Developing silvicultural systems based on partial cutting in western hemlock–Sitka spruce stands of southeast Alaska

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Summary

The effects of partial cutting on species composition, stand structure and growth, tree size distribution, and tree disease and mortality were evaluated on 73 plots in 18 stands that were harvested 12–96 years ago in southeast Alaska. Partially-cut stands had diverse and highly complex stand structures similar to uncut stands. Sitka spruce was maintained in mixed hemlock–spruce stands over a wide range of cutting intensities. Analysis of the data did not detect significant changes in tree species composition, stand growth, hemlock dwarf mistletoe infection and incidence of tree wounding or mortality rates with partial cuts. Silvicultural systems using partial cutting could provide a sustainable timber resource including more valuable spruce trees, while also maintaining stand structural diversity and old-growth characteristics.

Introduction

The temperate rain forests of southeast Alaska include simple tree composition but complex forest age and size structure. The predominant tree species, Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), together comprise over 90 per cent of the region's total growing stock volume (Hutchison, 1967). Abundant precipitation occurs throughout the year along with occasional hurricane-force winds. The significance of this climate for the forest is that moisture is generally not a limiting factor for regeneration, wildfires are rare and wind-caused disturbances are common (Harris, 1989; Nowacki and Kramer, 1998). The natural disturbance regime in southeast Alaska is characterized by high-frequency, low-magnitude disturbance events resulting in complex multi-aged or uneven-aged stands (Brady and Hanley, 1984; Deal *et al.*, 1991; Nowacki and Kramer, 1998).

Recent interest in old-growth forests (Franklin *et al.*, 1981; Lertzman and Krebs, 1991; Acker *et al.*, 1998) and biodiversity (Wilson, 1988; Hansen *et al.*, 1991; Grime, 1997; Angelstam,

1998) has led to increasing emphasis on forest management practices that accelerate the development of late-successional and old-growth forest characteristics. Silvicultural systems that provide for sustainable wood production and the protection of other forest values are currently being evaluated in southeast Alaska (McClellan *et al*., 2000; Deal, 2001; Deal and Tappeiner, 2002). Clearcutting with natural regeneration has been the predominant timber management practice in the western hemlock–Sitka spruce forest type of southeast Alaska. Thus, little is known about the use of silvicultural systems that use partial cutting and their effects on stand dynamics, stand regeneration and growth, tree disease and mortality.

Major silvicultural concerns with partial cutting have previously been reported (Harris and Farr, 1974); however, most of these concerns are speculative or based on research done in other regions. In this paper we assess the effects of partial cutting in 18 stands throughout southeast Alaska and evaluate the following concerns with partial cutting:

1. Partial cutting will increase the more shade-tolerant western hemlock and reduce the less tolerant and more valuable Sitka spruce.
2. Trees left after partial cutting will be of low vigour and value because of decay from logging damage and spread of hemlock dwarf mistletoe (*Arceuthobium tsugense*).
3. Partial cutting will result in windthrow of residual trees.

Methods

Study areas

Partial cutting of beach-fringe forests was a common practice in southeast Alaska from 1900 to 1950. Large Sitka spruce trees were often cut for sawtimber or pole-sized western hemlock trees were harvested for piling, resulting in stands with variable density, size and species composition. Eighteen sites were selected in 1995 and 1996 to sample a range of time since cutting and intensity of cutting throughout southeast Alaska (Figure 1) using the following criteria: (1) range of 'time-since-cutting' from 10 to 100 years ago; (2) only one partial cutting; (3) a wide range of cutting intensities at each site, including an uncut area; (4) uniform topography, soils and forest type. All research sites were within 2 km of the nearest shoreline and less than 100 m in elevation. At each site we located an uncut control and generally three partially cut areas (light, medium, heavy) and installed 0.2 ha plots in each cutting intensity area with a total of 73 overstorey plots (each of 0.2 ha) installed in 18 stands (Table 1).

