For. Snow Landsc. Res. 78, 1/2: 173–190 (2004)

Development of silvicultural systems for maintaining old-growth conditions in the temperate rainforest of southeast Alaska

Michael H. McClellan
USDA Forest Service, Pacific Northwest Research Station, 2770 Sherwood Lane, Suite 2A, Juneau, Alaska, USA 99801. mmcclellan@fs.fed.us

Abstract
In the old-growth temperate rainforests of southeast Alaska, concerns over clearcutting effects on habitat, visual quality, slope stability, and biodiversity have created a demand for the use of other silvicultural systems. The forest vegetation and animal taxa of southeast Alaska appear to be well adapted to frequent, widespread, small-scale disturbance, suggesting that variable-retention harvesting and maintenance of important structural features could sustain desired old-growth conditions in wood-producing forests. This hypothesis is tested in the alternatives to clearcutting (ATC) study, which uses experimental and retrospective approaches to evaluate several silvicultural systems for managing old-growth western hemlock-Sitka spruce forests. The operational-scale, long-term experimental study integrates research on stand dynamics, forest health, understory vegetation, wildlife habitat, stream ecology, slope stability, hydrology, economics, visual quality, and social acceptability.

Keywords: forest management, variable-retention harvesting, alternatives to clearcutting, temperate rainforest, old-growth forest

1 Introduction

1.1 Old-growth forest conditions

The rainforests of southeast Alaska are unique in that they include the largest remaining reserve of old-growth forest in the United States (SAMSON *et al.* 1991). Relatively little information is available on the structure and development of the old-growth (HARRIS and FARR 1979; ALABACK 1984; ALABACK 1990; ALABACK and JUDAY 1989). The principal forest cover types of southeast Alaska are western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and western hemlock-Sitka spruce (*Picea sitchensis* [Bong.] Carr.) (EYRE 1980). These cover types are found along the north Pacific coast from southern Oregon north and westward to south-central Alaska. Other forest cover types found in southeast Alaska include Sitka spruce, western redcedar (*Thuja plicata* Donn.) -western hemlock, -western redcedar, mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.), and lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *contorta*) (EYRE 1980; CAPP *et al.* 1992). Forest fires and widespread insect infestations are rare in the region (HARRIS and FARR 1974; RUTH and HARRIS 1979). Natural changes to the forest are mainly due to succession, endemic levels of insects and disease, and wind-caused damage. Conventional wisdom suggests that wind damage accounts for most losses (ALABACK 1990; HARRIS 1989; NOWACKI and KRAMER 1998). However, recent work (HENNON and MCCLELLAN 2003) suggests a greater role for senescence and disease in small-scale disturbance.

The chronic, small-scale disturbance common in southeast Alaska has produced old-growth stands with remarkably wide age distributions. In one study, trees were destructively sampled from 50 plots randomly selected from forest inventory plots throughout southeast Alaska (FARR *et al.* 1976). The oldest ages determined by species were 659 years for western hemlock, 785 years for Sitka spruce, 715 years for yellow cedar (*Chamaecyparis nootkatensis* [D. Don]), and 650 years for western redcedar. Eighty-four percent of all overstory trees were older than 200 years, 47% were older than 300 years, 15% were older than 400 years, and 5% were older than 500 years. Thirty-six percent of plots contained two or three distinct age classes with a 100-to-350-year age difference between classes. Young (less than 150 years old) even-aged stands made up 2% of the sample, two-aged stands 16%, three-aged stands 20%, and all-aged stands 62% (Farr and McClellan, data on file at the Forestry Sciences Laboratory, Juneau, AK). Maintaining such diverse age structures presents a considerable challenge to any silvicultural system.

Ten old-growth types, nested within the forest cover types and comprised of groupings of particular plant associations, have been defined in southeast Alaska (CAPP *et al.* 1992; DEMEO *et al.* 1992; MARTIN *et al.* 1995; PAWUK and KISSINGER 1989). Ecologically based old-growth definitions were also developed that specify minimum, measureable, stand-level attributes necessary for stands to be classified as old growth (CAPP *et al.* 1992). The definitions include estimates of numbers of large and decadent trees, canopy layers, tree diameter classes, standing snags and their state of decay, down material, and forb cover. For the common old-growth types on well-drained sites dominated by western hemlock, the definitions require 40 to 52 large (minimum DBH 48 to 53 cm) old (150–170 years old) trees per ha, 15 to 17 large decadent trees per ha (trees with dead or broken tops, stem defects, or decay), three canopy layers, and four to six 5-cm diameter classes. The minimum requirements for dead material are 5 to 12 large snags per ha (minimum height 3 m) in at least two decay classes and 15 pieces of down woody debris per ha (48 to 53 cm diameter at the thickest point and at least 3 m long), also in at least two decay classes. A minimum of 5% forb cover is also required (CAPP *et al.* 1992). These attributes have not been completely validated, but they do provide a useful benchmark for assessing the stand structural elements remaining after various silvicultural treatments.

1.2 Timber harvesting in southeast Alaska

HARRIS and FARR (1974) and RAKESTRAW (1981) have summarized the history of timber use in southeast Alaska up to the 1970s. Timber harvesting in southeast Alaska prior to 1950 was mostly subsistence use by Alaska Natives and selective harvest of wood needed for the mining and fishing industries and building construction. Early hand-loggers selectively harvested easily accessible areas bordering saltwater and low-lying river valleys (HARRIS and FARR 1974). In the 1920s, cable-yarding systems replaced hand logging and somewhat increased the extent of harvesting. During the two World Wars, Sitka spruce was selectively harvested, primarily in southern southeast Alaska, for use in aircraft construction. The size of harvest units and the inland extent of harvesting increased dramatically following World War II, when heavy equipment became more readily available.

Efforts to establish a pulp industry in southeast Alaska began after World War I, and the first large pulp mills were built in the early 1950s (RAKESTRAW 1981). The pulp industry was established to diversify the regional economy, to provide year-round employment, and to help convert unmanaged old-growth stands to the desired fast growing, uniform, even-aged stands (ANDERSEN 1955). Pulp mills would use the low quality trees that were abundant in the native forest and would make clearcutting economically feasible (HARRIS and FARR

1974). Long-term timber-sale contracts were thought necessary to secure the large investments needed to build pulp mills, so the National Forest System and the pulp industry established 50-year contracts for the harvest of 59 million m^3 to supply pulp mills in Ketchikan and Sitka. These changes in the timber industry led to significant changes in harvesting: larger harvest-units, clearcutting rather than selective cutting, and the extension of logging operations inland and to higher elevations (RAKESTRAW 1981).

