# Evaluating Effects of Thinning on Wood Quality in Southeast Alaska

**Eini C. Lowell, Dennis P. Dykstra, and Robert A. Monserud**

ABSTRACT

We examined the effect of thinning on wood quality of western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*) located on Prince of Wales and Mitkof Islands in southeast Alaska. Sample trees came from paired plots (thinned versus unthinned) in eight naturally regenerated, mixed stands of young-growth western hemlock and Sitka spruce in an effort to examine a range of thinning densities, from 10 × 10 ft to 20 × 20 ft spacing. The stands, which had been thinned in the late 1970s and early 1980s, ranged in age from 36 to 73 years at the time they were selected for this study in 2003. The main focus of the stand selection in this retrospective study was to find individual stands that included a thinned plot and an adjacent unthinned plot from the same original stand. A random sample of trees from both thinned and unthinned plots was selected, stratified by tree dbh. About 12 trees per species per stand (461 trees in total) were selected for the study. Selected trees were harvested, and a lumber recovery study was conducted, enabling us to relate log volume to recovered lumber volume by product grade. Surfaced dry dimension lumber was produced, graded, and nondestructively tested using the transverse E-vibration standard test for stiffness. We did not evaluate the resource for appearance-grade products. For each species, the overall treatment effect (thinned versus unthinned) on lumber grade recovery and transverse E-vibration modulus of elasticity by vertical-log position (butt log, middle log, or top log) were analyzed using a mixed-effects procedure. Results suggest that there were no significant differences in product recovery or value between the thinned plots and the untreated control plots in the manufacture of structural lumber products.

**Keywords:** precommercial thinning, thinning, wood quality, Sitka spruce, hemlock, second-growth timber

Since the mid-1900s, about 400,000 ac of timber on US Forest Service land and an equal amount on other ownerships have been harvested and naturally regenerated in southeast Alaska. Subsequently, several management themes have been developed for young-growth stands (McClellan 2005). They are designed to create stand structures beneficial to wildlife while simultaneously producing a sustainable timber supply. Each theme has a primary goal that ranges from maintaining the understory to producing high-value timber, but they all include the need for precommercial thinning (PCT) and in some cases commercial thinning or even pruning of lower limbs to accomplish the desired stand features. To manage the young-growth stands in ways that will achieve these goals, it is important to understand the product and economic potential of the wood fiber that is removed from these stands and of the trees that remain for possible harvest in the future. The Tongass National Forest continues to precommercially thin about 5,000 ac annually (Sheila Spores, pers. comm., US Forest Service, Tongass National Forest, Ketchikan, AK, Oct. 2011).

Lumber recovery from young-growth timber on the Tongass National Forest was identified as one of the key information needs in the Tongass land management plan revision (US Forest Service 1997). Of its more than 400,000 ac of young-growth, the Tongass National Forest has precommercially thinned more than 160,000 ac (McClellan 2005). The bulk of PCT was undertaken to meet wildlife habitat and forest health objectives. Wildlife forage was a major consideration with research on deer habitat being the primary focus. Moose habitat in southeast Alaska has also reportedly been affected by clear cutting because the dense regeneration provides little browse for the animals after crown closure (Lowell and Crain 1999). Harris (1974) reported a need for increased research on controlling stand density. Natural overstocking occurs following clearcutting in western hemlock (*Tsuga heterophylla*)/Sitka spruce (*Picea sitchensis*) stands (Hanley 2005), and heavy thinning in older stands also promotes dense conifer regeneration with reduced understory of herbs and shrubs (Deal and Farr 1994). Deal and Farr (1994) also found that established understory conifers rapidly filled the released growing space when conducting thinning in dense, natural stands of mixed hemlock and spruce less than 30 years old. Well-stocked, even-aged forests have been found to produce the least understory vegetation (Alaback 1984). One option to maintain diverse understory cover is through PCT (Deal and Farr 1994). Zaborske et al. (2002) found that thinning treatments increased deer forage. McClellan (2005) described silvicultural prescriptions that include wider spacings to delay crown closure and maintain understory plant diversity for wildlife habitat.

Thinning programs are often designed to increase volume yield. Poage (2008) found that thinning significantly increased basal area as compared with unthinned stands on 128 permanent plots in

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southeast Alaska. Zhang et al. (2009) found comparable stand volumes among control and plots precommercially thinned to different intensities 35 years following treatment. Macdonald and Hubert (2002) relate that there is limited information on factors affecting the quality of Sitka spruce when compared with other softwoods. They review literature on plantations that were established under different initial spacing, rather than naturally regenerated stands. When detailing contrasting results within a stand, they caution that subsequent self-thinning in more closely spaced stands can, over time, reduce some differences among stands thinned to different densities.

Thinning to wider spacings can increase growth rate, and the faster growth can have a negative impact on wood quality. Negative effects can include larger knots, lower specific gravity due to increased growth rates, and longer live crowns that may influence production of mature and juvenile wood (e.g., Maguire et al. 1991, Jozsa 1995, Hann et al. 1997). Barbour et al. (2005) reported that sawlog quality was reduced in trees from stands that had been thinned because of larger limbs and thus larger knots in the manufactured wood products as compared with trees from unthinned stands. These limbs, particularly in Sitka spruce, may be extremely persistent even when dead. Sitka spruce also tends to have a longer live crown, resulting in more knots in lumber from the generally more valuable butt log. DeBell et al. (1994) found that spacing did not affect the number of branches, but thinning increased branch size in young western hemlock stands. Farr and Harris (1971) and Herman (1964) both found increased epicormic branching in more heavily thinned stands. In Sitka spruce from southeast Alaska, numerous epicormic sprouts developed in response to pruning and thinning (Deal et al. 2003).

Measurable defects (e.g., fluting and cat face) have been found to be associated with thinning. A general increase in basal fluting of hemlock can result from PCT (Julin et al. 1993, Singleton et al. 2003, McClellan 2005), and the thin bark of both hemlock and spruce make residual trees highly susceptible to wounding in thinning operations (Ruth and Harris 1979, Sidle and Laurent 1986). Wounds provide infection courts for decay and stain fungi, thus reducing the volume and value recovered in future harvests due to increased defects. Straightness of the bottom log has been found to be negatively affected by increased spacing in Sitka spruce in Scotland (Stirling et al. 2000).

Management activities that influence growth, such as thinning, often have an impact on lumber quality. In addition to branching and crown characteristics, several wood quality attributes change from pith to bark and upward from the butt toward the top of the tree that influence visual and mechanical properties of wood products. Radial properties, such as specific gravity, change with the transition between juvenile wood (closest to the pith) and mature wood. Juvenile wood proportion of the stem increases as you move up the tree and is associated with decreased mechanical properties as reported by Middleton and Munro (2001). They found reductions in stiffness (modulus of elasticity [MOE]) and strength (modulus of rupture) as the proportion of juvenile wood increased in hemlock lumber. Moore et al. (2009) looked at site and stand factors affecting stiffness in Sitka spruce in the United Kingdom including initial spacing and thinning. Thinning was not a significant factor in the development of a predictive model for dynamic MOE of the tree. Zhang et al. (2009) examined the effects of PCT in eastern Canadian Balsam fir (*Abies balsamea* [L.] Mill.) on plots that were established at 12 years of age. They found that PCT of dense stands could affect lumber mechanical properties considerably when stands were heavily thinned. Weiskittel et al. (2009) found long-term effects of heavy PCT in red spruce (*Picea rubens* Sarg.) and balsam fir, including size of knots limiting the production of highest value structural lumber. In black spruce (*Picea mariana* [Mill.] B.S.P.) plantations, Tong et al. (2009) determined PCT had little effect on the yield of No. 2 and Better lumber. Six years after commercial thinning in a 49-year-old black spruce plantation, radial growth had increased, but little change was noted in wood density (Tong et al. 2011).

