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# Recent research on the management of hemlock–spruce forests in southeast Alaska for multiple values

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**Abstract**

This is a review of research findings from silvicultural studies that addressed information needs identified during the revision of the Tongass National Forest land management plan. A central concern of resource managers is balancing tradeoffs among habitat concerns, wood production, wood-product quality, and operability on the Tongass. This paper provides a historical overview of forest management in southeast Alaska and examines issues—and recent discoveries—related to the management of old- and young-growth forests for multiple-resource values. The studies reviewed here include a study of variable-retention harvesting in old-growth stands, an evaluation of the productivity of forested wetlands following clearcutting, an evaluation of the performance of a regional stand-growth model in predicting the growth of even-aged stands, and an assessment of the effects of silvicultural treatments on wood quality in young stands.


*Keywords:* Ecosystem management; Clearcutting; Alternative silviculture; Forest growth models; Wood quality

## 1. Historical overview of forest management in southeast Alaska

To understand fully the current scientific and technical issues associated with stand management in southeast Alaska, one must be familiar with past harvesting and stand-tending practices and their extent. These practices have shaped the quantity and quality of wood products that can be produced from young stands, the condition of wildlife and fish habitats in harvested areas, the social acceptance of active forest management, and a host of other biophysical and socioeconomic conditions. As management objectives change with improved scientific understanding, changing markets, and rapidly evolving societal demands, land managers are questioning whether the familiar tools of the past can create the forests desired for the future.

Harris and Farr (1974) summarized the history of timber management in southeast Alaska up to the early 1970s. Before 1950, timber harvesting in southeast Alaska consisted mostly of Native subsistence use and selective harvest for specific wood products used in mining, fish canneries, wharves, and building construction. Early hand-loggers did not cut trees that were too small or too large, defective, or not the desired species. A notable exception was the clearcutting on Verstovia Mountain in Sitka, which supported charcoal making

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and a foundry operation in the mid-1800s. Early loggers worked in easily accessible areas along shorelines and river valleys. The harvested areas were generally smaller than 50 ha in size (Deal, 1999).

Efforts by government and the private sector to establish a pulp industry in southeast Alaska began shortly after World War I but did not succeed until the early 1950s. They believed the industry would provide a sound economic base in southeast Alaska with year-round employment and would help convert slow-growing, heterogeneous, defect-ridden old-growth stands to fast-growing, uniform, even-aged stands. Early planners felt this conversion through clearcutting was essential to increase wood fiber production on the forest and to gain access to high-valued old-growth spruce trees that were commonly scattered throughout stands of lower-valued timber (Harris and Farr, 1974). Given the numbers of defective and low-grade trees in the native forest, they believed clearcutting would not be economical if the sole product was saw timber. Pulp mills would provide a market for the lower-quality trees and would make clearcutting feasible.

Timber harvesting expanded significantly after the Tongass National Forest and the pulp industry established long-term timber sale contracts. The long-term contracts were intended to ensure a stable supply of wood sufficient to justify the large investments necessary to build pulp mills. The 50-year contracts specified the harvest of more than 59 million $m^3$ and the construction of pulp mills in Ketchikan and Sitka. This era witnessed a major shift from selective cutting to clearcutting, larger harvest-unit sizes, and harvesting further inland, up slopes and river valleys. An extensive road network was constructed to support the inland harvesting, and many logging camps and small towns were established.

The scale of timber harvest in southeast Alaska expanded further with the passage of the Alaska Native Claims Settlement Act (ANCSA) in 1971. This law authorized the transfer to private ownership of 17.8 million ha of federal land throughout Alaska. ANCSA gave Native regional and village corporations the opportunity to select land holdings from federal land management agencies, including the National Forest System lands. Of the 220 320 ha selected by the Native corporations from the Tongass National Forest, an estimated 186 300 ha are productive forest land (Barbour et al., 2004). A primary objective of the Native corporations is to provide an economic return to their shareholders (Knapp, 1992). Most Native village corporations in southeast Alaska have harvested their forest lands to meet this objective (Barbour et al., 2004).

By 2001, approximately 267 400 ha in southeast Alaska had been harvested: 175 400 ha on national forest lands, 79 600 ha on Native corporation lands, and 12 400 ha on state of Alaska and other lands (Barbour et al., 2004). Clearcutting was the predominant harvesting method used across all land ownerships until the late 1990s. For wood-production objectives, clearcutting was well suited to the tree species and conditions found in southeast Alaska (Harris and Farr, 1974). The thin bark and poor decay resistance of western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*) make them susceptible to logging damage and subsequent wound infection by decay fungi, greatly increasing the risk associated with partial cutting (Hennon, 1990; Hennon and DeMars, 1997). Uprooting of residual trees in partial cuts is another serious risk, owing to the shallow rooting habit of the common conifers, thin soils, low strength of water-saturated soils, and violent windstorms common in southeast Alaska (Harris, 1989). Clearcutting disturbs less area for a given amount of timber volume harvested than does partial cutting and, compared to other harvesting methods, clearcutting is considered the most economical (Harris and Farr, 1974).