Stand structure and growth

To characterize current stand structure, we recorded the tree diameter at 1.3 m (diameter at breast height; d.b.h.), height, crown class and species of all live trees greater than 2.5 cm d.b.h., and species, d.b.h. and decay class for each snag (standing dead tree). On each plot, we reconstructed basal area of cut trees from stump diameter and took increment cores from 10–20 trees of each species and crown class to determine age, basal area growth and cutting date for each stand. We reconstructed stand structure, basal area, species composition and cutting intensity for each plot (Table 1) using site-specific regression equations (Deal and Tappeiner, 2002). New trees were defined as new regeneration and trees shorter than 1.3 m at time of cutting, and residual trees were at least 1.3 m tall at date of cutting. We blocked by site, and compared differences in tree species composition, tree-age cohorts and stand growth between cut and uncut plots using contrast analysis (Deal and Tappeiner, 2002). Tree radial growth increments were used to investigate the effects of partial cutting on the growth of hemlock and spruce trees, and the size and growth of new and residual trees.

Hemlock dwarf mistletoe, tree wounding and tree mortality

Each hemlock tree was rated for degree of dwarf mistletoe infection, using an index of 0–6 as described by Hawksworth (1977). Bole wounds determined to have occurred at cutting date or afterwards were recorded (P. Palkovic, unpublished data). For each dead tree >25 cm d.b.h., we recorded d.b.h., species, decay class and status

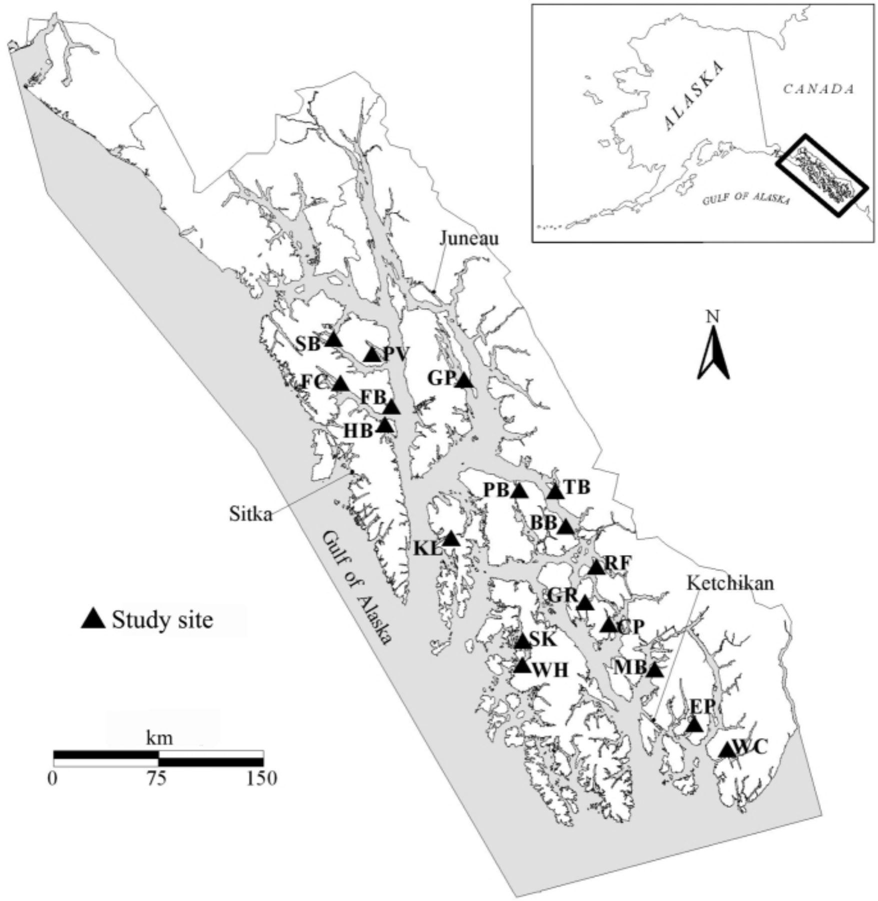

Figure 1. The 18 study sites in southeast Alaska. See Table 1 for definition of site codes.