The species examined in this study are western hemlock and Sitka spruce. Existing information on product values from western hemlock and Sitka spruce from southeast Alaska is based on trees that were sampled from old-growth stands during the 1960s to 1980s (Lane et al. 1972, Woodfin and Snellgrove 1976, Fahey 1983, Ernst et al. 1986). Little information is available about the characteristics of the young-growth resource in southeast Alaska and the relation between those characteristics and product value. Christensen et al. (2002) looked at volume recovery in 90-year-old Sitka spruce and hemlock trees from commercially thinned and unthinned stands in southeast Alaska and found few to no differences in volume recovery, grade yield, and bending MOE for both species. Historically, more hemlock than Sitka spruce has been harvested in southeast Alaska (Crone 2005), with the sawlog quality of hemlock commonly being lower than that of spruce. Brackley et al. (2006) state that western hemlock remains the dominant species of logs processed by southeast Alaska mills. Ultimately, the net value of the timber is determined by the cost of removing it and the market potential of the products. Therefore, an understanding of the markets and the characteristics of the wood that make it suitable for use in those markets is also important. Markets continue to develop for engineered wood products, such as glue laminated timber (glulam), which are designed to effectively use lower quality wood. Allen and Gorman (2003) undertook a feasibility study for siting a glulam manufacturing plant in Alaska. Although it was determined that it was too costly at the time, residential builders in Alaska use glulam beams, and the glulam market is well established (Roos et al. 2008).

The objectives of this study were as follows:

1. To establish baseline product recovery information about the volume and quality of lumber products manufactured from young-growth western hemlock and Sitka spruce from even-aged stands in southeast Alaska.
2. To compare wood product quality differences (lumber grade and stiffness) between stands that have been thinned and those that have not been thinned.

## Methods

### Sample

#### *Sites*

This is a retrospective study involving mixed stands at eight sites in southeast Alaska (Figure 1). Sampling sites were selected with the help of local agency experts to represent the types of stands, timber species, and sizes of trees that are likely to be harvested in the near future. Sites were identified on the basis of age and thinning history (Table 1) and the availability of an adjacent or nearby unthinned control plot from the same original stand. To facilitate the removal of trees for processing, all of the selected sites were accessible from existing roads and on terrain where locally available harvesting systems could operate efficiently. Sites were selected to represent as wide a range as possible of stand ages and site classes for both

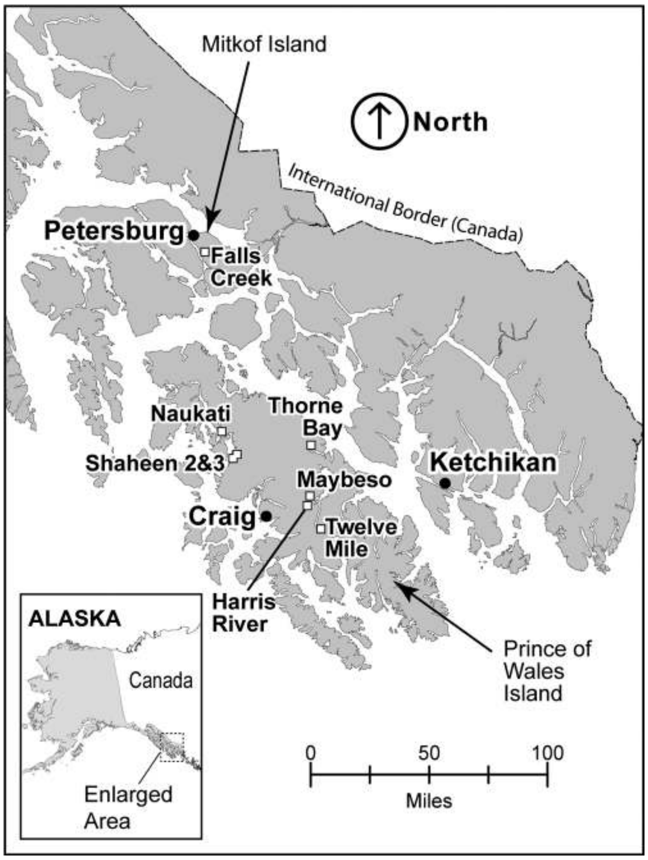


**Figure 1. Map of southeast Alaska showing the study sites on Prince of Wales and Mitkof Islands. The towns of Ketchikan, Craig, and Petersburg are also shown for orientation. The town of Thorne Bay is not shown but is located immediately to the east of the Thorne Bay study site.**

thinned and unthinned (hereafter referred to as control) stands. Seven of the eight stands are located on Prince of Wales (POW) Island. The remaining site is located on Mitkof Island. All but two sites are on the Tongass National Forest. The thinned treatment and unthinned control on the Harris River site (POW) and the control area at Falls Creek on Mitkof Island are on lands managed by the State of Alaska Department of Natural Resources.

*Sample Trees*

At each site, sample trees of western hemlock and Sitka spruce were selected. The sample design was stratified by five dbh classes to cover the full range of diameters on the thinned and control stands. Four-inch dbh classes were established, with the minimum dbh being 9 in. and the largest class being 24 in. and greater. The sampling matrix was designed to sample approximately 15 trees/species from each thinned and control site across the range of diameters in each stand. Because the number of trees available for sampling was limited by the actual diameter distribution on a site, the matrix served as a guide only, and the actual number of sample trees per species selected at each site ranged from 5 to 19. Each tree was tagged with a unique tree number.

## Processing

*Harvesting*

Sample trees were felled and bucked to normal industry standards. The minimum small-end diameter was specified as 5 in. inside bark. Tree age was obtained by counting annual rings on the stump. Total height of each tree was measured after the tree was felled. Each log was tagged on both ends with its tree number and log position to maintain its identity throughout the study. Logs were yarded to roadside using an excavator with cable winch, hauled by truck to dockside, and transported by barge to the Ketchikan Wood Technology Center (KWTC) in Ketchikan, Alaska.

*Scaling*

At KWTC, the woods-length logs were rolled out in the yard to allow scaling in cubic (US Forest Service 2002) and Scribner Decimal C (US Forest Service 1985). Log diameters at both ends were recorded to the nearest 0.1 in. and lengths to the nearest 0.1 ft. Inside-bark diameter measurements were taken at 4 ft from the large end of each butt log for use as the large-end diameter for cubic-volume calculations as specified in rule 21.4 of US Forest Service (2002). Defects were identified and diagrammed, and scaling deductions were made by Pacific Rim Scaling Bureau scalers and recorded by Pacific Northwest Research Station personnel. Log grades were assigned based on current Bureau log scaling rules then in effect (Northwest Log Rules Advisory Group 2003).

After the woods-length logs had been scaled, they were bucked into sawmill-length logs and scaled a second time using both cubic and Scribner rules. Tables 2 and 3 summarize data for the sawmill-length logs by species and treatment for the study sites individually and for all sites combined.

*Manufacturing*

Logs were not debarked prior to sawing. An AWMV LT300 Thin Kerf Headrig portable sawmill was set up at KWTC for processing the logs. Products manufactured from each log were dimension lumber, 2 × 4, 2 × 6, and 2 × 8 (nominal sizes in inches). Each log was assigned a sawing order number and the identity of the log and all the lumber from each individual log was maintained throughout the study. Lumber was kiln dried, surfaced, and graded according to National Lumber Standard Grading Rules (Western Wood Products Association [WWPA] 2005). Different visual structural grading systems were used depending on lumber product size: Structural Light Framing rules for 2 × 4s and Structural Joists and Planks rules for 2 × 6s and 2 × 8s. Laminating grades (WWPA 2005) were also assigned to each piece. Length to the nearest foot along with nominal width and thickness and the assigned grade were recorded for each piece of lumber. The grade-limiting (controlling) defect was recorded for each piece to determine how often, and to what extent, knot size and other defects influenced lumber grade and prevented that piece from being assigned a higher grade. Every piece of lumber was nondestructively tested using the Metriguard Model 340 E-Computer according to American Society for Testing and Materials standard D6874 (American Society for Testing and Materials 2003) to determine its MOE. The moisture content of each board was measured at the same time using a portable Wegner Moisture Meter.