On Tongass National Forest lands, harvested areas generally receive no site preparation and regenerate naturally with a mix of advance regeneration and new germinants. On occasion, managers plant Sitka spruce seedlings or, more commonly, western redcedar (*Thuja plicata*) or yellow-cedar (*Chamaecyparis nootkatensis*) seedlings. After stands are established, precommercial thinning is by far the most common intermediate silvicultural treatment. Tongass silviculturists rarely prescribe release, weeding, pruning, or fertilization, apart from some removal of western hemlock saplings for hemlock dwarf mistletoe (*Arceuthobium tsugense*) control.

From 1950 to 2003, about 82 572 ha of young stands on the Tongass were precommercially thinned, starting with 85 ha in the 1950s and peaking at 28 439 ha thinned during the 1980s. About 1570 ha $year^{-1}$ are currently being thinned (unpublished data, on file at the Forestry Sciences Laboratory, Juneau, AK).

Despite a long-standing preference for Sitka spruce (Taylor, 1929), thinning prescriptions differed among districts in terms of preferred crop-tree species, and whether hardwoods, such as red alder (*Alnus rubra*), were retained or killed. Western redcedar and yellow-cedar have been almost universally favored over other species, however. There is a clear recent trend toward selecting the best crop tree, without regard to species, and a greater acceptance of red alder's presence.

Thinning prescriptions called for relatively uniform spacing from 2.4 m × 2.4 m up to 3.6 m × 3.6 m. Spacing has increased over time—in the 1980s, managers abandoned close spacing and prescribed 4.3 m × 4.3 m to 4.9 m × 4.9 m spacing. By the late 1990s, 5.5 m and even 6.1 m spacing was tried, although the most common prescriptions ranged from 3.6 to 4.9 m (R. Zaborske, Personal Communication, Regional silviculturist, Alaska Region, Juneau, AK, 2002). The motivation for this radical reduction of stand density was two-fold: first, the closest spacing did not yield significant growth improvements and would require a second precommercial thinning to achieve the intended result; second, managers hoped that the widest spacing would delay crown closure and the resultant loss of understory plants important for wildlife habitat.

Until the mid-1990s, much of the focus of silvicultural practice and research in southeast Alaska was on density management and, to a lesser extent, control of species composition. There was great interest in tools and techniques for managing density and for using stand-density management to enhance a range of forest values, including wood production, understory plant diversity and abundance, and wildlife habitat. More recently, there has been a growing awareness that density management alone is unlikely to achieve all management objectives, and we should consider manipulating a greater number of stand attributes, including density (number of trees per unit area), the number of canopy layers, the variability of the horizontal spacing of trees, age and diameter distributions, species composition, the presence of old-growth legacies, and so on.

The apparent failure of density management alone to provide desired forest values and the recognition that thinning young growth was not a panacea led to many new silvicultural approaches during the 1990s, some of which were codified in the Tongass land management plan revision. Alternatives to clearcutting, variable-spaced thinning, 'gaps and thickets' (cutting small groups of trees and leaving unthinned areas), 'blobs and stringers' (leaving unthinned patches for cover and unthinned corridors for travel), extended rotations, mixed alder–conifer plantations, and crown-cover retention guidelines are all examples of management and research attempts to improve the compatible production of values by 'moving off the density axis' and manipulating more stand attributes.

This expansion of silvicultural options, however satisfying, created daunting knowledge gaps and discomfort with their widespread adoption in the absence of scientific evaluation of their effects. Research, in partnership with management, is needed to discover how to develop stands within this newly expanded space by using silvicultural treatments and, once they are there, how will they continue to develop and what sorts of outputs can we expect. The studies described below are some first steps toward answering these questions.

## 2. Old-growth management

### 2.1. Management issues

Our research addressed two general issues related to the management of old-growth forests: (1) uncertainty regarding the effects of alternatives to clearcutting, and (2) the inability of the FVS-SEAPROG (a Prognosis geographic variant of the Forest Vegetation Simulator) growth model (Dixon et al., 1992) to reliably predict growth of uncut or partially cut old-growth stands. Alternatives to clearcutting create stands with multiple canopy layers, variable spacing of trees, and a range of tree densities. It is hoped that the greater structural complexity of these stands, in comparison to stands regenerated by clearcutting, will foster maintenance of values associated with old-growth forests along with sustainable wood production. Although many unresolved issues exist with regard to the adoption of alternatives to clearcutting in old-growth stands (McClellan et al., 2000), only the following questions relating to operations, vegetation structure, and stand dynamics will be addressed:

- Are alternatives to clearcutting technically and operationally feasible in old growth?

- How do conventional clearcutting and alternatives such as variable-retention cutting compare with regard to stand growth and species composition?
- How do conventional clearcutting and alternatives such as variable-retention cutting compare with regard to harvest-related and post-harvest damaging agents (e.g., wounding, decay, mistletoe, and wind damage)?
- Are variable-retention treatments more effective than clearcutting in maintaining stand structural features?
- Are variable-retention treatments more effective than clearcutting in maintaining understory plant diversity and abundance over time?

