naturally regenerated, uneven-aged stands may be related to high precipitation and shallow soils. Harmon and Franklin (1989) suggested that elevated sites afford freedom from competition from shrubs such as salmonberry (*Rubus spectabilis* (Prush)) and layers of shorter vegetation.

In the coastal forests of southeast Alaska, light is considered the primary factor affecting survival and growth of understory vegetation, as precipitation is abundant throughout the growing season and temperatures are moderate (Ruth and Harris 1979). Previous studies show that establishment of shrub seedlings in the forests was strongly related to photosynthetically active radiation at the forest floor (Tappeiner and Alaback 1989) as was the growth of hemlock, spruce, and *Vaccinium* seedlings in and adjacent to windthrow gaps (Alaback and Tappeiner 1991).

Although seedling bank density is greater on logs, high densities of both species occur on other substrates as well. For example, at our sites we found an average of 20,000 western hemlock and 2,000 Sitka spruce seedlings/ha on forest floor. In recently harvested stands, spruce clearly regenerates well on heavily disturbed areas such as skid trails where mineral soil was exposed (Deal et al. 1991, Harris 1990, Ruth and Harris 1979, Yount 1997). Windthrow mounds and pits, disturbed soil from the root systems of windthrown trees, are another source of exposed mineral soil, yet we rarely observed either spruce or hemlock seedlings more than a few years old growing in the mineral soil of mounds and pits. Perhaps there is a functional difference, such as soil movement in pits and mounds, between the exposed mineral soil from windthrow and from logging.

It appears that growing conditions in the understory become limiting after seedlings become 25 to 50 cm tall. There were high densities of seedlings in size classes one and two (0 to 25 cm), but the height distribution decreased rather abruptly after these size classes (fig. 2, table 3). Ages at these size classes were quite variable, ranging from 7 to 95 years for hemlock class 5 and 7 to 33 years for Sitka spruce class 5. Thus, it appears from the size class distributions (fig. 2), taller and older seedlings that die are replaced as new seedlings are continually established.

Seedling Growth Rates

At Thomas Bay, harvested 1984, both conifer species clearly responded to postharvest stand conditions with increased seedling growth rates, compared to seedlings of similar age in closed-canopy stands on either logs or undisturbed soil. Suppressed hemlock 50 to 60 years old commonly develop into vigorously growing trees after release, although ability to respond decreases after age 100 (Packee 1990). Deal (1999) found advance regeneration spruce grew rapidly and slightly better than hemlock after partial cutting. If the advance regeneration at these closed-canopy 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.

Deal (1999) found advance regeneration spruce grew rapidly and slightly better than hemlock after partial cutting.

Management Implications

Seedlings and saplings in the understory do not grow as rapidly as seedlings in clearcuts. What is important, however, is their potential for growth after overstory density is reduced. These seedlings and saplings should not be expected to grow at the maximum rates that are seen after clearcuts, but rather to maintain their potential for growth should they be released. More work is needed to determine the response of advance regeneration to release from competition with overstory trees.

Advance regeneration left after cutting grew rapidly and was a significant and dominant component of the current stand (Deal and Tappeiner 2002). Most of the current stand structure and growth came from residual trees and little growth was seen for newly established trees (Alaback and Tappeiner 1991). Thus, the existence of a seedling bank in the partially cut stands provides a new cohort of trees that could easily release and grow following another cutting or disturbance event. This would suggest that partial cutting in this forest type is a sustainable silvicultural system that could maintain current tree species composition and structure on a long-term basis.

Concern about the effects of clearcut harvesting on forest ecosystems in southeast Alaska and throughout the Pacific Northwest (Gray and Spies 1997) has led to discussion of alternative methods such as partial cutting or uneven-age management for regeneration during timber management. With a shift in forest land management to include biodiversity of forest ecosystems, other methods of harvesting and regenerating these stands need to be examined.

This study indicates that partial cutting could be implemented as part of a new silvicultural system in southeast Alaska. By leaving spruce seed-trees, disturbing soil judiciously, planning entries to regulate overstory density to promote seedling establishment, 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 uneven-aged stands.

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English Equivalents

If you know:	Multiply by:	To find:
Centimeters (cm)	.394	Inches
Meters (m)	3.28	Feet
Square meters (m^2)	10.76	Square feet
Hectares (ha)	2.47	Acres
Square meters per hectare (m^2/ ha)	4.37	Square feet per acre
Degrees Celsius (°C)	1.8 °C + 32	Degrees Fahrenheit

Literature Cited

Alaback, P.B. 1982. Dynamics of understory biomass in Sitka spruce-western hemlock forests of southeast Alaska. Ecology. 63: 1932–1948.

Alaback, P.B.; Tappeiner, J.C., II. 1991. Response of western hemlock (*Tsuga heterophylla*) and early huckleberry (*Vaccinium ovalifolium*) seedlings to forest windthrow. Canadian Journal of Forest Research. 21: 534–539.

Anderson, H.E. 1955. Clearcutting as a silvicultural system in converting old forests to new in southeast Alaska. Society of American Foresters: 59–61.

Bormann, B.T.; Spaltenstein, H.; McClellan, M.H.; Ugolini, F.C.; Cromack, K.J.; Nay, S.M. 1995. Rapid soil development after windthrow disturbance in pristine forests. Journal of Ecology. 83: 747–757.

Christy, E.J.; Mack, R.N. 1984. Variation in demography of juvenile *Tsuga heterophylla* across the substratum mosaic. Journal of Ecology. 72: 75–91.