## Analysis

Measurements taken in this project permitted tree characteristics to be correlated with lumber quantity and quality (grade and stiffness). Analysis to correlate tree characteristics include developing relationships between log size, species, and stand treatment with the

**Table 1. Stand data for the nine sites in the southeast Alaska thinning study.**

| Name | Location[a] | Year of regeneration harvest | Thinning type[b] | Year thinning occurred | Stand age, years[c] | Thinned target spacing, ft[d] (trees/ac) |
|---|---|---|---|---|---|---|
| Falls Creek | Mitkof, PRD | 1967 | PCT | 1980 | 36 | 10 (436) |
| Harris River | POW, CRD | 1962 | PCT | 1977 | 41 | 16 (170) |
| Maybeso | POW, CRD | 1959 | PCT | 1980 | 44 | 10 (436) |
| Naukati 20 × 20 | POW, TBRD | 1930 | CT | 1985 | 73 | 20 (109) |
| Shaheen Unit 2 | POW, TBRD | 1945 | CT | 1985 | 58 | 18 (134) |
| Shaheen Unit 3 | POW, TBRD | 1945 | CT | 1985 | 58 | 20 (109) |
| Thorne Bay Dump | POW, TBRD | 1963 | PCT | 1983 | 40 | 12 (302) |
| Twelve Mile | POW, CRD | 1960 | PCT | 1982 | 43 | 12 (302) |

[a] Mitkof, Mitkof Island; POW, Prince of Wales Island; CRD, Craig Ranger District; PRD, Petersburg Ranger District; TBRD, Thorne Bay Ranger District.
[b] PCT, precommercial thinning; CT, commercial thinning. However, the designation CT is used merely to indicate that the logs harvested were of a size that could conceptually have been used; none of the logs from these thinnings were actually used because of lack of market interest.
[c] Stand age in years when the sites were selected for this project in 2003.
[d] A spacing entry of 12 corresponds to average physical spacing between trees of 12 × 12 ft, assuming that trees are spaced uniformly over the stand.

**Table 2. Tree and mill-length log data for western hemlock by site and treatment.**

| Site | Treatment | No. of trees | dbh Mean | dbh Range | No. of logs | Small-end diameter Mean | Small-end diameter Range |
|---|---|---|---|---|---|---|---|
| | | | (in.) | | | (in.) | |
| Falls Creek | Control | 7 | 11.0 | 9.5–14.0 | 15 | 7.6 | 5.8–11.0 |
| Falls Creek | Thinned | 11 | 12.3 | 10.2–14.9 | 23 | 7.7 | 5.4–11.4 |
| Harris River | Control | 10 | 11.5 | 9.8–13.5 | 35 | 7.9 | 5.0–11.7 |
| Harris River | Thinned | 11 | 12.5 | 9.5–18.4 | 30 | 8.2 | 5.0–14.8 |
| Maybeso | Control | 16 | 13.6 | 9.6–19.8 | 55 | 8.7 | 5.1–15.0 |
| Maybeso | Thinned | 15 | 14.4 | 10.0–19.7 | 55 | 9.5 | 5.3–16.0 |
| Naukati | Control | 2 | 13.8 | 11.1–16.4 | 8 | 9.6 | 5.8–14.0 |
| Naukati 20 × 20 | Thinned | 9 | 14.3 | 9.9–18.9 | 35 | 10.0 | 5.7–15.6 |
| Shaheen Unit 2 | Control | 7 | 12.4 | 9.5–15.8 | 24 | 8.0 | 5.2–11.2 |
| Shaheen Unit 2 | Thinned | 9 | 14.2 | 9.6–19.8 | 30 | 9.4 | 5.5–16.3 |
| Shaheen Unit 3 | Control | 4 | 11.5 | 9.8–13.3 | 15 | 7.7 | 5.1–10.2 |
| Shaheen Unit 3 | Thinned | 12 | 13.1 | 9.7–16.4 | 44 | 8.9 | 5.0–14.0 |
| Thorne Bay Dump | Control | 7 | 11.0 | 9.9–12.5 | 14 | 6.8 | 5.2–8.9 |
| Thorne Bay Dump | Thinned | 10 | 12.3 | 9.5–15.7 | 22 | 7.4 | 5.0–12.1 |
| Twelve Mile | Control | 11 | 12.1 | 10.0–15.4 | 30 | 8.0 | 5.0–12.5 |
| Twelve Mile | Thinned | 11 | 13.6 | 9.5–18.5 | 29 | 8.3 | 5.3–14.7 |
| All sites | Control | 64 | 12.2 | 9.5–19.8 | 196 | 8.1 | 5.0–15.0 |
| All sites | Thinned | 88 | 13.3 | 9.5–19.8 | 268 | 8.9 | 5.0–16.3 |
| All sites | Control + thinned | 152 | 12.9 | 9.5–19.8 | 464 | 8.5 | 5.0–16.3 |

volume and quality of the lumber produced. The analysis was conducted using data from paired plots (thinned versus control) on the eight stands, representing trees of different ages that had been thinned to five different levels of intended residual spacing, ranging from 10 × 10 ft to 20 × 20 ft.

Lumber grade recovery and stiffness often vary according to the vertical and horizontal location within a tree. Mill logs were separated into three vertical-log categories: butt, middle, and top logs. The number of logs assigned to each category from a particular tree depended on the total number of 16-ft logs from that tree. There could be as many as two 16-ft butt logs from a tree because a butt log is commonly considered to be 32 ft long in southeast Alaska; however, shorter trees having only one 16-ft log were considered to have a single butt log, and a tree with only two 16-ft logs was considered to have one butt log and one top log. Logs above the butt log(s) were classified as middle or top logs in approximately equal proportions. If there was an uneven number of logs above the butt log(s), the extra log was classified as a middle log. As logs are the common manufacturing unit, we present the results only on the vertical-log basis and do not address spatial variation of lumber properties within a log.

*Volume Recovery*

Regression analysis was used to characterize volume recovery of Sitka spruce and hemlock by small-end diameter for mill-length logs (< 21 ft). Gross cubic volumes were calculated using Smalian's formula for all logs in the tree, with the 4-ft inside bark measurement being used as the large diameter for the butt log as described previously. Smalian's formula (Equation 1) is as follows:

$$V = .002727 \times L \times (LED^2 + SED^2) \quad (1)$$

where $V$ = volume of the log (cu ft); $L$ = log length (ft); $LED$ = log large-end diameter (in); and $SED$ = log small-end diameter (in).

Stepwise regression was used to develop a lumber volume recovery model using as the dependent variable green cubic recovery percentage (cubic volume of lumber divided by gross cubic volume of mill-length logs, expressed as a percentage). Final model selection and validity were based on the SD about the regression ($s_{yx}$), hypotheses tests, evaluation of residual patterns, and ease of model use. We used the coefficient of determination (adjusted $R^2$) to describe the amount of explained variation.

*Grade Recovery and Stiffness (MOE)*

For each species, the overall treatment effect (thinned versus control) on lumber grade recovery and transverse E-vibration MOE by vertical-log position (butt log, middle log, or top log) was analyzed using the mixed-model procedure in SAS (SAS Institute, Inc., 2009). Although the paired-plot design with discrete treatments