The second set of issues relates to FVS-SEAPROG performance. Project-level and forest-wide planning needs are beyond the range of applicability of this forest growth and yield model. The preponderance of data used to calibrate this model variant were obtained from even-aged stands with one canopy layer and relatively uniform spacing. As we manipulate more stand attributes and increase the complexity of treated stands, we move out of the calibrated space of the model. Responsible evaluation of silvicultural options requires sound, data-based, predictive models to determine the effects on vegetation composition and structure. Increasingly, however, managers find that FVS-SEAPROG cannot be applied to site conditions, stand structures, and alternative treatments under consideration. Managers are unable to model with any confidence tree growth in two- or more-aged stands, stands with varying levels of canopy retention, or stands with heterogeneous spacing.

### 2.2. Research response

To address issues related to alternatives to clearcutting, the Pacific Northwest Research Station and the Tongass National Forest are collaborating in an interdisciplinary study of ecosystem and social responses to alternative silvicultural systems: *Alternatives to Clearcutting in the Old-Growth Forests of Southeast Alaska* (ATC). The project has two parts: a short-term retrospective study and a longer-term, operational-scale (15–20 ha per experimental unit), experimental study. Retrospective sites span the breadth of the Tongass. Three experimental sites have been established on the Sitka, Petersburg, and Craig Ranger Districts. Limited post-treatment data are available from the Hanus Bay and Portage Bay blocks, but the Lancaster Cove site is awaiting harvest treatment.

ATC research began in 1994, and studies of stand dynamics and understory response were funded by the PNW Research Station, with additional funding provided by the USDA Forest Service Ecosystem Management Research Initiative. Tongass land management plan-related funding received from the National Forest System enabled additional management-related studies of forest health, including pretreatment levels of tree damage and mortality, tree damage associated with timber harvesting, and subsequent post-harvest tree damage owing to wind, dwarf mistletoe, fungi, insects, and other damaging agents.

The large scale of the ATC experimental units is a major departure from traditional silvicultural trials, which often are established on plots 0.1 ha or smaller. The operational scale of the units encompasses more of the variability that typically exists in management units. This reduces the scaling problems that often plague field trials, and it increases our confidence in the real-world applicability of our findings, a quality sometimes lacking in traditional small-plot studies (Peterson and Monserud, 2002).

We evaluated the current version of FVS-SEAPROG to document its strengths and weaknesses in analyzing relatively simple even-aged management options and devised strategies for improving model performance and extending its application to more complex stand structures. During the ATC pretreatment data collection, we obtained 10-year diameter-growth increment data for 27 old-growth stands and provided it to the Forest Management Service Center (FMSC) at Ft. Collins. These data will be used to improve the model calibration for growth in unmanaged stands. We will collect ATC post-treatment growth response data to calibrate the model for similar partial cutting treatments. Two extensions of FVS-SEAPROG were identified as possible at this time. The first incorporates Trummer's model (Trummer et al., 1998) of mistletoe spread from residual trees to the regenerating stand. The second would add the Hennon–DeMars model (Hennon and DeMars, 1997) of decay development following bole wounding of Sitka spruce and western hemlock.

### 2.3. Key findings

The examination of stands prior to cutting revealed that wind played a much smaller role in small-scale disturbance than previously thought. In the ATC experimental study, tree mortality was evaluated in 27 old-growth stands at three locales before treatment to determine how types of tree death contributed to stand structure, production of woody debris, and small-scale disturbance. The basal area, density of dead trees, and types of dead tree structures were described for each tree species. Three types of dead tree structures were identified, and of these three, broken boles were the most common, followed by intact standing trees and uprooted trees. The proportion of broken trees increased with increasing time since death (estimated from the degree of snag and log deterioration), indicating that most trees died standing and subsequently broke. Reconstructed annual mortality rates for overstory trees averaged 0.3–0.5% per year for the three locales and were relatively stable through the previous century. Treefall direction for both uprooted and broken trees aligned significantly with downslope direction. The number of dead trees, basal area of dead trees, annual mortality rates, and percentage of uprooted trees did not differ significantly by classes of wind exposure (Hennon and McClellan, 2003) predicted by a regional wind-risk model (Kramer et al., 2001). The common occurrence of all three types of dead tree structures contributed to the structural diversity and indicated complexity in factors responsible for most of the small-scale disturbance at the three study locales (Hennon and McClellan, 2003).

The retrospective ATC studies—which have examined partial cutting done over the past 90 years—show that Sitka spruce can be maintained in mixed western hemlock–Sitka spruce stands over a wide range of cutting intensities. Partial cutting maintained stand structures similar to uncut old-growth stands, and the cutting often had no significant effect on tree species composition. However, in stands with few Sitka spruce trees, selective cutting could eliminate Sitka spruce from the residual stand. As expected, the establishment of new-tree cohorts was positively related to the proportion of basal area cut. The current stand basal area, tree species composition, and stand growth were significantly related to trees left after harvest ($P<0.001$). Trees that had diameters at breast height (1.3 m, DBH) of 20–80 cm at time of cutting had the greatest tree-diameter and basal-area growth and contributed the most to stand growth. Diameter growth of Sitka spruce and western hemlock was similar, and the proportion of stand basal-area growth between species was consistent for different cutting intensities (Deal and Tappeiner, 2002).