(uprooted, standing dead, or broken bole). Snag and log decay classes and estimated time since death for hemlock and spruce are reported elsewhere (Hennon *et al*., 2002). Only trees that we determined to have died after partial cutting were used in reconstructing tree mortality. Analysis of variance with site as a blocking independent variable was used to test for differences in dwarf mistletoe rating, and the incidence of tree wounding and mortality between uncut and cut plots. Regression analysis tested for correlation between these variables and the intensity of cutting (i.e. percentage basal area removed). Tests were conducted for both understorey and overstorey trees.

Results and discussion

Tree species composition

Partial cutting had little effect on tree species composition. We found no significant difference between cut and uncut plots in either the proportion of western hemlock trees ($P = 0.84$) or Sitka spruce trees ($P = 0.46$). The proportion of Sitka spruce trees averaged 17 per cent in the cut plots and 15 per cent in the uncut plots. The proportion of spruce trees and basal area increased slightly with increasing cutting intensity, but cutting intensity explained only 3–5 per cent of the variation in tree-species proportion. We found no significant relation between cutting intensity

Table 1: Descriptions of research sites listed from the oldest to most recently cut site

	Cutting intensity				Current stand* composition and site inform							
			Basal area									
Research site	Cutting date (year)	Cut (%)	Cut (m^2 ha^{-1})	Left (m^2 ha^{-1})	Basal area (m^2 ha^{-1})	All trees (trees ha^{-1})	*Picea* (%)	*Tsuga* (%)	Other† (%)	Forest type	Elevation (*m*)	Site‡ $index_{50}$ (*m*)
WC: Weasel Cove	1900	17–51	9–23	22–45	53–75	450–1220	0–24	67–100	0–17	*Picea*	30	24
GP: Glass Peninsula	1911	23–69	15–41	17–47	60–84	147–397	11–34	28–83	0–49	*Picea*	20	29
FB: Florence Bay	1914	50–57	33–38	26–38	56–83	120–360	18–75	25–82	0	*Picea*	10	32
PB: Portage Bay	1918	26–65	7–28	14–25	47–56	459–1202	5–33	67–95	0	*Tsuga*	35	27
KL: Kutlaku Lake	1920	31–63	17–31	18–37	58–13	305–525	5–49	35–95	0–16	*Picea*	5	32
HB: Hanus Bay	1922	49–96	24–85	3–25	56–83	413–1180	6–62	38–94	0	*Picea*	25	30
SK: Sarka	1925	27–59	14–28	19–37	57–76	467–1163	0–11	89–100	0	*Tsuga*	60	30
EP: Elf Point	1927	17–73	12–36	13–57	42–11	453–1443	2–4	72–96	0–24	*Tsuga*	30	24
CP: Canoe Passage	1927	16–75	9–57	19–46	44–66	815–2452	2–13	74–92	6–19	*Tsuga*	100	27
SB: Salt Lake Bay	1928	48–55	28–35	29–31	63–87	158–642	17–73	27–83	0	*Picea*	10	30
WH: Winter Harbor	1932	24–38	19–39	56–70	73–95	785–1311	2–33	67–98	0	*Picea*	5	29
FC: Finger Creek	1941	18–41	11–33	44–51	58–75	331–522	5–60	40–95	0	*Tsuga*	5	30
RF: Rainbow Falls	1942	34–61	15–25	16–29	44–66	348–1108	0–28	63–100	0–10	*Picea*	20	27
MB: Margarita Bay	1958	23–83	9–48	10–30	41–63	694–2695	4–24	76–96	0	*Tsuga*	20	30
BB: Big Bear Creek	1958	17–36	9–27	47–63	53–79	270–754	15–47	53–85	0	*Picea*	20	23
PV: Pavlof River	1977	36–58	21–43	31–47	37–69	288–823	4–29	42–96	0–46	*Picea*	20	30
GR: Granite	1983	18–86	9–51	9–50	13–70	368–1440	0–7	93–100	0	*Tsuga*	30	27
TB: Thomas Bay	1984	20–29	18–19	42–77	49–70	237–766	1–17	83–99	0	*Tsuga*	15	30