Deal, R.L. 1999. The effects of partial cutting on stand structure and growth, and forest plant communities of western hemlock–Sitka spruce stands in southeast Alaska. Corvallis, OR: Oregon State University. 191 p. Ph.D. thesis.

Deal, R.L. 2001. The effects of partial cutting on forest plant communities of western hemlock–Sitka spruce stands in southeast Alaska. Canadian Journal of Forest Research. 31: 2067–2079.

Deal, R.L.; Tappeiner, J.C., II. 2002. The effects of partial cutting on stand structure and growth of western hemlock–Sitka spruce stands in southeast Alaska. Forest Ecology and Management. 159: 173–186.

Deal, R.L.; Oliver, C.D.; Bormann, B.T. 1991. Reconstruction of mixed hemlock–spruce stands in coastal southeast Alaska. Canadian Journal of Forest Research. 21(5): 643–654.

Deal, R.L.; Tappeiner, J.C., II; Hennon, P.E. 2002. Developing silvicultural systems based on partial cutting in western hemlock–Sitka spruce stands of southeast Alaska. Forestry. 75(4): 425–431.

Godman, R.M. 1952. A classification of the climax forests of southeastern Alaska. Journal of Forestry. 50(6): 435–438.

Gray, A.N.; Spies, T.A. 1997. Microsite controls on tree seedling establishment in conifer forest canopy gaps. Journal of Ecology. 84: 635–645.

Harmon, M.E. 1987. The influence of litter and humus accumulations and canopy openness on *Picea sitchensis* (Bong.) Carr. and *Tsuga heterophylla* (Raf.) Sarg. seedlings growing on logs. Canadian Journal of Forest Research. 17: 1475–1479.

Harmon, M.E.; Franklin, J.F. 1989. Tree seedlings on logs in *Picea-Tsuga* forests of Oregon and Washington. Ecology. 701: 48–59.

Harris, A.J. 1967. Natural reforestation on a mile-square clearcut in southeast Alaska. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 16 p.

Harris, A.J. 1969. Ripening and dispersal of a bumper western hemlock–Sitka spruce seed crop in southeast Alaska. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 11 p.

Harris, A.S. 1990. *Picea sitchensis* (Bong.) Carr. Sitka spruce. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 260–267.

Harris, A.S.; Farr, W.A. 1974. The forest ecosystem of southeast Alaska, 7: Forest ecology and timber management. Gen. Tech. Rep. PNW-25. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 109 p.

Harris, A.S.; Hutchinson, O.K.; Meehan, W.R.; Swanston, D.N.; Helmers, A.E.; Hendee, J.C.; Collins, T.M. 1974. The forest ecosystem of southeast Alaska, 1: The setting. Gen. Tech. Rep. PNW-12. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 40 p.

James, G.; Gregory, R.A. 1959. Natural stocking of a mile-square clear cutting in southeast Alaska. Juneau, AK: U.S. Department of Agriculture, Forest Service, Alaska Forest Research Center. [Pages unknown].

McClellan, M.H. 2004. Development of silvicultural systems for maintaining old-growth conditions in the temperate rainforest of southeast Alaska. Forest Snow and Landscape Research. 78(1/2): 173–190.

McCullagh, P.; Nelder, J.A. FRS. 1989. Generalized Linear Models. London: Chapman and Hall. Chapter 6.

McKee, A.; LaRoi, G.; Franklin, J.F. 1982. Structure, composition and reproductive behavior of terrace forests, south fork Hoh River, Olympic National Park. In: Starkey, E.E.; Franklin, J.F.; Matthews, J.W., eds. Ecological research in national parks of the Pacific Northwest. Corvallis, OR: Oregon State University, Forest Research Laboratory: 22–29.

Minore, D. 1972. Germination and early growth of coastal tree species on organic seed beds. Res. Pap. PNW-135. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 40 p.

Ott, R.A. 1997. Natural disturbance at the site and landscape levels in temperate rainforests of southeast Alaska. Fairbanks, AK: University of Alaska Fairbanks. 169 p. Ph.D. thesis.

Packee, E.C. 1990. *Tsuga heterophylla* (Raf.) Sarg. Western hemlock. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 613–622.

Ruth, R.H.; Harris, A.S. 1979. Management of western hemlock–Sitka spruce forests for timber production. Gen. Tech. Rep. PNW-88. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 197 p.

SAS Institute Inc. 1996. SAS/STAT Software: changes and enhancements through release. 6.11. Cary, NC: SAS Institute Inc. Chapter 10.

Smith, D.M. 1986. The practice of silviculture. 8^{th} ed. New York. John Wiley & Sons, Inc. 527 p.

Tappeiner, J.C., II; Alaback, P.B. 1989. Early establishment and vegetative growth of understory species in the western hemlock–Sitka spruce forests of southeast Alaska. Canadian Journal of Botany. 67: 318–326.

Taylor, R.F. 1935. Available nitrogen as a factor influencing the occurrence of Sitka spruce and western hemlock seedlings in the forests of southeastern Alaska. Ecology. 16: 580–607.

U.S. Department of Agriculture, Forest Service [USDA FS]. 1997. Record of Decision for Tongass National Forest Land and Resource Management Plan Revision. R10-MB-338a. Juneau, AK: Alaska Region. 44 p.

Yount, L.S. 1997. Sitka spruce and western hemlock regeneration after selective harvesting, Tongass National Forest, southeast Alaska. Corvallis, OR: Oregon State University. 77 p. M.S. thesis.

Zasada, J.C.; Packee, E.C. 1995. The Alaska Region. In: Barrett, J.W., ed. Regional silviculture of the United States. New York, NY: John Wiley & Sons: 559–605.

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