Partial cutting did not result in large timber losses to windthrow, dwarf mistletoe, or bole wounding. These are all concerns that managers have about partial harvests in old-growth forests. The proportion of trees that died from uprooting was marginally higher in partially harvested than in unharvested stands, but overall tree mortality rates were similar. Partial harvesting resulted in the maintenance of dwarf mistletoe at generally undamaging levels with a trend of less of the disease with more intensive harvesting. Bole wounds on trees were common in partially harvested stands, but natural tree injuries from falling trees and animal feeding were far more abundant at several sites (Deal et al., 2002).

Species richness and community structure of understory plants were similar among uncut and partially cut plots; however, plots where more than 50% of the basal area was cut had significantly different plant community structure (diversity and abundance of species). Time-since-cutting did not have a significant effect on plant community structure as older and more recently harvested stands had similar understories following partial cutting. Species composition and abundance also appeared to be distinctly different among hemlock-dominated and spruce-dominated stands. Partial cutting did not significantly change abundance for most of the important forage species for deer. The similarity in plant community structure between partially cut and uncut old-growth stands may be related to stand structures (Deal, 2001).

Because only two of the three ATC experimental blocks have been treated, and because most of the biophysical responses take some time to develop, it is too early to present most post-treatment findings. However, our observations of the harvest and post-treatment tree damage surveys at two sites led to the following early findings:

- In the market conditions prevailing during the late 1990s, purchasers accepted timber sales that included alternatives to clearcutting.

- Partial cutting of old-growth stands in steep terrain was technically feasible across a wide range of cutting intensity when helicopter yarding was used.
- Group selection with gap diameters of 30 m or less significantly increased reported problems during tree falling and yarding.
- Harvest-related damage to residual trees was greater at lower retention levels. Where 75% of the trees were left, generally fewer than 15% were damaged; when 25% of the trees remained, up to 40% were damaged to some extent.
- The spatial pattern of tree removal also affected damage to residual trees. Uniform retention led to a far higher rate of wounding of residual trees than in treatments where cutting was limited to groups or where patches of residual trees were retained.
- Windthrow following partial harvest is related more to local topography and proximity to clearcuts than to the experimental treatments or a published wind model (Kramer et al., 2001).

### 2.4. Management implications

With some confidence, we can say we demonstrated the technical ability to create the stand structures envisioned in the ATC silvicultural prescriptions. However, the costs associated with sale layout, timber marking, and helicopter yarding were clearly higher than those associated with clearcutting or with ground-based yarding systems, so the treatments that are technically feasible may not prove to be economically viable. Further work is needed to define the cost and production rates for partial-cutting treatments, for both helicopter and ground-based yarding systems.

Results of the retrospective study showed that, in most cases, concerns about changing tree species composition, lack of spruce regeneration, and greatly reduced stand growth and vigor with partial cuts were unsubstantiated. However, the study illustrated the critical role of residual trees, as opposed to newly established trees, in shaping the quality of the future stand. In stands with many poor quality trees, or stands where one species overwhelmingly dominates, partial cutting can create a residual stand of low quality or with reduced overstory diversity. Silvicultural systems based on partial cutting can provide rapidly growing trees for wood production, while maintaining complex stand structures with mixtures of spruce and hemlock trees similar to old-growth stands, but only if close attention is paid to the pretreatment stand conditions and the quality of trees to be left after cutting.

It is too early to conclude much from the experimental study, but the stands examined in the retrospective study indicate that partial cutting can produce acceptable wood product values. Timber growth rates were good, volumes were in the expected range, and levels of defect were acceptable. There was no evidence that these stands were degraded by the partial cutting, despite the fact that they were subject to purely economic selective cutting, with no thought for the long-term health and development of the stands. The similarities between the understory plant communities in old-growth and stands partially cut at moderate levels suggests that subsistence use of plants, non-timber forest products, deer forage, and biodiversity values can be maintained with partial-cutting treatments. These findings need to be interpreted and applied with some care, however, because the retrospective study only examined beach-fringe stands. Responses may differ in stands on poorer sites, with lower-quality trees, or with significantly unbalanced proportions of species.

### 2.5. Outstanding information needs related to old-growth management

Post-treatment effects on overstory and understory vegetation will be determined from the ATC experimental study over the next 5–10 years, building on the findings of the retrospective research. This is an important and necessary step owing to the limitations inherent in the retrospective work: it was limited to beach-fringe stands, the stands were cut selectively—without thought to silvicultural principles, pretreatment conditions and treatments were poorly defined, and true controls and randomization were absent. The results are useful and promising but must be substantiated with the results from properly designed experimental studies conducted on sites typical of the current wood-production land base.

Because the ATC experimental study was limited to one yarding method and a necessarily limited number of treatments and replications, further opportunities could be sought in adaptive management studies associated with the ongoing timber-sale program. Roughly 70–80% of the silvicultural prescriptions in development are for some form of partial cutting (J.M.

Russell, Personal Communication, Forest silviculturist, Tongass National Forest, Sitka, AK, 2001), and these sales might present opportunities to examine the effects of ground-based yarding systems in partial cutting, additional harvest intensities and patterns, cost and production values, and interactions with infrequent stochastic events such as damaging windstorms.