**Table 3. Tree and mill-length log data for Sitka spruce by site and treatment.**

| Site | Treatment | No. of trees | dbh Mean | dbh Range | No. of logs | Small-end diameter Mean | Small-end diameter Range |
|---|---|---|---|---|---|---|---|
| | | | . . . . . . .(in.) | . . . . . . . | | . . . . . . . .(in.). | . . . . . . . . |
| Falls Creek | Control | 15 | 14.1 | 11.2–19.8 | 42 | 9.2 | 5.7–16.6 |
| Falls Creek | Thinned | 14 | 14.4 | 10.4–18.5 | 38 | 8.9 | 5.5–15.0 |
| Harris River | Control | 15 | 14.3 | 9.8–20.5 | 59 | 9.5 | 5.3–17.5 |
| Harris River | Thinned | 16 | 14.4 | 10.3–23.3 | 55 | 9.4 | 5.3–21.1 |
| Maybeso | Control | 19 | 15.8 | 9.5–28.2 | 81 | 10.7 | 5.0–22.4 |
| Maybeso | Thinned | 16 | 15.4 | 10.0–27.0 | 64 | 10.6 | 5.5–23.7 |
| Naukati | Control | 16 | 17.3 | 11.1–24.7 | 82 | 11.1 | 4.3–19.9 |
| Naukati 20 × 20 | Thinned | 14 | 18.9 | 11.5–30.3 | 82 | 12.3 | 5.5–22.2 |
| Shaheen Unit 2 | Control | 15 | 16.1 | 10.0–24.3 | 69 | 10.3 | 5.2–19.3 |
| Shaheen Unit 2 | Thinned | 11 | 18.5 | 10.9–25.9 | 62 | 11.6 | 5.2–23.1 |
| Shaheen Unit 3 | Control | 16 | 16.7 | 9.8–26.6 | 84 | 11.1 | 4.9–23.5 |
| Shaheen Unit 3 | Thinned | 17 | 15.7 | 9.5–24.4 | 77 | 10.6 | 5.3–20.1 |
| Thorne Bay Dump | Control | 12 | 13.0 | 9.8–18.9 | 31 | 8.4 | 5.1–15.5 |
| Thorne Bay Dump | Thinned | 5 | 13.6 | 12.3–15.2 | 11 | 8.1 | 5.0–11.1 |
| Twelve Mile | Control | 16 | 14.6 | 10.2–21.1 | 53 | 9.3 | 5.2–17.3 |
| Twelve Mile | Thinned | 15 | 14.7 | 10.7–22.3 | 50 | 9.3 | 5.0–18.9 |
| All sites | Control | 124 | 15.3 | 9.5–28.2 | 501 | 10.2 | 4.3–23.5 |
| All sites | Thinned | 93 | 15.7 | 9.5–30.3 | 439 | 10.6 | 5.0–23.7 |
| All sites | Control + thinned | 232 | 15.5 | 9.5–30.3 | 940 | 10.4 | 4.3–23.7 |

could have been analyzed using a classic analysis of variance, there were not enough degrees of freedom to analyze separate main effects associated with residual spacing from the thinning treatments.

To limit the number of inferences drawn and thus reduce Type I errors, a lumber grade grouping, No. 2 (or Standard) and Better was formed under the structural lumber grading rules. Dimension lumber is often sold as No. 2 (or Standard) and Better, a category that combines the three highest grades. This grouping combines the No. 2 (Standard), No. 1 (Construction), and Select Structural grades. Select Structural was also retained as a separate grade category since it represents the best-quality and highest-value lumber produced.

*Value Recovery*

Value recovery was assessed for each species separately, using the same vertical-log classes as lumber grade recovery. The dependent variable for analysis of value is dollars per 100 $ft^3$ of gross log volume ($/CCF), and the independent variable is small-end log diameter or some transformation of it. Dollars of lumber value recovered per 100 $ft^3$ of log volume provides an indication of average lumber value from individual logs. To calculate $/CCF, the volume of lumber recovered in each size and lumber grade from a particular log was multiplied by the price for that size and grade, and then the sum of the lumber values for the log was divided by the gross cubic volume of the log. The results of such a derivation are dependent on the pricing structure existing at any particular time. Prices used for the analysis presented here were from Random Lengths (2011) and WWPA (2011) and represent average prices by lumber grade for all of calendar year 2010.

## Results

The sample included 207 western hemlock trees and 254 Sitka spruce trees, which were converted into 721 and 1,056 mill-length logs, respectively. Harvested trees that were clearly older than the age of the stand (based on logyard ring counts and X-ray densitometry ages of butt logs) were dropped from the sample. The sample used for statistical analyses comprised 152 western hemlock and 232 Sitka spruce trees converted into 464 and 940 mill-length logs, respectively. Table 1 summarizes overall data for the study sites, and Tables 2 (hemlock) and 3 (spruce) provide means and ranges for trees (dbh) and logs (small-end diameter) by site and treatment type and reveals the relatively wide range of stand ages represented in the study.

**Scaling Volumes and Deductions**

Gross and net cubic and Scribner volumes are shown in Table 4. Scaling deductions for spruce logs from both the thinned and control plots were less than 1% of gross volume and affected 6% of spruce logs. There were more deductions for defects in the hemlock, averaging between 6 and 10% for both scaling systems and affecting 25% of hemlock logs. Sweep was the primary cause of volume deductions in both species, although fluting deductions were also common in the hemlock butt logs. Sweep deductions were approximately equally distributed among logs from thinned and control plots. Fluting was more common in thinned plots, from which 77% of hemlock logs with fluting deductions originated. Even so, only 3.1% of all hemlock logs exhibited fluting severe enough to warrant a deduction. The incidence of deductions for rot was very low for both species (2.1% of hemlock logs and 0.1% of spruce logs). Deductions for rot were more likely to occur in logs from thinned plots (1.2% of logs) than in logs from control plots (0.6% of logs).

Except as described above for hemlock butt fluting and for rot, deductions for scaling defects were more or less evenly distributed among sample trees from thinned and control plots. In both hemlock and spruce, butt logs were more likely to have deductions than logs from higher in the tree; 64% of hemlock deductions and 59% of spruce deductions were in butt logs. Overall, scaling defects were slightly more prevalent on sample trees from thinned plots for both species: 25.6% of hemlock logs from thinned plots had defects compared with 24.8% from control plots. Similarly, 6.2% of spruce logs from thinned plots had defects compared with 5.9% from control plots. Overall, no practical differences were noted between logs from the thinned and control trees.

**Effects: Treatment, Log Position, and Log Diameter**

A variance component analysis showed that little variability was accounted for by the site or by the trees within a site for the two

**Table 4. Gross and net cubic and Scribner volumes for mill-length logs (<21 ft).**

| Species | Treatment | Cubic scale | | Scribner scale | |
|---|---|---|---|---|---|
| | | Gross | Net | Gross | Net |
| | | . . . . . .($ft^3$). . . . . . | | . . . .(board ft). . . . | |
| Hemlock | Control | 1,358.7 | 1,263.0 | 6,000 | 5,360 |
| Hemlock | Thinned | 2,282.3 | 2,148.8 | 10,430 | 9,590 |
| Spruce | Control | 5,857.6 | 5,816.7 | 29,990 | 29,750 |
| Spruce | Thinned | 5,675.1 | 5,636.9 | 29,320 | 29,070 |

**Table 5. Results of variance component analyses for cubic recovery (the cubic volume of surfaced dry lumber recovered from mill-length logs as a percentage of cubic log volume, expressed as a percentage) and dollars of lumber value recovered per hundred cubic feet of gross log volume by species ($/CCF).**

| Species | Treatment | Dependent | Variance component | Variance component (%) |
|---|---|---|---|---|
| Hemlock | Control | Cubic recovery | Var(Stand) | 8.75 |
| | | | Var(Tree(Stand)) | 6.77 |
| | | | Var(Log) | 84.47 |
| | Thinned | | Var(Stand) | 9.22 |
| | | | Var(Tree(Stand)) | 7.29 |
| | | | Var(Log) | 83.49 |
| Spruce | Control | | Var(Stand) | 2.24 |
| | | | Var(Tree(Stand)) | 0.00 |
| | | | Var(Log) | 97.76 |
| | Thinned | | Var(Stand) | 3.82 |
| | | | Var(Tree(Stand)) | 0.00 |
| | | | Var(Log) | 96.18 |
| Hemlock | Control | $/CCF | Var(Stand) | 9.90 |
| | | | Var(Tree(Stand)) | 8.99 |
| | | | Var(Log) | 81.11 |
| | Thinned | | Var(Stand) | 12.22 |
| | | | Var(Tree(Stand)) | 3.85 |
| | | | Var(Log) | 83.93 |
| Spruce | Control | | Var(Stand) | 4.36 |
| | | | Var(Tree(Stand)) | 0.00 |
| | | | Var(Log) | 95.64 |
| | Thinned | | Var(Stand) | 5.01 |
| | | | Var(Tree(Stand)) | 0.00 |
| | | | Var(Log) | 94.99 |

response variables, cubic volume recovery and lumber value recovery (Table 5). The majority of the variation (greater than 80% in all cases) occurred among logs within trees.