A second major expansion of timber harvesting in southeast Alaska followed the Alaska Native Claims Settlement Act (ANCSA) in 1971, which allowed the transfer of 220 320 ha from the Tongass National Forest to Alaska Native corporations (BARBOUR *et al.* in press). Since then, most of the forest land held by Alaska Native village corporations in southeast Alaska has been harvested (BARBOUR *et al.* in press) to create investment capital and dividends for shareholders (KNAPP 1992).

Approximately 267 400 ha in southeast Alaska had been harvested by 2001: 175 400 ha on National Forest lands, 79 600 ha on Alaska Native corporation lands, and 12 400 ha on State of Alaska and other lands (BARBOUR *et al.* in press). Until the late 1990s, clearcutting was used almost exclusively across all land ownerships because, for wood-production objectives, clearcutting was well suited to southeast Alaskan tree species and site conditions (HARRIS and FARR 1974). Managers were concerned that partial cutting would greatly favor the shade-tolerant western hemlock and hinder the establishment and growth of the less tolerant Sitka spruce (DEAL *et al.* 2002). Partial cutting was also thought to increase the risk of logging damage and subsequent decay (HENNON 1990; HENNON and DEMARS 1997), hemlock dwarf mistletoe infection (TRUMMER *et al.* 1998), and wind damage (HARRIS 1989). Economic concerns also limited the use of partial cutting, because logging costs are lower and harvest volumes per unit area are greater with clearcutting (HARRIS and FARR 1974).

1.3 Concerns with clearcutting

Objections to widespread clearcutting in southeast Alaska reached a critical point in 1970 with the lawsuit *Sierra Club v. Hardin*, which sought to stop harvesting on the west side of Admiralty Island (RAKESTRAW 1981). Since then, clearcutting has come under continued attack on biological, philosophical, and aesthetic grounds. Critics of conventional harvest practices assert that clearcutting of old-growth forests in southeast Alaska creates young-growth forests that are poor habitat for many important wildlife and understory plant species (HANLEY 1984; HANLEY *et al.* 1989; IVERSON *et al.* 1996; PERSON *et al.* 1996); reduces biodiversity by eliminating understory plants after crown closure (ALABACK 1982); and diminishes important structural components found in old-growth stands, such as logs on the forest floor and in streams, snags, large green trees, and multilayered canopies. Others hold that clearcutting reduces slope stability, increases landslide activity (WU and SWANSTON 1980), and accelerates erosion and sediment production, leading to degraded fish habitat (CHAMBERLIN *et al.* 1991). Perhaps the greatest fault many critics find is that conventional harvesting of large clearcuts creates landscapes that are aesthetically displeasing to both residents and visitors (BURCHFIELD *et al.* 2003).

1.4 Genesis of the ATC study

Prior to the ATC study, there were no studies of regeneration methods other than clearcutting for old-growth hemlock-spruce forests in southeast Alaska. In 1950, a small study of partial cutting was established in a 96-year-old even-aged stand of western hemlock and Sitka spruce at Karta Bay (FARR and HARRIS 1971). This study had only two levels of cutting intensity and was not in old-growth stands. In the early 1980s, a small study of partial cutting was begun on Chichagof Island, but it was abandoned before full implementation. By the early 1990s, researchers and land managers recognized an urgent need for information on a broader range of silvicultural options for southeast Alaskan forests (USDA Forest Service 1992).

In 1994, the Pacific Northwest (PNW) Research Station and the Alaska Region of the U.S. Forest Service created a research partnership to study alternatives to clearcutting in the old-growth forests of southeast Alaska. The partners successfully competed for funding from a national ecosystem management research initiative funded by the Washington Office of the U.S. Forest Service. In addition to the $500 000 provided annually by this initiative, the PNW Research Station and the Alaska Region provided significant additional funding to ensure the success of this project. An interdisciplinary team of scientists and land managers developed an ambitious set of objectives for the study (MCCLELLAN *et al.* 2000). The general objectives were:

1. Increase our understanding of old-growth stand structure and dynamics in southeast Alaska and how these factors influence responses to selected silvicultural systems.
2. Determine how selected even- and uneven-age silvicultural systems affect stand dynamics, stand structure and composition, understory plant diversity and abundance, and tree damaging agents.
3. Characterize the effects of selected silvicultural systems on forest bird communities.
4. Characterize the effects of selected silvicultural systems on headwater stream conditions and productivity.
5. Evaluate the effects of clearcutting and variable-retention harvesting on ground-water accumulation and movement.
6. Evaluate selected silvicultural systems for their social acceptability and determine how social acceptability differs among various geographic and stakeholder groups.
7. Identify and document technical and operational problems encountered while implementing alternative silvicultural systems.

It was apparent to the study planners that the research objectives could only be met by an operational-scale, interdisciplinary study. Traditional, narrowly focused silvicultural field trials with small (<1 ha) plots could not address many of the questions posed. The planners also recognized the urgent need for information on silvicultural alternatives. Accordingly, a two-part study was planned. The first part was a short-term, retrospective study of stands partially cut from the early 1900s to the present. This two-to-three year study would take advantage of the extensive selective harvesting that had occurred near shorelines throughout southeast Alaska. The retrospective study was meant to provide some information and interim guidelines to serve until more comprehensive scientific studies were completed. The second part of the study was planned as a long-term, large-scale, experimental study with controls, replication, and random assignment of treatments. The scale of this study was such that the cooperation and participation of land managers – in this case the Tongass National Forest staff – was essential. The study was too large for researchers to carry out alone. There was a significant risk that the planned experimental treatments would not be carried out, because of environmental concerns, political or public pressure, economic feasibility, or research funding uncertainty. Recognizing this risk, many of the participating researchers planned to collect extensive pre-treatment information that would make a significant contribution to our understanding of old-growth temperate rainforests, whether the experiment was fully implemented or not (MCCLELLAN *et al.* 2000).

2 Materials and methods

2.1 Experimental design

Retrospective Study – Researchers used historical materials, management records, and timber maps to identify 270 stands throughout southeast Alaska that had been selectively logged since the early 1900s. Eighteen of the partially cut stands (Fig. 1) were selected for study based on the time since harvest (10–100 years), size of harvest (>10 ha), uniformity of site conditions, geographic distribution, and a range of cutting intensities within each stand. During the 1995–96 field seasons, the 18 stands were intensively studied by an interdisciplinary team that examined the growth response of residual trees, understory abundance and diversity, conifer regeneration dynamics, harvest-related damage to the residuals, and subsequent damage from wind, mistletoe, or fungal decay in wounds. The within-stand variations in cutting intensity were used to extend the range of residual densities examined. Tree increment cores and stem sections, along with comprehensive overstory and understory vegetation data, were used to ascertain stand histories and to describe their response to partial cutting. Detailed descriptions of the methods have been described elsewhere (DEAL 1999, 2001; DEAL and TAPPEINER 2002; YOUNT 1997; DE SANTO *et al.* 2003).