The next step in the improvement of FVS-SEAPROG performance in more complex, uneven-aged management scenarios could be the calibration of growth in partially cut stands. Existing data sets from the ATC retrospective study should be evaluated for their suitability for this calibration. As growth data are collected in the ATC experimental study, they should be made available to developers for model calibration.

To meet wildlife and other objectives when partial cutting old-growth stands, silviculturists need improved models that use standard stand-exam data to predict post-harvest crown cover. Tongass land management plan standards and guidelines for marten (*Martes americana*) and goshawk (*Accipiter gentiles*) habitat specify amounts of crown cover to remain following timber harvesting in heavily cut watersheds. The use of crown cover to characterize habitat quality is intuitively satisfying, but practical applications present problems. Field methods commonly used to measure crown cover are difficult to use or inaccurate (Bonham, 1989; Avery and Burkhart, 2002). Predicting crown cover remaining after proposed silvicultural treatments is hampered by the lack of locally developed and validated models. A useful model would predict crown cover from commonly available stand data such as species, diameter, and tree density.

## 3. Young-growth management

### *3.1. Overview*

Numerous management issues and knowledge gaps have been identified regarding the management of young-growth stands in southeast Alaska. The following five questions have been the focus for our young-growth research over the past 5 years:

- How does stand density affect the growth and yield of even-aged young-growth stands?
- Are intermediate silvicultural treatments effective in maintaining or restoring understory plant diversity and abundance following clearcutting?
- Are forested wetlands sufficiently productive following clearcutting to meet national standards for commercial forest land?
- How do existing and alternative silvicultural prescriptions affect the wood quality of young-growth stands?
- Does the vegetation growth simulation model FVS-SEAPROG provide accurate predictions of growth, mortality, and composition of even-aged young-growth stands?

The Tongass land management plan follow-on research program did not support our studies on stand-density effects and on understory–overstory relations, so I will not address those results in this paper. An overview of the stand-density research can be found in DeMars (2000) and a major analysis and reporting effort is currently underway for this study. Some of the understory study results have been reported elsewhere (Zaborske et al., 2002; Hanley, 2004), and work continues on this topic.

### *3.2. Productivity of forested wetlands*

#### *3.2.1. Management issues*

During revision of the Tongass land management plan, the question arose whether forested wetlands should be included in the land base tentatively suitable for timber production. The lands in question were on four organic soil series: Kaikli, Karheen, Kitkun, and Maybeso (Julin and Meade, 1997). Uncertainty regarding the productive capacity of these lands dated to the late 1970s but was unresolved, so a resource assessment was conducted to evaluate whether existing knowledge was sufficient to inform the land-allocation decision (Julin and Meade, 1997). Of six criteria for tentative suitability, the forested wetlands in question were deemed to meet four: (1) they were forested, (2) they were not withdrawn from timber production, (3) they could produce industrial wood crops, and (4) they could be restocked within 5 years following harvest. Two criteria were not met: (1) there were insufficient data to ensure that timber production would not damage resources irreversibly, and (2) there were insufficient growth response data (Julin and Meade, 1997).

Continued uncertainty over the productive capacity of forested wetlands and their response to timber harvesting led to direction in the 1999 Tongass land management plan Record of Decision to avoid, for the time being, harvesting on four organic soil series (Kaikli, Karheen, Kitkun, and Maybeso). The decision to include these soil series in the tentatively suitable land base was to be re-evaluated once research determined the productivity of these sites following harvesting. The total land area of concern was relatively small (40 500 ha), but these soils typically occur as small inclusions within more-productive forests, and avoiding them greatly complicated timber sale planning and layout.

### 3.2.2. Research response

In 1996, the PNW Research Station began research to determine the growth response of forested wetlands following clearcutting (K.R. Julin, M.H. McClellan, Study plan for forest growth on wetland soils in southeast Alaska, On file at the Forestry Sciences Laboratory, Juneau, AK, 1996, 53 pp.). The study focused on four organic soils of concern to determine whether the stands met the Forest Service wood production threshold for commercial forest land: a mean annual production rate of 1.4 $m^3$ $ha^{-1}$ $year^{-1}$ at the culmination of mean annual increment (MAI). Researchers examined 18 unthinned western hemlock–Sitka spruce stands that regenerated following clearcutting, with stand ages of 15–46 years. Suitable older stands were not found, and the stands studied had not yet reached the culmination of MAI, so it was necessary to estimate their future wood production with a growth model. Soils at the study sites were Histosols (Cryohemists and Cryosaprists), 0.4 m to over 2 m deep (Julin and D'Amore, 2003).