A mixed-effects analysis (Table 6) assuming common variation between controls and thinned stands was undertaken in an effort to determine whether thinning had any measurable effect on the variables of interest: lumber volume recovery, lumber grade recovery, lumber value recovery, and log-weighted MOE for the lumber recovered from each mill-length log. The mixed-effects procedure from SAS (SAS Institute, Inc., 2009) was used for all tests but was unable to produce a solution in one case, the test of log-weighted MOE for hemlock. That test was therefore run using the "high performance" mixed-effects procedure in SAS, an experimental procedure that has been designed to overcome limitations of the conventional mixed-effects procedure when estimation problems are encountered.

As shown in Table 6, thinning (i.e., treatment) had no statistically significant effect on any of the response variables for either species. This suggests that the thinnings considered in this study had no negative effects on the various lumber recovery and wood quality measurements evaluated. As a result, all of the remaining statistical analyses were conducted with data from the thinned and control plots combined.

Table 6 also shows that the position of the log within the tree had a statistically significant effect on the percentage of lumber recovered in the Select Structural grade for both species, in the No. 2 and Better grade aggregation for hemlock, and in Laminating grade 1 (the top laminating grade) for spruce. It was also statistically significant for MOE in spruce.

For both lumber volume recovery and lumber value recovery, Table 6 shows that the log *SED* was statistically significant in the 1/*SED* transformation. This transformation has proven useful in a variety of lumber recovery studies (see, for example, Willits and Fahey 1988), and we elected to use it in this study as well.

### Lumber Volume Recovery

Using SAS (SAS Institute, Inc., 2009) we derived regression equations for predicting cubic lumber volume recovery expressed as a percentage of the cubic log volume. Equations were derived for each species separately using the following functional form:

$$R_i = \beta_0 + \beta_1 \cdot (1/SED) \quad (2)$$

where $R_i$ = cubic lumber volume recovery for species *i*, calculated as surfaced dry cubic lumber volume recovered divided by the gross cubic volume of mill-length logs (%); *SED* = mean log diameter at the small end of the mill-length log (in.); $\beta_0$ = estimated regression intercept parameter (%); and $\beta_1$ = estimated regression slope parameter (percent × in.).

Gross log volume was used when calculating $R_i$ to avoid any bias that may be introduced by log-scaling deductions. Results of the regression analysis are summarized in Table 7.

Both of the regression equations derived using the model of Equation 2 were highly significant overall ($P < 0.0001$ for the $F$ value) and for both the intercept and slope parameters ($P < 0.0001$ for each $t$ value). As is common in lumber recovery studies, $R^2$ values were relatively low (0.15 for hemlock and 0.37 for spruce). The equations are shown with their respective fit statistics in Table 7 and the regression curves are plotted in Figure 2. Spruce logs had a higher percentage recovery than hemlock for all diameter classes. We attribute this to differences in taper (the spruce trees were taller for a given dbh, averaging more than 4 mill-length logs per tree compared with 3.5 mill-length logs per hemlock tree), the fact that the hemlock trees were somewhat smaller in general than the spruce trees (Tables 2 and 3), and the prevalence of fluting in the hemlock butt logs.

### Lumber Grade Recovery

Lumber grade is an expression of perceived value as defined by the grading rules. Lumber grade is indicative of log quality and is important in determining log value. The vertical position of a log within the tree stem influences lumber quality (e.g., Christensen et al. 2002). Butt logs and those from lower on the stem contain more mature wood and generally more clear wood (free from knots), yielding higher-grade lumber. The size and frequency of knots strongly influence structural lumber grades (WWPA 2005).

The mixed-model tests showed no significant interaction between treatment and log position (Table 6) for either of the grading systems in hemlock or spruce. Treatment (thinned versus control) also had no significant effect for either species. However, for spruce, log position was a significant predictor for the highest grades in both grading systems. The mean fraction of Select Structural lumber from spruce butt logs was 34%. Middle logs contained about 25%

**Table 6. Results of the mixed-effects tests for significant effects associated with treatment (thinned versus unthinned), log position within the tree, and interactions of those variables on lumber sawn from western hemlock and Sitka spruce mill-length logs. For lumber volume and value recovery, continuous covariates were also tested as transformations of log small-end diameter (*SED*).**

| | | Hemlock | | | Spruce | | |
|---|---|---|---|---|---|---|---|
| Response variable | Effect | DF | *F* value | $P = \Pr > F$ | DF | *F* value | $P = \Pr > F$ |
| Lumber volume recovery (%) | Treatment | 1; 7 | 0.00 | 0.9480 | 1; 7 | 0.00 | 0.9575 |
| | Log position | 2; 27 | 0.46 | 0.6378 | 2; 28 | 0.77 | 0.4708 |
| | Treatment × position | 2; 27 | 0.07 | 0.9306 | 2; 28 | 0.37 | 0.6936 |
| | 1/*SED* | 1; 414 | 21.25 | <0.0001[a] | 1; 889 | 141.22 | <0.0001[a] |
| | (1/*SED*) × position | 2; 414 | 0.43 | 0.6518 | 2; 889 | 1.10 | 0.3339 |
| Select structural grade (%) | Treatment | 1; 7 | 1.44 | 0.2696 | 1; 7 | 0.93 | 0.3658 |
| | Log position | 2; 27 | 10.69 | 0.0004[a] | 2; 28 | 39.71 | <0.0001[a] |
| | Treatment × position | 2; 27 | 0.53 | 0.5956 | 2; 28 | 0.12 | 0.8890 |
| No. 2 and better grade (%) | Treatment | 1; 7 | 0.02 | 0.8850 | 1; 7 | 0.33 | 0.5837 |
| | Log position | 2; 27 | 9.52 | 0.0007[a] | 2; 28 | 1.14 | 0.3343 |
| | Treatment × position | 2; 27 | 0.57 | 0.5716 | 2; 28 | 0.89 | 0.4216 |
| Laminating grade 1 (%) | Treatment | 1; 7 | 0.19 | 0.6764 | 1; 7 | 0.27 | 0.6208 |
| | Log position | 2; 27 | 0.77 | 0.4718 | 2; 28 | 23.68 | <0.0001[a] |
| | Treatment × position | 2; 27 | 0.77 | 0.4716 | 2; 28 | 0.06 | 0.9376 |
| Laminating grade 2 (%) | Treatment | 1; 7 | 1.67 | 0.2371 | 1; 7 | 4.78 | 0.0650[a] |
| | Log position | 2; 27 | 0.22 | 0.8067 | 2; 28 | 2.22 | 0.1276 |
| | Treatment × position | 2; 27 | 0.48 | 0.6218 | 2; 28 | 0.70 | 0.5043 |
| Flat MOE[b] | Treatment | 1; 7 | 1.42 | 0.2730 | 1; 7 | 0.06 | 0.8208 |
| | Log position | 2; 28 | 0.54 | 0.5864 | 2; 28 | 8.13 | 0.0016[a] |
| | Treatment × position | 2; 28 | 0.08 | 0.9210 | 2; 28 | 0.12 | 0.8918 |
| Lumber value recovery ($/CCF) | Treatment | 1; 7 | 0.00 | 0.9958 | 1; 7 | 0.08 | 0.7915 |
| | Log position | 2; 27 | 0.31 | 0.7329 | 2; 28 | 0.92 | 0.4092 |
| | Treatment × position | 2; 27 | 0.17 | 0.8416 | 2; 28 | 0.91 | 0.4158 |
| | 1/*SED* | 1; 414 | 17.59 | <0.0001[a] | 1; 889 | 111.35 | <0.0001[a] |
| | (1/*SED*) × position | 2; 414 | 0.29 | 0.7501 | 2; 889 | 5.85 | 0.0030[a] |

DF, degrees of freedom (numerator; denominator).
[a] Statistically significant results are those for which $P < 0.05$.
[b] Results from the standard MIXED procedure in SAS (2009) were indeterminate for Flat MOE in hemlock lumber, so the experimental HPMIXED procedure was used to provide the Flat MOE results for hemlock shown here. Spruce results are from the MIXED procedure.