Experimental Study – The second part of the study is a long-term, experimental test of ecological responses to eight silvicultural systems ranging from even-aged management with clearcutting to uneven-aged systems employing single-tree or group selection, plus an untreated control. Three factors and their interactions are being tested: (1) the stand density retained after timber harvest, (2) the spatial pattern of the retained trees (i.e., uniform vs. patchy), (3) and the size of patches. The patches were either groups (small circular areas where all trees with DBH ≥23 cm were cut) or clumps (small circular areas where no trees were cut). Treatments were arranged in a randomized complete block factorial split-plot design. Retained stand density and spatial pattern are the factorial, whole-plot treatments and patch size is the subplot treatment. Total basal area per unit area is the measure of stand density, and treatment levels were defined by the percentage of the initial stand density retained after timber harvest. Post-treatment densities ranged from 0 to 100% of the initial stand density (clearcut and uncut control, respectively), with three intermediate densities.

Three spatial arrangements of retained trees are being tested. In the first, retained trees were uniformly dispersed throughout the stand, in the second, uncut trees were left aggregated in clumps within a uniform matrix, and in the third, groups were cut within a uniform matrix. The matrix density differed according to the desired stand-level density, but the number, diameters, and total area of patches were the same in all patch treatments. Patches were one, two, or three tree heights in diameter, and we used a previously determined average regional overstory tree height of 32 m (Farr and McClellan, data on file at the Forestry Sciences Laboratory, Juneau, AK) for all experimental units. When possible, equal numbers of small, medium, and large patches were marked in each unit. Figure 2 is a schematic illustration of the proposed treatments.

Detailed descriptions of the treatments follow. Note that the Society of American Foresters' silvicultural terminology (HELMS *et al.* 1998) is used to describe the treatments.

Treatment 1. This treatment is an even-age silvicultural system. The regeneration method is clearcutting and the stand will be re-established with a combination of natural seeding and advance regeneration. All trees above merchantable size (23 cm diameter at breast height, DBH) are cut. We expect that some of the sub merchantable trees will be cut or otherwise destroyed during logging. No further regeneration cuts are planned for the current rotation, but intermediate treatments such as thinning may be appropriate and necessary. The final cutting will be clearcutting 110 to 140 years after the initial regeneration cut. This has been the dominant silvicultural prescription in southeast Alaska until recently, and this treatment allows us to compare the effects of alternative treatments to the status quo.

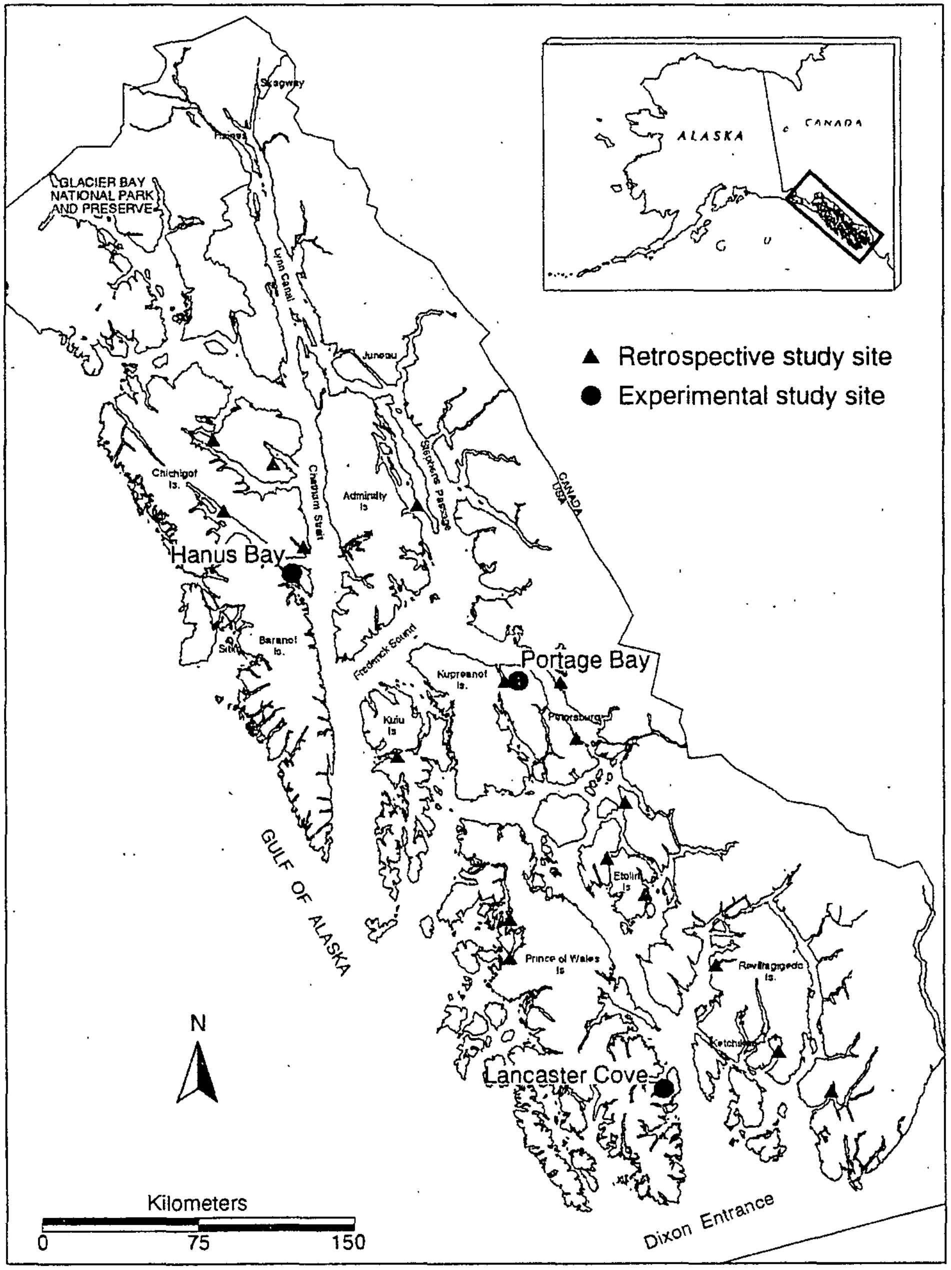

Fig. 1. Distribution of experimental and retrospective study sites.