### 3.2.3. Key findings (Julin and D'Amore, 2003)

- The stands were densely stocked with natural regeneration that grew slowly, yet predictably, during the first 50 years after clearcutting.
- Wood volume production ranged from 12 to 78 $m^3$ $ha^{-1}$ for 15- and 46-year-old stands, respectively.
- Observed wood production rates in the first 50 years of stand development were consistent with estimates produced by the FVS-SEAPROG growth-and-yield model (Fig. 1).
- If the observed growth rates continue, these stands will exceed the USDA Forest Service wood production threshold for commercial timberland.
- Forested organic soils were much deeper (>1 m) than indicated in soil resource descriptions and of-

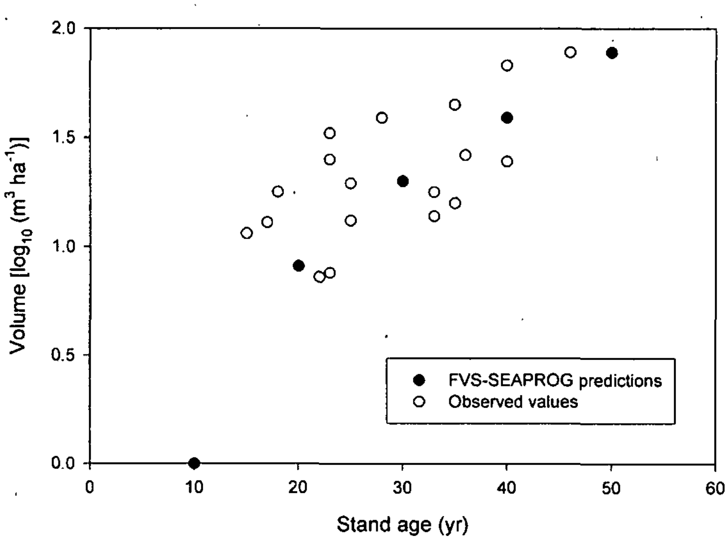


Fig. 1. Timber volume observed on forested wetland sites and predicted by FVS-SEAPROG (after Julin and D'Amore (2003)).

ten existed as small inclusions within areas of better drained soils.

In addition to these findings relating to the main study objectives, a companion study of the fiber content of these Histosols (D'Amore and Lynn, 2002) found the following:

- A broader range of fiber decomposition was observed than that described in the established Tongass soil classification system.
- Aboveground vegetation was not a good indicator of wetland soil types, despite the heavy reliance on such characteristics in the Tongass soil survey.
- Chemical analysis of decomposition indicated the transport of soluble carbon into organic soil horizons via downslope water flow.

#### *3.2.4. Management implications*

The research findings confirmed that these four wetland soil types met national wood productivity standards for commercial forest lands. Accordingly, on 17 April 2000, Forest Supervisor Thomas Puchlerz signed a decision letter stating that "These areas are included in the suitable land base and should be managed to attain the multiple use goals and objectives of the Forest Plan".

The good agreement between the observed growth and the FVS-SEAPROG growth predictions suggests that the model predictions for low-productivity sites may be used with greater confidence in their accuracy. This is significant because the stands used to calibrate this model are generally of moderate to high productivity (DeMars, 2000), and critics of its use in the planning process suggested that this yielded a model bias toward overestimation of growth.

The new information on the fiber content of organic soils has several implications, because the decomposition state of organic soils exerts a powerful effect on biological, chemical, and physical processes, including respiration, nitrogen content, cation exchange capacity, flow and retention of water, and carbon content (D'Amore and Lynn, 2002). Global carbon budgets and estimates of carbon sources and sinks rely on accurate estimates of soil carbon content, and this information will help improve estimates for southeast Alaskan soils.

### *3.3. Effects of silvicultural treatments on wood quality*

#### *3.3.1. Management issues*

The long-term existence of a sustainable timber industry in southeast Alaska depends upon continued availability of wood of sufficient quality to compete in the world marketplace. Clearcut harvesting of old-growth forests provided a mix of high-quality saw logs and lower-grade saw and utility logs. Before the closure of the two southeast Alaskan pulp mills, a local market existed for all harvested material, including the lower-grade material. If recent trends continue, we can expect fewer and fewer old-growth forests available for timber harvesting and a shift of harvesting to maturing, even-aged, young-growth forests. There is concern that current management practices applied to young-growth will produce low-grade, low-value saw logs that cannot be harvested economically. The trend toward wide spacing in precommercial thinning prescriptions has raised concerns over unknown tradeoffs with respect to wood quality.

Accordingly, wood quality and its relation to silvicultural practices has become an important emerging issue in young-growth management. Young-growth stands have low levels of disease-caused defects compared with old-growth stands (Hennon and Shaw, 1986). In addition, results from a study of product recovery in young-growth Sitka spruce and western hemlock (Christensen et al., 2002) indicate very low defect rates and good wood quality. It should be noted, however, that the sampled stands might not represent our more intensively managed young stands. The fire-origin stands sampled were 60 years old at the time of thinning and had 1235–11 115 trees $ha^{-1}$. Under these conditions, we would expect relatively low taper, tight ring spacing, and good self-pruning of lower branches.

In contrast, many young stands under current management practices are precommercially thinned at 15–25 years to 550 trees $ha^{-1}$. Lower post-thinning densities are sometimes prescribed to maintain or enhance understory plant cover. These treatments could increase taper, stimulate the production of epicormic branches, increase the size and longevity of branches (thus increasing knots and reducing grade), increase fluting occurrence (Julin et al., 1993) and severity in western hemlock, increase ring width and, perhaps, alter wood strength and stiffness. These characteristics do not cause great concern if wood pulp is the desired product but they may radically reduce profitability in a quality-driven market.