**Table 7. Results of regression analyses on cubic lumber recovery (percentage) for western hemlock and Sitka spruce separately, with data from the thinned and control plots combined for each species. The regression equations are of the form described in Equation 2.**

| Species | Attribute | $\beta_0$ | $\beta_1$ | *n* | MSE | $R^2$ | *F* significance |
|---|---|---|---|---|---|---|---|
| Hemlock | Regression | 55.73 | −127.84 | 464 | 108.56 | 0.15 | <0.0001 |
| | Standard error | 1.81 | 13.79 | | | | |
| | *t* value | 30.72 | −9.27 | | | | |
| | $P = \Pr > \lvert t \rvert$ | <0.0001 | <0.0001 | | | | |
| Sitka spruce | Regression | 64.14 | −163.78 | 940 | 76.56 | 0.37 | <0.0001 |
| | Standard error | 0.83 | 7.03 | | | | |
| | *t* value | 77.40 | −23.28 | | | | |
| | $P = \Pr > \lvert t \rvert$ | <0.0001 | <0.0001 | | | | |

MSE, mean squared error.

and top logs about 12% of Select Structural lumber (Figure 3). However, if the lumber were to be sold as No. 2 and Better, the significance disappears and an overall mean of 77% of the lumber from all trees was produced in this grade grouping.

Hemlock returned slightly different results, with log position being significant for both the Select Structural and for the No. 2 and Better grade classifications. Hemlock butt logs contained 26% Select Structural lumber, middle logs about 18% and top logs just over 10% (Figure 4). For the grade grouping No. 2 and Better, the fraction of lumber in the butt log was 72%, falling to 67% for middle logs and just over 57% in top logs.

When examining grade-controlling defect, the three most commonly found defects were knots, wane, and warp (Table 8). Although knots were the leading cause of downgrade in lumber, there was no significant difference between thinned and control stands in average knot size. However, average knot size was significantly influenced by log position in both spruce ($P = 0.0004$) and hemlock ($P < 0.0001$). Knot placement and distribution within the board is also an important factor in visual lumber grading but could not be tested statistically. Wane was the limiting defect more often in the upper logs, where taper in the tree is greater. Because we sampled logs to a 5-in. top, the occurrence of wane was greater in logs cut from near the top of the tree.

Glulam grades are based on physical characteristics such as knots and cross grain. More than 74% of the pieces of hemlock lumber and about 58% of the spruce lumber pieces did not meet any of the laminating grades. There was not much lumber produced from either species that met either the highest laminating grade of L1 (13% for both hemlock and spruce) or the next quality level of L2 (8% hemlock, 14% spruce). There were no significant interactions between treatment and log position for either species. Log position was not significant for either L1 or L2 grades in hemlock, whereas log position in spruce was significant for L1 grade.

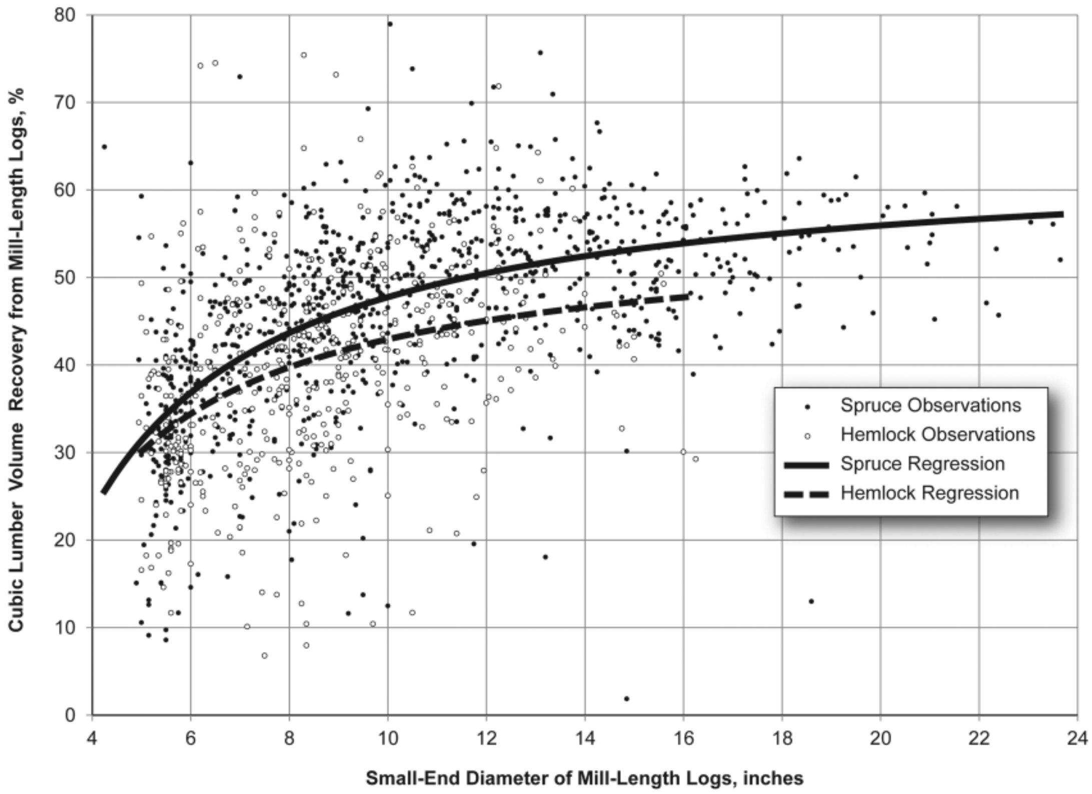


Figure 2. Cubic volume of surfaced dry lumber recovered from mill-length logs as a percentage of cubic log volume in relation to log small-end diameter. Individual observations are shown for both western hemlock (464 logs) and Sitka spruce (940 logs). The regression lines are for data fit to Equation 2 for each species separately and with logs from both thinned and control areas combined.

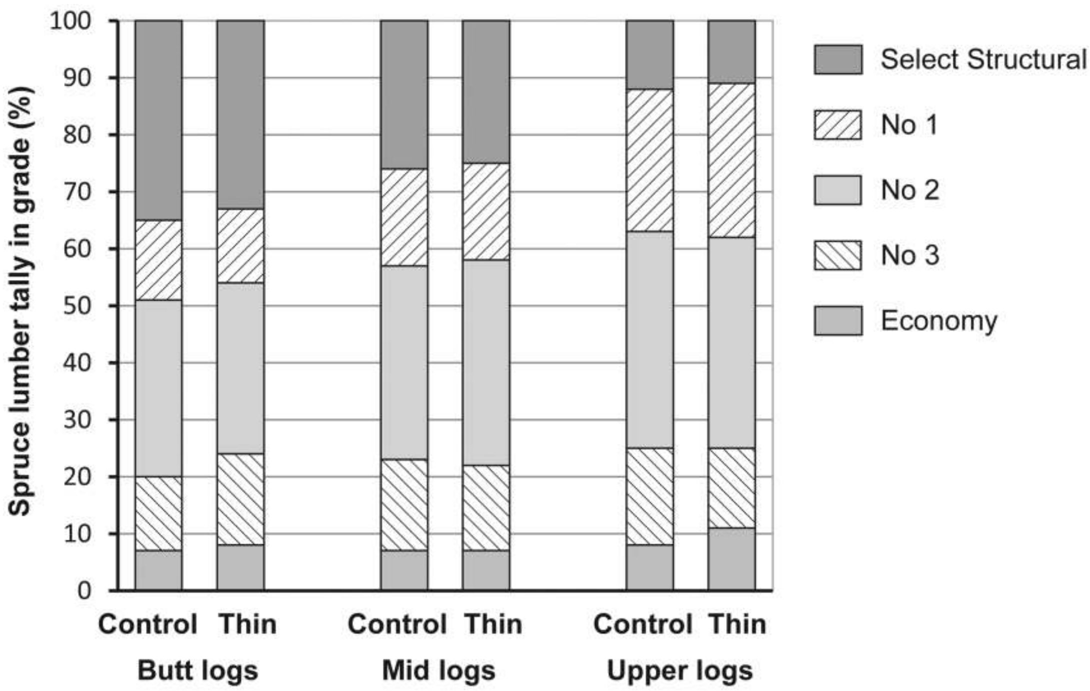


Figure 3. Percentage of Sitka spruce lumber recovered by volume in each grade under the Western Wood Products Association (2005) visual grading rules for structural lumber, presented by treatment and log position within the tree.