Treatment 2. This treatment is an even-age silvicultural system. The regeneration method is clearcutting with reserves and the stand will be re-established with a combination of natural seeding and advance regeneration. Most trees above merchantable size are cut, except for 5% of the basal area that will be retained as green trees with DBH greater than 25 centimeters, spaced evenly across the unit. We expect that some of the sub merchantable trees will be cut or otherwise destroyed during logging. No further regeneration cuts are planned for the current rotation, but intermediate treatments such as thinning may be appropriate and necessary. The final cutting will be clearcutting with reserves 110 to 140 years after the initial regeneration cut, leaving 5% of the basal area in reserve trees.

Treatment 3. This treatment is a two-age silvicultural system. The regeneration method is clearcutting with dispersed reserves and the stand will be re-established with a combination of natural seeding and advance regeneration. Twenty-five percent of the basal area will be retained in reserve trees dispersed evenly throughout the experimental unit. No further regeneration cuts are planned for the current rotation, but intermediate treatments such as thinning may be appropriate and necessary. The final cutting will be clearcutting with reserves 120 to 150 years after the initial regeneration cut, leaving 25% of the basal area in reserve trees. Some reserve trees will be recruited from the new cohort to replace original reserve trees that have died since the original entry.

Treatment 4. This treatment is an uneven-age silvicultural system. The regeneration method is single-tree selection. Seventy-five percent of the basal area will be retained in the first harvest and the remaining trees will be dispersed evenly throughout the experimental unit. It is uncertain whether the initial cutting will result in the establishment of a new age class, or whether it will simply promote the growth of the remaining trees. Additional single-tree selection cuts are planned on a 30-to-40-year cutting cycle, and each cut will remove 25% of the basal area. We are confident that the second cutting will result in the establishment of a new age class. A combination of natural seeding and advance regeneration will regenerate the stand.

Treatment 5. This treatment is an uncut control. Natural mortality and regeneration will be allowed to proceed without management intervention, maintaining the stand's uneven-aged condition. No harvesting or salvage will occur in this stand.

Treatment 6. This treatment is a two-age silvicultural system. The regeneration method is clearcutting with aggregated reserves and the stand will be re-established with a combination of natural seeding and advance regeneration. Twenty-five percent of the basal area will be retained in reserve trees aggregated into clumps scattered throughout the experimental unit. The area surrounding the clumps will be clearcut. The clumps will be one, two, and three tree heights in diameter (based on a regional average height for old-growth overstory trees, 31.7 m). In this treatment, about 25% of the treated area is in clumps: the clump diameters are 31.7 m (0.08 ha), 63.4 m (0.32 ha), and 95.1 m (0.71 ha). No further regeneration cuts are planned for the current rotation, but intermediate treatments such as thinning may be appropriate and necessary in the clearcut part of the unit. The final cutting will be clearcutting with aggregated reserves 110 to 140 years after the initial regeneration cut, leaving 25% of the basal area in aggregated reserve trees. We expect that some of the reserved clumps from the first harvest will be cut and replaced with clumps of trees from the new age class created in the first harvest. This allows for replacement of damaged clumps and the long-term recruitment of large, old trees and snags.

Treatment 7. This treatment is an uneven-age silvicultural system. The regeneration method is single-tree selection. Seventy-five percent of the basal area will be retained in the first harvest. To achieve this, 25% of the area will be left uncut in clumps (the same size and number as in treatment 6), and in the area surrounding the uncut clumps, one-third of the basal area will be cut by single-tree selection. The initial cutting should result in the establishment of a new age class outside of the clumps. A combination of natural seeding and advance regeneration will regenerate the stand. Additional single-tree selection cuts are planned on a 30-to-40-year cutting cycle, and each cut will remove 25% of the basal area. We expect that some of the reserved clumps from the first harvest will be cut and replaced with clumps made up of trees from the new age class created in the first harvest and residual trees remaining after the first harvest. This allows for replacement of damaged clumps and the long-term recruitment of large, old trees and snags.

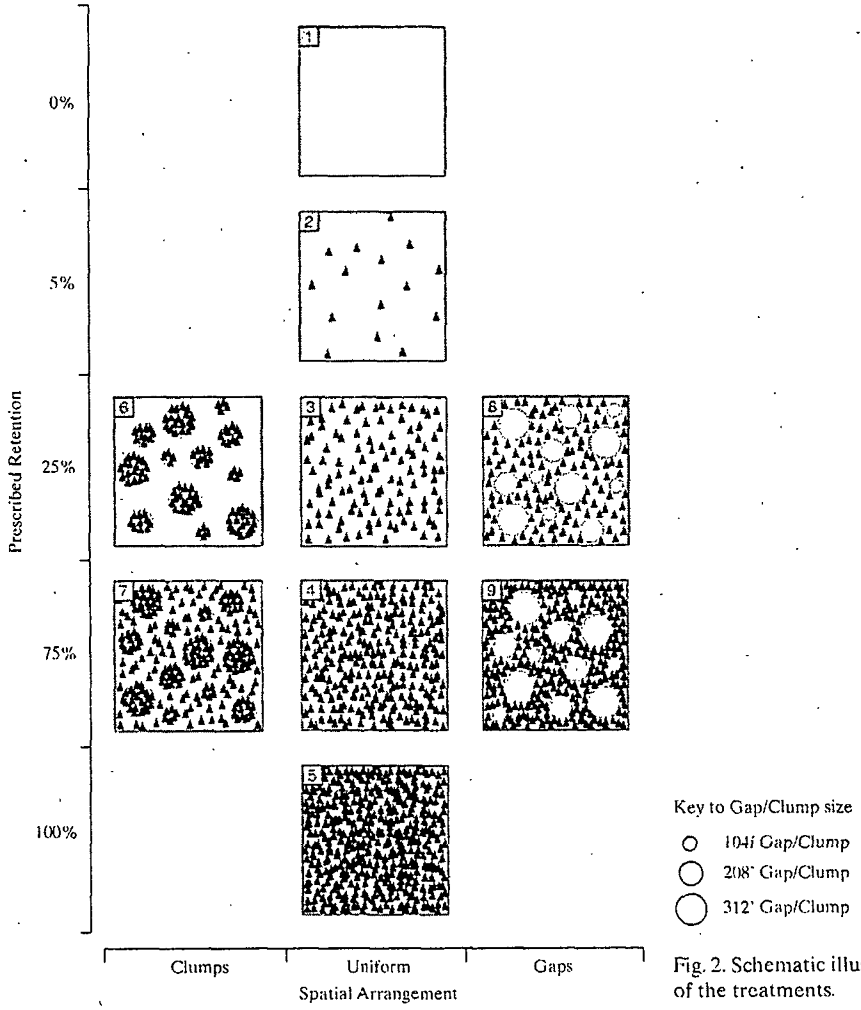

Fig. 2. Schematic illustration of the treatments.