Pruning has been suggested as a means of maintaining wood quality in widely spaced stands. Pruning could eliminate knot-causing branches, reduce stem taper, and diminish the production of juvenile wood (Petruncio, 1994). There are several concerns with pruning, however, including the potential growth loss, expense of treatment, the tendency of Sitka spruce to produce epicormic branches, and the potential for stain development in pruned western hemlock. These issues must be settled before significant investments are made in pruning.

Lastly, there is a need for a fast, accurate, and inexpensive way to evaluate wood mechanical properties (strength and stiffness) in standing trees so that the effects of silvicultural treatments can be assessed. Traditional methods for assessing mechanical properties require falling the tree or resorting to time-consuming and expensive methods for destructively removing a sample.

### *3.3.2. Research response*

In 1998, the PNW Research Station began a series of related studies to evaluate the effects of thinning and pruning on wood quality. The first was a collaborative effort with the USDA Forest Service Forest Products Laboratory (Madison, WI) to compare traditional destructive methods (static bending tests) and a non-destructive ultrasound (stress wave) technique to evaluate mechanical properties in standing trees. The primary objective of this study was to investigate the usefulness of a stress wave technique for evaluating wood strength and stiffness in standing, young-growth western hemlock and Sitka spruce trees. The secondary objective was to determine if the effects of thinning on these properties could be identified with this technique. Stands sampled in this study were part of a PNW stand-density study (DeMars, 2000) and provided trees grown at several densities and thinned at stand ages of 14–48 years.

Two companion studies used the same sites and sample trees. The first used X-ray densitometry to assess whole-tree treatment effects on basic wood properties such as specific gravity, growth ring width and uniformity, earlywood:latewood ratios, and the distribution of heartwood, juvenile wood, and reaction wood. The second was an evaluation of thinning effects on branch frequency, size, and distribution.

In 1999, we examined an existing trial of pruning established in 1991 (Petruncio, 1994). Our objectives were to analyze the effects of thinning and pruning on tree height and diameter growth, live crown development, epicormic branch development on spruce trees, understory plant diversity and abundance, and conifer regeneration.

### *3.3.3. Key findings*

- Stress wave measurements provided relatively accurate and reliable information for the nondestructive evaluation of wood properties in standing trees. Mean stress wave speed and dynamic modulus of elasticity values from standing trees agreed with values determined from small, clear wood specimens destructively tested in the laboratory (Wang et al., 2000, 2001).
- Regression analyses confirmed strong relationships between the field-measured stress wave properties of trees and static bending properties of wood specimens obtained from destructively sampling the trees (Wang et al., 2000, 2001).
- The effect of thinning on wood mechanical properties could be identified from the stress wave properties of trees (Wang et al., 2000, 2001).
- Tree height growth was similar among the different pruning lifts, but diameter growth was significantly reduced when 40% or more of the live crown was removed (Petruncio, 1994).
- Six to 9 years after pruning, epicormic sprouts were common: 232 of 236 Sitka spruce trees produced sprouts at a rate of 9–11 sprouts per meter of tree bole. Controls that were thinned, but not pruned, also developed sprouts (Deal et al., 2003).
- The total numbers of sprouts were similar among pruning treatments, but significantly more large sprouts (3–19 mm in diameter) were produced in the highest (5.2 m) pruning lift treatment (Deal et al., 2003).
- Trees that developed large sprouts had significantly smaller diameters, heights, and crown lengths at time of treatment than did trees without sprouts (Deal et al., 2003).

#### 3.3.4. Management implications

Analysis is continuing on several of the wood quality studies, but several implications are apparent. The availability of an inexpensive and reliable field test of wood mechanical properties creates an enormous opportunity for managers to assess the effects of diverse silvicultural treatments across a wide geographic area and assortment of site conditions. Mechanical properties of wood are likely to become increasingly important as engineered wood products become more dominant in the market place, and it is likely that price premiums will be paid for wood with desired quality. This technique would offer a quick means of assessing standing stocks or sorting logs to match buyer requirements.

Pruning study results demonstrate that Sitka spruce responds to thinning and pruning treatments with the production of numerous epicormic sprouts. If the goal of pruning is to produce clear higher-valued wood, Sitka spruce may be a poor candidate species for pruning, at least under the conditions of this trial. Closer spacing or the use of 'trainer trees' (Oliver and Larson, 1990, p. 88) could reduce the amount of light reaching the pruned boles, and this could reduce the severity of epicormic sprouting. The finding that larger trees tended to have fewer sprouts is encouraging, because these are the trees that would commonly be selected for pruning if only select trees were pruned. The great variation in sprouting severity among trees treated similarly suggests genetic control of susceptibility, and it is possible that phenotypic traits could be discovered that would allow managers to select for pruning only those trees with a low likelihood of sprouting.