The cutting intensity data is the range for the partially cut plots at each site. The current stand data include the range of both uncut and cut plots at each site. The forest type is the major overstorey tree species at each site.

* Stand data for trees and basal area includes all trees that are at least 2.5 cm d.b.h.

† The other minor species include western red cedar (*Thuja plicata* Donn ex D. Don), yellow cedar (*Chamaecyparis nootkatensis* (D. Don) Spach), red alder (*Alnus rubra* Bong.), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.).

‡ Potential site index, base age 50, height in metres.

and the proportion of either spruce or hemlock trees ($P = 0.42$ and 0.72, respectively) or the proportion of spruce and hemlock basal area ($P = 0.69$ and 0.28, respectively).

The results of this study show that the establishment of new regeneration and the growth of residual trees of both hemlock and spruce can maintain species composition similar to that of study plots before cutting. New regeneration was generally plentiful on cut plots, and cutting more than 50 per cent of the stand basal area always led to the establishment of new regeneration (Deal and Tappeiner, 2002). New cohort spruce trees were found on 44 per cent of the cut plots and on only 11 per cent of the uncut plots. These results indicate that partial cutting can generally enable tree regeneration and, contrary to some other opinions (e.g. Andersen, 1955), spruce will in fact regenerate after partial cutting. Our results indicate that silvicultural systems using partial cutting can successfully maintain spruce in mixed western hemlock–Sitka spruce forests in southeast Alaska.

Stand structure and growth

Most trees cut were large-diameter spruce trees, and more residual hemlock than residual spruce trees were left in almost all plots. However, after cutting, there were usually some large trees left in the stand. The number of trees of all species left after cutting in diameter class A (>100 cm), B (71–100 cm) and C (41–70 cm) averaged 7, 14 and 43 trees ha^{-1}, respectively (Figure 2). Before cutting, an average of 18, 32 and 64 trees ha^{-1} were in these diameter classes, and we found significant differences ($P < 0.01$) between stands before and after cutting in the number of A-, B- and C-class trees. After 60 years, however, the number of trees of all species in these size classes was similar to the stands before cutting, with an average of 16, 29 and 81 trees ha^{-1} in the A-, B- and C-classes, respectively (Figure 2). The current stands had slightly more trees in class C (+17 trees ha^{-1}) and slightly fewer trees in B (–3 trees ha^{-1}) and A (–3 trees ha^{-1}) classes than the stands before cutting, but no significant differences were found in the frequency of trees for any diameter class ($P = 0.20$, 0.40 and 0.42, respectively).

Sitka spruce diameter growth was slightly greater than western hemlock growth for all tree-diameter classes, but growth differences between species were not statistically significant ($P > 0.05$) for any diameter class. Residual trees of both species in all size classes increased diameter growth after cutting. The current stand basal area, tree species composition and stand growth for all cutting intensities was strongly related to trees left after harvest. These results are contrary to conventional thinking about partial cutting in southeast Alaska, where residual trees are assumed to be of poor quality and low vigour. In this study, we found that these small advance regeneration and larger residual trees responded with rapid and sustained growth after overstorey removal and became a major part of the current stand.

Hemlock dwarf mistletoe, tree wounding and mortality

Dwarf mistletoe levels did not differ significantly between cut and uncut plots for overstorey or understorey hemlock trees (Table 2), but there was a tendency towards less dwarf mistletoe with higher cutting intensities. Dwarf mistletoe infection averaged a rating of 1.0 (maximum of 6.0) in partially cut stands, a level where the disease

Figure 2. The numbers of trees per hectare by size classes in the partially cut plots before and immediately after cutting, and in the current stand 60 years after cutting. Vertical lines represent standard errors.