Treatment 8. This treatment is a two-age silvicultural system. The regeneration method is clearcutting with dispersed reserves and the stand will be re-established with a combination of natural seeding and advance regeneration. Twenty-five percent of the basal area will be retained in reserve trees dispersed throughout the experimental unit, with the exception that groups will be cut, covering roughly 25% of the area. The group sizes and number will be the same as those of the clumps in treatment 6. In the area surrounding the groups, two-thirds of the basal area will be harvested by single-tree selection. No further regeneration cuts are planned for the current rotation, but intermediate treatments such as thinning may be appropriate and necessary throughout the unit. The final cutting will be clearcutting with dispersed reserves 120 to 150 years after the initial regeneration cut, leaving 25% of the basal area in dispersed reserve trees. We expect that some of the reserve trees from the first harvest will be cut and replaced with reserve trees from the new age class created in the first harvest. This allows for replacement of trees that are no longer meeting the ecological objectives of this treatment and the long-term recruitment of large, old trees and snags.

Treatment 9. This treatment is an uneven-age silvicultural system. The regeneration method is group selection with reserves and the new age classes within groups will be re-established with a combination of natural seeding and advance regeneration. Over the entire stand, 75% of the basal area will be retained. To achieve this, 25% of the area will be cut by group selection (groups of the same size and number as the clumps in treatment 6), and the area surrounding the groups will be left uncut. Additional group selection cuts are planned on a 30-to-40-year cutting cycle, and each cut will remove approximately 25% of the basal area. No reserve trees will be left within groups in the initial cut, but in subsequent entries reserve trees will be left uncut along group margins. Intermediate treatments such as thinning may be appropriate and necessary within the groups.

Each experimental unit was to be at least 18 ha, the minimum area judged sufficient to conduct the bird community studies, and was to contain at least two headwater streams not bearing anadromous fish, to allow stream ecology research. Units within a block were expected to be reasonably similar in terms of topography, stand conditions, disturbance history, and landscape context, but slope and aspect did vary among units within some blocks. We required that all treatments be assigned randomly to experimental units. We also stipulated that all units would be yarded by helicopter and that all experimental units within a block must be cut and yarded within one field season. Early versions of the study plan called for six blocks of eleven units each, but this was later reduced to three blocks of nine units each when we came to our senses.

Detailed descriptions of the methods used in the vegetation, bird, stream, hydrology, and social studies have been described elsewhere (McClellan *et al.* 2000; Wipfli and Gregovich 2002; Burchfield *et al.* 2003).

2.2 Experimental study areas

Block 1-Hanus Bay – The Hanus Bay block (57°23'32" N. latitude, 134°58'22" W. longitude, on the Sitka Ranger District, Tongass National Forest) lies within two ecological subsections. The North Baranof Complex subsection (Baranof Island, experimental units 1 and 2) is an area of steep, rugged terrain underlain by metamorphic bedrock such as greenschist, greenstone, and phyllites (Nowacki *et al.* 2001). The Peril Strait Granitics subsection (Catherine Island, experimental units 3 through 9) is underlain by granodiorite and gabbro bedrock forming rounded glacially scoured ridges, steep hill slopes, and broad valleys. Debris flows are common in this subsection (NOWACKI *et al.* 2001). Common tree species in the experimental units include western hemlock, Sitka spruce, yellow cedar, and mountain hemlock. Common mammals in these subsections include brown bear *(Ursus arctos)*, Sitka black-tailed deer *(Odocoileus hemionus)*, mountain goat *(Oreamnos americanus)*, marten *(Martes americana)*, ermine *(Mustela erminea)*, red squirrel *(Tamiasciurus hudsonicus)*, common shrew *(Sorex cinereus)*, Keen's mouse *(Peromyscus keeni)*, long-tailed vole *(Microtus longicaudus)*, and tundra vole *(Microtus oeconomus)* (NOWACKI *et al.* 2001).

Block 2-Portage Bay – The Portage Bay block (56°56'16" N. latitude, 133°10'23" W. longitude, on the Petersburg Ranger District, Tongass National Forest) lies wholly within the Wrangell Narrows Metasediments ecological subsection (NOWACKI *et al.* 2001). Bedrock in this area is mostly sedimentary with some granodiorite and tonalite intrusions. Rounded mountains and wide U-shaped valleys dominate the heavily glaciated landscape. Common tree species in the experimental units include western hemlock, Sitka spruce, yellow cedar, and mountain hemlock. Common mammals include black bear *(Ursus americanus)*, Sitka black-tailed deer, moose *(Alces alces)*, wolf *(Canis lupus)*, wolverine *(Gulo gulo)*, marten, ermine, mink *(Mustela vison)*, common and dusky shrew *(Sorex monticolus)*, red squirrel, northern flying squirrel *(Glaucomys sabrinus)*, and long-tailed and meadow vole *(Microtus pennsylvanicus)* (NOWACKI *et al.* 2001). Porcupines *(Erethizon dorsatum)*, important tree-damaging agents (HOLSTEN *et al.* 2001), were also present in this block.

Block 3-Lancaster Cove – The Lancaster Cove block (55°11'03" N. latitude, 132°06'01" W. longitude, on the Craig Ranger District, Tongass National Forest) is entirely within the Hetta Inlet Metasediments ecological subsection (NOWACKI *et al.* 2001). The bedrock in this area includes metamorphosed sedimentary and volcanic rock and some carbonate rocks. The topography is steep, mountainous, and glaciated. Common tree species in the experimental units include western hemlock, Sitka spruce, yellow cedar, western redcedar, and mountain hemlock. Common mammals include black bear, Sitka black-tailed deer, wolf, marten, ermine, mink, dusky shrew, northern flying squirrel, long-tailed vole, Keen's mouse, river otter *(Lontra canadensis)*, and beaver *(Castor canadensis)* (NOWACKI *et al.* 2001).