### 3.4. FVS-SEAPROG performance

#### 3.4.1. Management issues

FVS-SEAPROG (Dixon et al., 1992) is the vegetation growth model commonly used for forest management in southeast Alaska. FVS-SEAPROG is widely available and there exists a large corps of trained users, but the model is used very little. The analysis of management options requires reliable predictions of how proposed treatments will affect vegetation composition and structure. The range and complexity of management options considered by silviculturists have increased greatly since the revision of the Tongass land management plan, and this has increased the expectations of vegetation-model users. Unfortunately, FVS-SEAPROG users reported that the model predictions were unrealistic, that its user interface was unfriendly, and its ability to model silvicultural treatments other than clearcutting was limited. Limited evaluations of FVS-SEAPROG were conducted in the past (Dixon et al., 1992; Golnick et al., 1995; Julin and D'Amore, 2003), but a thorough validation had not been done.

#### 3.4.2. Research response

McClellan and Biles (2003) evaluated FVS-SEAPROG's performance by comparing model predictions to observed values from two sets of long-term plots located in even-aged stands regenerated by clearcutting, windthrow, or fire. Six variables were examined: trees per acre, quadratic mean diameter, basal area per acre, height of the largest 40 trees per acre, cubic-foot volume per acre, and board-foot volume per acre. They also contacted FVS-SEAPROG users in government and the private sector to determine the level of use and the perceived problems with the model.

#### 3.4.3. Key findings (McClellan and Biles, 2003)

- USDA Forest Service silviculturists reported using FVS-SEAPROG only for the preparation of their certification prescriptions, with almost no use thereafter.
- Two primary reasons for the limited use of FVS-SEAPROG were (1) user perceptions that the model predictions are unrealistic, and (2) the model has not been calibrated to predict the effects of silvicultural systems currently being prescribed, such as two-age and uneven-age management.
- Differences between observed and predicted values often were large enough to render the model's predictions useless.
- The model tended to retain too many trees per acre, which could indicate problems with the mortality subroutines.
- Quadratic mean diameter, basal area, height, and volume were systematically underestimated in the model predictions.
- The scope of the validation data available prevented an adequate test of the effect of total stand age, site index, elevation, and slope on model performance.

#### 3.4.4. Management implications

The results of this study appeared to validate many of the concerns expressed by users. McClellan and Biles (2003) concluded that FVS-SEAPROG would not be used widely until these issues were resolved. The first step to improve the model should be to investigate the reasons for the poor performance in predicting the growth of even-aged stands. This should be resolved before attempts are made to calibrate the model for two-age or uneven-age management and before the understory plant growth model is calibrated for southeast Alaskan conditions. In the absence of a reliable growth model, the evaluation of future management options will need to be guided by limited empirical trials and professional judgment.

### 3.5. Outstanding information needs related to young-growth management

What are the likely effects of extended rotations (≥120 years) on overstory and understory vegetation, with and without intermediate treatments such as thinning? The 1999 Record of Decision for the Tongass land management plan placed 42 Wildlife Analysis Areas on an extended rotation of 200 years, in contrast to the 100–120-year rotation specified in earlier plans. The stated primary objective of extending rotations is to protect site-specific deer habitat. Existing research and management practices for even-aged stands are keyed to the shorter rotation; extending the rotation raises significant issues on the appropriate range of treatments, effects on the production of wood and other forest values, and the efficacy of longer rotations in providing the intended improvement of deer habitat. Because long-term projections of the Tongass timber supply assume a significant contribution from commercial thinning of stands on extended rotations, it is essential to determine the quality and quantity of wood likely to be produced by these stands. For example, the even-aged stand on Sitka's Mt. Verstovia, 150 years after Russian clearcutting (with no subsequent treatment), displays some alarming characteristics: excessive height:diameter ratios leading to stem breakage, heavy fluting of western hemlock, and accelerated mortality of the spruce component of the stand. It is unknown whether these attributes are common in other 150–250-year-old even-aged stands, or if modern clearcuts will develop these undesirable characteristics, but the health and productive capacity of this highly visible stand are evidently threatened.

## 4. Conclusion

Until the late 1990s, uneven-aged old-growth forests used for wood production were clearcut and converted to even-aged stands managed for pulp and saw-timber production. Much of the existing silvicultural knowledge relating to southeast Alaska's forests was developed for this management system, but recent changes in management objectives and practices have created an urgent need for new silvicultural knowledge, particularly since the last revision of the Tongass land management plan. The studies reviewed in this paper represent a small part of the research effort underway to provide new silvicultural treatments that foster a wide range of forest resource values. The forest plan revision highlighted many information needs, and the research program developed after the revision provided many new opportunities for researchers and resource managers to collaborate in framing research questions, implementing studies, and integrating new findings into management activities. In silvicultural research, however, there was already a long-standing tradition of close cooperation between research and management, exemplified by our studies of stand-density management (DeMars, 2000), variable-retention harvesting (McClellan et al., 2000), and thinning effects on understory plants (Zaborske et al., 2002). This collaboration continues and it is growing, with new large-scale studies of commercial thinning, managing young stands to enhance understory vegetation and wildlife habitat, and effects of silvicultural treatments on wood quality. Researchers and managers alike recognize that this collaborative adaptive-management approach is an efficient means of bringing the best abilities of both organizations to bear on complex resource-management questions. We all expect these studies to yield significant new information that will advance forest science, improve future management, and aid the development of future forest plans.

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