Table 2: Levels of disease, wounding, mortality, and type of tree death in uncut and partially cut plots. Values are means with ranges in parentheses

	Dwarf mistletoe† (index = 0 to 6)	Bole wounding (% trees wounded)	Dead trees (%)	Uprooted trees (% of dead)
Overstorey trees‡				
Cut plots	1.5 (0–3.5)	17 (0–30)*	27 (5–55)	37 (16–77)
Uncut plots	1.7 (0–4.2)	10 (0–47)*	22 (5–56)	28 (0–50)
Understorey trees§				
Cut plots	0.8 (0–1.8)	7 (0–25)	5 (0–25)	NA¶
Uncut plots	1.2 (0–4.1)	15 (0–100)	14 (0–100)	NA¶
All trees				
Cut plots	1.0 (0–2.2)	11 (4–30)	15 (4–30)	35 (16–77)
Uncut plots	1.4 (0–3.5)	11 (0–26)	17 (6–40)	30 (0–50)

* Denotes values are significantly different ($P < 0.05$).
† Only western hemlock was included in analysis for this factor.
‡ Trees that were 25 cm d.b.h. or larger at the date of cutting.
§ Trees that were smaller than 25 cm d.b.h. or not yet present in stand at the date of cutting.
¶ Sample size was too small at most sites for analysis.

would be expected to cause little or no growth loss or tree mortality (Smith, 1969; Thompson *et al*., 1985). Thus, dwarf mistletoe was maintained but was not eliminated, as frequently occurs following clearcutting.

Overstorey trees had significantly greater incidence of wounding ($P = 0.04$) in cut than uncut plots (Table 2) and wounding increased with intensity of cutting ($P = 0.03$). Many wounds could not be attributed to logging, however, as falling trees and porcupine damage were other causal factors on some sites.

For trees of all sizes, mortality was not significantly different ($P = 0.32$) between cut and uncut plots. The fate of large residual trees is of particular interest because of concern about windthrow: the percentage of dead large residual trees in cut plots (27 per cent) was not significantly different ($P = 0.11$) than in uncut plots (22 per cent) (Table 2). Of large residual trees that died, an average of 37 per cent and 28 per cent, respectively, died through uprooting in partially cut and uncut plots (Table 2); the remainder died standing or by bole breakage. Windthrow did not significantly increase after partial cutting; indeed, mortality of residual trees was only marginally higher in partially cut than in uncut stands. For residual trees that died, the higher rate of uprooting associated with cutting does suggest that wind has an increased role in tree death. The beach-fringe stands we studied have a low risk of wind damage; in southeast Alaska the greatest risk of windthrow is on exposed south-facing ridges and hill slopes (Harris, 1989; Nowacki and Kramer, 1998). Thus, our results may underestimate the severity of wind-damage risk in some landscape settings. Managers concerned about windthrow should consider wind exposure (Kramer *et al*., 2001) when designing partial cutting treatments.

Conclusion

The stands we studied were cut to provide specific wood products. Cutting occurred without a planned silvicultural system and little effort was taken to ensure spruce regeneration, encourage stand growth, control or reduce tree damage agents, or maintain the complex stand structures found in old-growth forests. Nevertheless Sitka spruce was maintained in these stands and we did not detect any significant changes in tree species composition, stand growth and vigour, rates of hemlock dwarf mistletoe infection, and incidence of tree wounding, decay and windthrow mortality with partial cuts. Stand structural diversity, and plant diversity and abundance were much greater in partially cut stands than in young-growth stands developing after clearcutting (Deal, 2001). Our results indicate that new silvicultural systems that use partial cutting could alleviate some of the problems associated with conventional clearcutting in southeast Alaska, while also providing a sustainable timber resource.

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