3 Results

3.1 Retrospective study results

DEAL and TAPPEINER (2002) found that 16 to 96% of the original basal area was harvested in the 18 western hemlock-Sitka spruce stands they studied. When they compared the density and basal-area of western hemlock and Sitka spruce on cut and uncut plots, they detected no significant differences in the species proportions, and thus concluded that the cutting had no significant effect on tree species composition (DEAL and TAPPEINER 2002; DEAL *et al.* 2002). The sampled trees were divided into two classes: first, a new age class composed of trees that were shorter than 1.3 m at the time of cutting and trees which germinated after cutting and, second, residuals that were 1.3 m or taller at the time of cutting. Not surprisingly, they found that the proportion of sampled trees in the new age class increased with increasing cutting intensity, but the new trees always remained in the minority, even in the most heavily cut stands. The residuals dominated the character of the current stands and most of the stand growth was attributed to them, particularly those with DBH greater than 20 cm at the time of cutting. Reconstructed diameter-class distributions showed significant changes immediately following cutting, but after 60 years they found that this measure of stand structure had recovered to pre-harvest conditions (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).

DEAL (2001) found a slight but non-significant decline in understory plant species richness with increased cutting intensity. A comparison of understory species composition and abundance across all uncut and partially cut plots did not reveal significant treatment effect. Cutting effects may have been masked by between-site differences that were typically far greater than within-site differences across cutting intensities. Significant differences in composition and abundance were observed between cut and uncut plots, however, when the analysis was limited to cut plots with more than 50% of the basal area removed. This difference was present in both recent and old cut areas. DEAL (2001) concluded that most of the important deer-forage species were unaffected by selective cutting.

The study did not confirm managers' concerns that partial cutting would greatly increase damage due to windthrow, dwarf mistletoe, or bole wounding (DEAL *et al.* 2002). The partially harvested stands had slightly more trees that died from uprooting, but tree mortality rates were similar overall. Hemlock dwarf mistletoe infection generally was at undamaging levels in partially harvested stands and, as expected, more intensive harvesting reduced the amount of the disease present. Harvest-related bole wounds were common in partially harvested stands, but at several sites natural agents such as falling trees and feeding animals caused many more tree injuries (DEAL *et al.* 2002).

The Winter Wren is a year-round resident forest bird useful as an indicator of the well being of the forest bird community. Harvest-induced changes in forest structure led to changes in predator density, with associated changes in wren nest placement, territory size, pairing status, and nest productivity. Wrens nesting in even-aged stands had lower nest success, fewer mates, and larger territories than birds living in the partially harvested stands (DE SANTO *et al.* 2003).

3.2 Experimental study implementation issues

We faced many difficult problems implementing the experimental part of the ATC study and some remain unresolved at this time. Of the many proposals for research in Alaska competing for funding by the Ecosystem Management Research Initiative, this project was the highest priority of the PNW Station and the Alaska Region. Despite this there was initial reluctance to fund the study because it required significant, large-scale harvests of timber from old-growth forests, including clearcuts, and there were serious doubts about our ability to achieve this. The stringent site-selection criteria, the inclusion of clearcutting to ensure the widest possible range of treatments, and the required random assignment of treatments combined to eliminate many potential research sites. The most common obstacle was the chance that random assignment of treatments would place the clearcut treatments in visually sensitive areas. Site selection was protracted and frustrating but ultimately we succeeded in establishing all three blocks.

Our desire to keep the study as realistic as possible, using operational-scale treatment units and relying on open-market sales for timber harvesting, meant that we were exposed to risks inherent in the environmental impact assessment process, timber-sale scheduling, pressure-group lawsuits and appeals, and timber markets. Each block was selected through a different process, each providing unique challenges and examples of how plans go awry.

The first block, at Hanus Bay, was established in 1994. Nine units were selected from an existing timber sale that was originally intended for the long-term contract with the APC pulp mill in Sitka, which had recently closed. Harvesting at Hanus Bay was delayed for one year by a lawsuit challenging the purpose and need for the sale, but the research study was not an issue in the suit. Once the suit was resolved, the units were released for sale and the District proceeded with the timber sale. Because of poor market conditions, no one bid on the sale when it was first offered, so the logger non-competitively purchased the timber in September 1996 for $279 640. A subsequent rate re-determination lowered the price to $64 000. The experimental ATC units made up about half the sale volume (36 100 of 70 400 m^3). The purchaser harvested all of the ATC units in the 1997 field season. The one-year delay of this sale actually benefited our research, because it provided an opportunity for the hydrologists, stream ecologists, and bird biologists to gather additional baseline data.

The second block, at Portage Bay, was established in 1996. The review of potential research sites on the Stikine Area began in 1994 when we were searching for a site for the first block. Site selection resumed early in 1995 when the Stikine Area and Petersburg Ranger District staff identified 15 potential sites. Subsequent reviews with PNW scientists selected the best two alternatives. This was the only block that used experimental units identified specifically for the study, unlike the other two blocks which used units previously identified for normal timber sales. An environmental assessment (EA) was prepared solely for the purpose of the ATC research site. Based on public comments, which were generally quite supportive of this research, a site near Portage Bay on northeast Kupreanof Island was chosen as the preferred alternative. The timber sale was purchased by one of four bidders in 1997 for $435 000. The purchaser harvested all of the ATC units in the 1999 field season.

The third block, at Lancaster Cove, was established in 1997. The site selection process for this block began in the summer of 1996, but numerous problems delayed the process. In May 1997, an agreement was finally reached to use units from a planned timber sale, just in time to begin pretreatment vegetation sampling. The timber sale was purchased for $530 000 in 1999, but before the experimental units were harvested, the purchaser declared bankruptcy. As of early 2004, the third block remains unharvested. The original purchaser gave up their rights to the timber sale and the ATC units were combined in a new timber sale with a number of other unharvested units and re-sold. At present, environmental groups are challenging that timber sale in court.

3.3 Experimental study results

3.3.1 Pre-treatment results

An analysis of tree mortality (HENNON and MCCLELLAN 2003) demonstrated how different modes of tree death contribute to stand structure and the production of woody debris. Hemlocks dominated the population of dead trees at all sites and the mean number of dead trees (DBH $\geq$25 cm) ranged from 34 to 58 stems ha^{-1} and the dead basal area varied from 12 m^2 ha^{-1} to 40 m^2 ha^{-1}. The ratios of live to dead trees ranged from 2.3 to 3.7. Dead trees with broken boles were observed most frequently, followed by dead standing intact (height >10 m), and uprooted trees. By examining the frequencies of dead trees within decay classes, it was determined that most trees died standing and subsequently broke. This indicates that damaging agents other than wind play a greater role in the disturbance regime of these forests than is commonly assumed. Annual mortality rates for overstory trees (DBH 45 cm) were estimated from 1880 to the present. The mean at Hanus was 0.27% (SE = 0.03), Portage was 0.49% (0.7), and Lancaster was 0.39% (0.03). The rates were fairly constant over the past 100 years. All three types of tree mortality contributed substantially to structural diversity, reflecting a high degree of complexity associated with small-scale disturbance at these three study locales.