**Transverse E-Vibration Stiffness (MOE)**

Transverse e-vibration testing is a nondestructive testing method used to sort dimension lumber by stiffness and assign a machine stress rated (MSR) grade designation. MSR lumber can command a higher price than visually graded dimension lumber. The MOE data collected in this study will be used in a later report evaluating the

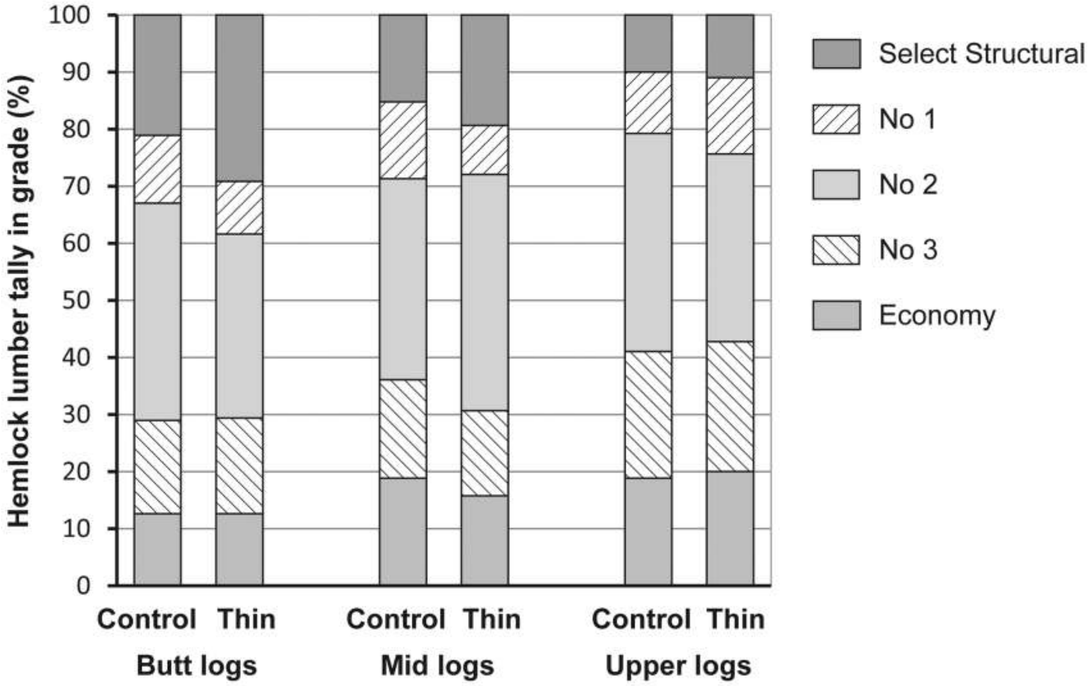


**Figure 4. Percentage of western hemlock lumber recovered by volume in each grade under the Western Wood Products Association (2005) visual grading rules for structural lumber, presented by treatment and log position within the tree.**

**Table 8. Grade-controlling defects by species and vertical log position. Values in each column are percentages of all grade-controlling defects for that species and log position.**

| | Hemlock | | | Spruce | | |
|---|---|---|---|---|---|---|
| Defect type | Butt log | Middle log | Upper log | Butt log | Middle log | Upper log |
| Knot | 42.2 | 38.6 | 30.2 | 53.0 | 57.1 | 57.2 |
| Wane | 33.6 | 31.6 | 26.5 | 17.8 | 21.4 | 21.1 |
| Warp | 14.1 | 17.3 | 31.0 | 4.9 | 4.9 | 10.8 |
| Shake | 3.4 | 5.3 | 6.4 | 6.2 | 3.0 | 2.1 |
| Unsound wood | 1.1 | 2.1 | 1.0 | 4.0 | 6.5 | 2.4 |
| Slope of grain | 1.2 | 1.0 | 0.0 | 8.4 | 2.8 | 1.8 |
| Other defects | 4.4 | 4.1 | 4.9 | 5.7 | 4.3 | 4.6 |
| Totals | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

effectiveness of nondestructive measurement techniques to predict product quality. Here, we are determining the effect of treatment on stiffness values. The mixed model indicated no significant differences in MOE between the control and thinned plots. There was no significant interaction between treatment and log position in either species (Table 6). Log position significantly affected the MOE of the spruce lumber ($P = 0.0016$), but not that of the hemlock. Even so, the difference in MOE for lumber from spruce butt logs (mean $1.40 \times 10^6$ psi) was only modestly different from the MOE for lumber from middle and upper spruce logs (mean $1.47 \times 10^6$ psi).

## Lumber Value Recovery

Using SAS (SAS Institute, Inc., 2009), we derived regression equations for predicting the value of lumber recovered from mill-length logs expressed in \$/CCF gross log volume. Equations were derived for each species separately using the following two functional forms and the best equation selected from the two results for each species:

$$V_i = \beta_0 + \beta_1 \cdot (1/SED) \quad (3a)$$

$$V_i = \beta_0 + \beta_1 \cdot (1/SED) + \beta_2 \cdot (1/SED) \cdot (P) \quad (3b)$$

where $V_i$ = cubic lumber value recovery for species $i$, calculated as the total value of lumber recovered from each mill-length log divided by the gross volume of the log measured in hundreds of cubic feet (\$/CCF); $SED$ = mean log diameter at the small end of the mill-length log (in.); $P$ = position of the log within the tree, with 1 = butt log, 2 = mid, 3 = top; $\beta_0$ = estimated regression intercept parameter (\$/CCF); $\beta_1$ = estimated regression slope parameter (\$/CCF × in.); and $\beta_2$ = estimated regression slope parameter (\$/CCF × in.).

As with the volume-recovery regression equations (Equation 2), gross log volumes were used to avoid unnecessary variation associated with scaling deductions. Results of the regression analysis are summarized in Table 9.

Both of the regression equations were highly significant overall ($P < 0.0001$ for the $F$ value), with $R^2$ values similar to those for the volume-recovery regressions (Table 7). The regression parameter for the interaction variable ($1/SED \times P$) was not significantly different from zero for western hemlock but was highly significant for Sitka spruce ($P < 0.0001$). In Equation 3b, we checked variance inflation factors and they were small, indicating no problem with multicollinearity between the two *SED* transformations. This suggests that for western hemlock the position of the log within the tree had no measurable effect on recovered lumber value, whereas for Sitka spruce, logs nearer the base of the tree tended to have higher recovered lumber values. The regression equations are plotted in Figure 5, with each equation plotted over the corresponding range of values for small-end

**Table 9. Results of regression analyses on lumber value recovery ($/CCF) for western hemlock and Sitka spruce separately with data from the thinned and control plots combined for each species. The regression equations are of the form described in Eq. [3a] (western hemlock) and Eq. [3b] (Sitka spruce).**

| Species | Attribute | $\beta_0$ | $\beta_1$ | $\beta_2$ | $n$ | MSE | $R^2$ | $F$ significance |
|---|---|---|---|---|---|---|---|---|
| Hemlock | Regression | 261.39 | −676.37 | | 464 | 2,553 | 0.18 | <0.0001 |
| | Standard error | 8.80 | 66.90 | | | | | |
| | $t$ value | 29.71 | −10.11 | | | | | |
| | $P = \Pr > \|t\|$ | < 0.0001 | < 0.0001 | | | | | |
| Sitka spruce | Regression | 288.92 | −554.17 | −60.41 | 940 | 1,870 | 0.36 | <0.0001 |
| | Standard error | 6.05 | 93.89 | 22.11 | | | | |
| | $t$ value | 47.77 | −5.90 | −2.73 | | | | |
| | $P = \Pr > \|t\|$ | < 0.0001 | < 0.0001 | 0.0064 | | | | |

MSE, mean squared error.