Headwater streams were found to export considerable quantities of invertebrate prey and detritus to downstream reaches (WIPFLI and GREGOVICH 2002), demonstrating an important linkage between upland forests and aquatic habitats. Seasonal sampling of 50 streams within the ATC experimental units, plus two non-ATC streams, revealed export rates of 163 mg invertebrate dry mass and 10.4 g organic detritus per stream per day. Both aquatic and terrestrial invertebrates were captured and 65 to 92% were aquatic. Coleoptera contributed the most to both the aquatic and terrestrial biomass. They estimated that salmonid-bearing streams receive enough food resources from headwater streams to support 100 to 2000 young-of-the-year salmonids per kilometer.

3.3.2 Post-treatment results

With only two of the three blocks harvested, and because most of the biophysical responses take some time to develop, our post-treatment findings are limited. However, our observations of the harvesting and post-treatment damage surveys at two sites lead to the following preliminary findings.

Harvest related damage is greater to residual trees where fewer are left. Where 75% of the trees were left, generally fewer than 15% were damaged; when only 25% of the trees remained, up to 40% were damaged to some extent. The spatial pattern of tree removal also affects damage to residual trees, with a far higher rate of wounding of residual trees where removal was uniform throughout the stand. Thus far in the study, windthrow following partial harvest is related more to local topography and proximity to clearcuts than to the experimental treatments or a published wind model.

One objective of variable-retention harvesting is to preserve structural features found in old-growth forests. Snags are important structural features of old-growth forests in southeast Alaska and they provide habitat for many organisms. Snags may be purposefully or accidentally destroyed during logging operations, or they may be damaged by natural agents following the opening up of stands. We examined the fate of relatively sound large snags (decay class 1 or 2, DBH ≥ 25 cm) at the two blocks harvested to date (McClellan and Hennon, data on file at the Forestry Sciences Laboratory, Juneau, AK). At Hanus Bay, there were 191 snags in the sample and 13.3 snags per ha. Species composition was 82.7% hemlock (western and mountain), 7.9% Sitka spruce, and 9.4% yellow cedar. At Portage Bay, there were 161 snags and 11.1 snags per ha. Species composition was 85.1% hemlock, 11.8% Sitka spruce, and 3.1% yellow cedar. After logging, 51.8% of the snags survived at Hanus Bay and 39.1% survived at Portage Bay (Table 1).

Table 1. Snag survival by treatment. STS: single-tree selection. Bold text indicates that the treatment met the old-growth definition (CAPP *et al.* 1992) snag guidelines for this forest type.

	Treatment Number								
	1	2	8	3	6	9	4	7	5
Treatment Description	Clearcut	Wildlife Tree	STS/ Group	STS	Clump	Group	STS	STS/ Clump	Control
Retention	0%	5%	25%	25%	25%	75%	75%	75%	100%
Hanus Bay	8.8%	0.0%	18.8%	16.7%	64.3%	**72.4%**	**90.5%**	**83.3%**	**100%**
Portage Bay	4.4%	10.7%	5.9%	13.3%	**47.8%**	**52.9%**	75.0%	**100.0%**	**100%**

No additional losses were observed at Portage Bay two years after logging. Five years after logging at Hanus Bay, 18 snags (18%) had suffered additional breakage from natural forces. No uprooting of snags was observed at Hanus Bay.

In an investigation of the social acceptability of the ATC treatments, 27 subjects representing nine interest groups were shown photographs of the Hanus Bay treated and control units. They were also given information on the predicted effects of the treatments on several forest values (fish production, deer production, timber yield, visual quality, biodiversity, and damage to the residual trees). Subject interviews revealed that fish and deer production were the most important values to this group; visual quality and timber yield were the least important. The unharvested control treatment was rated the most acceptable and the clearcut least acceptable, and the 75% retention treatments were rated more acceptable than the 25% retention treatments. Although the interest groups might be expected to hold very different views on forest management (e.g., loggers, environmentalists, tourist industry operators), the researchers found no significant differences between groups in their treatment preferences (MILLER 2000; BURCHFIELD *et al.* 2003).

Variable-retention harvesting is technically feasible across a wide range of cutting intensities in southeast Alaskan old-growth forests. Economic viability in the current marketplace is unknown. L.E. Christian, Tongass National Forest (personal communication) conducted a case study of helicopter logging costs at the Portage Bay block. Logging costs for the clearcut (treatment 1) were \$48 per 1 m^3 versus \$143 per 1 m^3 for the 75% uniform retention (treatment 5). Terrain differences between units and the inexperience of the logging crew may have affected the outcomes.

4 Discussion

Addressing current management issues will likely require experimental studies that are large-scale, interdisciplinary, and long-term. The history of the ATC study demonstrates the significant scientific, institutional, and legal challenges that must be overcome to implement studies at this scale. There are significant benefits as well. On the Tongass National Forest, there has been a major shift toward variable-retention harvesting and two-age or uneven-age silvicultural systems. At the onset of the ATC study, essentially all harvesting was done with clearcutting. Now, roughly 70 to 80% of the silvicultural prescriptions being prepared employ some form of variable retention. Silviculturists have told us that the ATC study greatly increased their comfort with these systems, simply by demonstrating that it could be done, using conventional timber sales and operational-scale units. A traditional silvicultural field trial with small plots, subsidized by research funds, would not have had the same impact on managers.

Retrospective studies have significant limitations, but the retrospective ATC study has yielded much new information and it has played a major role in changing silvicultural practices in southeast Alaska. However, there is the danger that its findings may be misinterpreted, or applied improperly to justify high grading or harvesting practices that could reduce the future value of residual stands. The retrospective study only examined stands in the beach fringe, selectively harvested using ground-based yarding systems – most likely with little control of soil disturbance or damage to advance regeneration. Results may differ in stands at higher elevations, on steeper ground, and yarded with much less disturbance to the soil and existing vegetation. The experimental ATC study will provide critically needed information for managing stands under those conditions. The retrospective study also demonstrated the critical role of residual trees, as opposed to newly established trees, in controlling the future quality and value of the stand. The results suggest that in stands dominated by poor quality trees, or stands largely composed of one low-valued species, careless partial cutting could easily create stands with little future economic value.