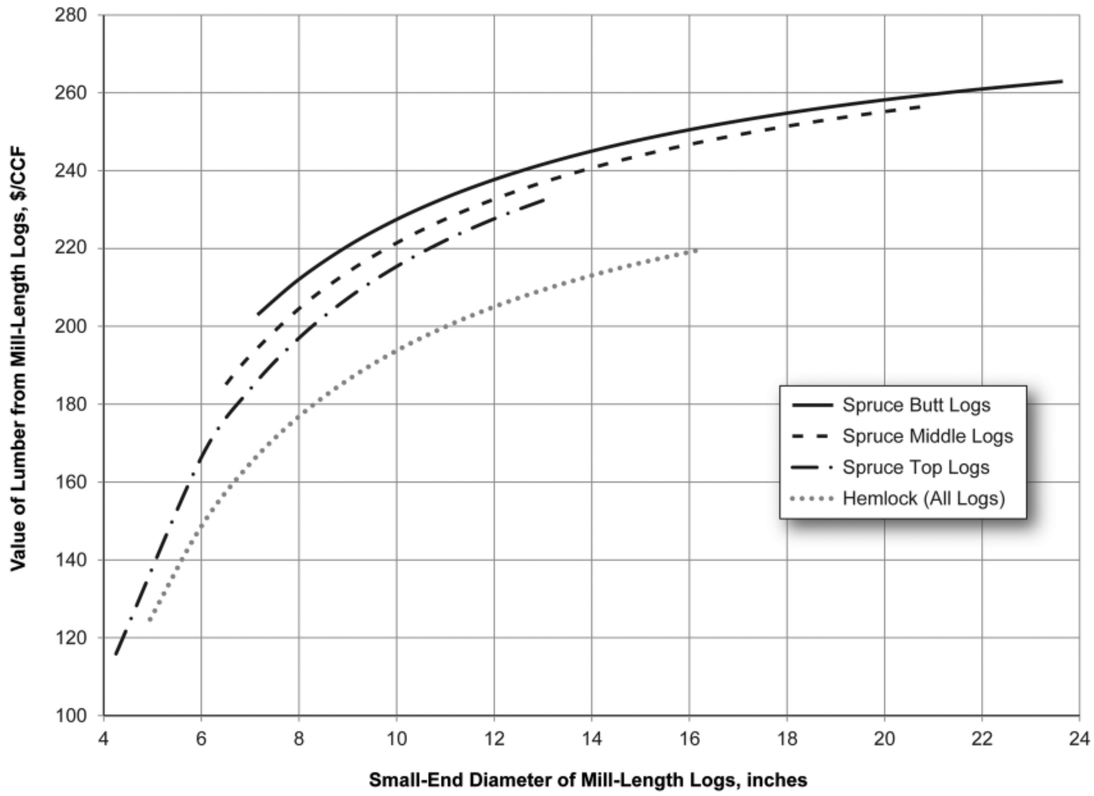


**Figure 5. Regression lines showing the value of lumber from mill-length logs, measured in dollars per 100 ft$^3$ of gross log volume ($/CCF) of log volume, as a function log small-end diameter. The regression line for western hemlock is for all logs combined (Equation 3a), whereas separate regression lines are shown for Sitka spruce by log position using the form of Equation 3b.**

log diameter. Note that the value of lumber recovered from western hemlock logs is lower for any small-end log diameter than that recovered from Sitka spruce logs. Although dependent on the current pricing structure, this reflects the difference in lumber grade recovery, overall 77% No. 2 and Better for the Sitka spruce and only 65% in that same grade grouping for hemlock.

## Management Implications

For decades, the Tongass National Forest has conducted an active precommercial thinning program in overstocked young stands of western hemlock and Sitka spruce. Although the focus of precommercial thinning in plantations and production forestry has been increased volume recovery, the primary goals of the precommercial thinning program in southeast Alaska were to meet wildlife habitat and forest health objectives. Partly because of the importance of subsistence hunting in Alaska, maintaining wildlife forage and suitable deer habitat is a major consideration. Concerns about effects of this management activity on future harvesting opportunities (in terms of wood products volume or value) exist.

Economic return from harvesting operations is based on both the volume of lumber recovered from a tree and the quality of lumber (or other product) manufactured. Volume recovery is a function of tree size and form, whereas wood quality is defined by end product. Stand density affects both tree growth (volume) and wood quality. Response to thinning varies by species (Tong et al. 2009). Very wide spacing (heavy thinning) can increase growth rate (yielding more volume) and delay crown recession, yet it tends to promote larger diameter, live branches lower on the bole. Dense, natural stands may have trees that retain smaller, dead branches lower on the bole. Therefore, active management of stand density can affect lumber grade through influence on branch size and condition.

Anatomical characteristics (e.g., branch size, specific gravity) vary within a tree in both the radial and vertical positions, causing mill-length logs within each tree to vary in quality (value). Knot size is one of the key lumber grade limiting defects. Knots were the grade limiting defect in over half the pieces of lumber produced in this study. Butt logs would be expected to contain more clear lumber (thus yielding more of the higher Select Structural grade lumber) as trees increase in diameter and crowns lift. This was observed for the structural lumber grades in this study, with butt logs having a higher proportion of Select Structural lumber than the mid- or upper logs for both spruce and hemlock. In hemlock, the butt logs also had the least amount of economy lumber and contained a slightly higher proportion of No. 2 and Better lumber. The difference in proportion of No. 2 and Better was less pronounced by log position but still statistically significant. Sitka spruce had more knots as the grade-controlling defect in the butt log than hemlock, although the mean knot size was just over 1 in. in the butt logs for both species.

Wane was the second most common grade limiting defect and was the reason for downgrade in slightly less than 25% of the pieces of lumber sawn. Logs were not debarked, and lumber was not trimmed. The larger amount of wane on the butt logs in hemlock likely resulted from fluting and sawing pattern. Equipment used for processing this sample was designed for efficiency and not optimization of volume or grade. There is the possibility that trimming the lumber to remove wane and end splits would have increased the grade recovery (but the tradeoff would be reduced overall volume recovery).

Because there has been interest in manufacturing laminated lumber from Alaskan species, the lumber was also graded for this end use. Laminating grades are based on knot cross section in a piece of lumber, as well as grain (rings per inch), slope of grain, stain, wane, and white speck (WWPA 2005). Log position was only significant for the highest laminating grade in spruce. Although knots were the primary grade-controlling defect, wane and the number of rings per inch also influenced the proportion of lumber that met the higher laminating grades.

Stiffness (or MOE) depends on a number of wood characteristics (e.g., wood density, grain, proportion of juvenile wood) in addition to both the size and position of knots. MOE was not influenced by log position in hemlock but was in spruce ($P = 0.0016$). Further analysis of wood density samples from these trees and their relation to mechanical properties will be conducted.

Although most of the variation existed within the tree, results indicate no significant differences in product recovery or value (quality) for structural lumber between plots that had been thinned and the control plots that were untreated for the age classes examined (ages 36 to 73 years). Overall, site conditions in southeast Alaska may be such that there are no limiting factors (such as moisture) that affect tree growth in densely stocked or released stands. Because this study was conducted when trees had reached harvestable size, the immediate effects of thinning on wood quality may no longer be apparent. This could be because of abundant natural regeneration filling the space, as Deal and Farr (1994) found, or self-thinning in denser stands reducing differences, as reported by Macdonald and Hubert (2002). We did not evaluate the effects of thinning on diameter or volume growth, only on wood quality. Thinning of naturally regenerated, densely stocked western hemlock and Sitka spruce stands in southeast Alaska for purposes other than wood production does not appear to adversely affect wood quality when evaluated for structural purposes. Because much of the lumber did not meet the laminating grades, opportunities to use this material in a value-added application such as glulam lumber appear limited. Other applications that typically command higher value in the marketplace, such as appearance-grade lumber (e.g., molding and millwork), should be explored. This market is also dependent on visual characteristics, so number and sizes of knots are critical, but for different reasons than structural lumber. Clear lumber is the desired end product. Clear cuttings (smaller pieces with no knots or other defects) from the lumber require further manufacturing and industry infrastructure. As with the study on a glulam industry in Alaska (Allen and Gorman 2003), the economics of producing appearance-grade lumber would need to be studied.

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