The future of the ATC study is uncertain, but clearly it will not continue as its designers planned. It is likely that the third block will be harvested in 2004 or 2005, but personal and institutional commitments to long-term work change. The stream ecology, hydrology, bird ecology, and social studies are being terminated, but the studies of vegetation and damaging agents will probably continue. The widespread adoption of variable-retention harvesting in the region insures a continuing need for the results of this research.

Acknowledgements

This paper is a contribution from the USDA Forest Service study, Alternatives to Clearcutting in the Old-Growth Forests of Southeast Alaska, a joint effort of the Pacific Northwest Research Station, the Alaska Region, and the Tongass National Forest.

5 References

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

ALABACK, P.B., 1984: A comparison of old-growth forest structure in the western hemlock-Sitka spruce forests of southeast Alaska. In: MEEHAN, W.R.; MERRELL, T.R.J.; HANLEY, T.A. (eds) Fish and Wildlife Relationships in Old-Growth Forests. Morehead City, NC., American Institute of Fishery Research Biologists. 219–226.

ALABACK, P.B., 1990: Dynamics of old-growth temperate rainforests in southeast Alaska. In: MILNER, A.M.; WOOD, J.D. (eds) Proceedings of the 2nd Glacier Bay Science Symposium, September 19–22, 1988, Gustavus, AK. Anchorage, AK, National Park Service, Alaska Region. 150–153.

ALABACK, P.B.; JUDAY, G.P., 1989: Structure and composition of low elevation old-growth forests in research natural areas of southeast Alaska. Nat. Areas J. 9: 27–39.

ANDERSEN, H.E., 1955: Clearcutting as a silvicultural system in converting old forests to new in southeast Alaska. In: Proceedings of the Annual Meeting of the Society of American Foresters, October 1955, Portland, Oregon. Society of American Foresters.

BARBOUR, R.J.; ZABORSKE, R.R.; MCCLELLAN, M.H.; CHRISTIAN, L.E.; GOLNICK, D. (in press): Young-stand management options and their implications for wood quality and other values. Landsc. Urban Plan.

BURCHFIELD, J.A.; MILLER, J.M.; ALLEN, S.; SCHROEDER, R.F.; MILLER, T., 2003: Social implications of alternatives to clearcutting on the Tongass National Forest: an exploratory study of residents' responses to alternative silvicultural treatments at Hanus Bay, Alaska. Gen. Tech. Rep. USDA For. Serv., PNW-GTR-575. 28 pp.

CAPP, J.; VAN ZEE, B.; ALABACK, P.; BOUGHTON, J.; COPENHAGEN, M.; MARTIN, J., 1992: Ecological definitions for old-growth forest types in southeast Alaska. U.S. Department of Agriculture, Forest Service, Alaska Region, Juneau, Alaska. 63 pp.

CHAMBERLIN, T.W.; HARR, R.D.; EVEREST, F.H., 1991: Timber harvesting, silviculture, and watershed processes. In: MEEHAN, W.R. (ed) Influences of forest and rangeland management on salmonid fishes and their habitats. Bethesda, Maryland. American Fisheries Society. 181–205.

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

DEAL, R.L., 2001: The effects of partial cutting on forest plant communities of western hemlock-Sitka spruce stands in southeast Alaska. Can. J. For. Res. 31: 2067–2079.

DEAL, R.L.; TAPPEINER, J.C., 2002: The effects of partial cutting on stand structure and growth of western hemlock-Sitka spruce stands in southeast Alaska. For. Ecol. Manage. 159: 173–186.

DEAL, R.L.; TAPPEINER, J.C.; HENNON, P.E., 2002: Developing silvicultural systems based on partial cutting in western hemlock-Sitka spruce stands of southeast Alaska. Forestry 75: 425–431.

DEMEO, T.; MARTIN, J.; WEST, R.A., 1992: Forest plant association management guide: Ketchikan Area, Tongass National Forest. U.S. Department of Agriculture, Forest Service, Alaska Region, Juneau, Alaska. 405 pp.

DE SANTO, T.L.; WILLSON, M.F.; BARTECCHI, K.M.; WEINSTEIN, J., 2003: Variation in nest sites, nesting success, territory size; frequency of polygyny in Winter Wrens in northern temperate coniferous forests. Wilson Bull. 115: 29–37.

EYRE, F.H., 1980: Forest cover types of the United States and Canada. Washington, DC, Society of American Foresters. 148 pp.

FARR, W.A.; HARRIS, A.S., 1971: Partial cutting of western hemlock and Sitka spruce in southeast Alaska. Res. Pap. USDA For. Serv., PNW-124. 10 pp.

FARR, W.A.; LABAU, V.J.; LAURENT, T.H., 1976: Estimation of decay in old-growth western hemlock and Sitka spruce in southeast Alaska. Res. Pap. USDA For. Serv., PNW-204. 24 pp.

HANLEY, T.A. 1984. Relationships between Sitka black-tailed deer and their habitat. Gen. Tech. Rep. USDA For. Serv., PNW-GTR-168. 21 pp.

HANLEY, T.A.; ROBBINS, C.T.; SPALINGER, D.E., 1989: Forest habitats and the nutritional ecology of Sitka black-tailed deer: a research synthesis with implications for forest management. Gen. Tech. Rep. USDA For. Serv., PNW-GTR-230. 52 pp.

HARRIS, A.S., 1989: Wind in the forests of southeast Alaska and guides for reducing damage. Gen. Tech. Rep. USDA For. Serv., PNW-GTR-244. 63 pp.

HARRIS, A.S.; FARR, W.A., 1974: The forest ecosystem of southeast Alaska: 7, Forest ecology and timber management. Gen. Tech. Rep. USDA For. Serv., PNW-GTR-25. 109 pp.

HARRIS, A.S.; FARR, W.A., 1979: Timber management and deer forage in southeast Alaska. In: Sitka Black-tailed Deer: Proceedings of a Conference in Juneau, Alaska; February 22–24, 1978. Washington, DC, U.S. Department of Agriculture, Forest Service. 15–24.

HELMS, J.A., 1998: The dictionary of forestry. The Society of American Foresters, Bethesda, MD. 210 pp.

HENNON, P.E., 1990: Wounding on residual Sitka spruce and western hemlock remaining after thinning on Prince of Wales Island, Alaska. Forest Pest Management Report. U.S. Department of Agriculture, Forest Service, Alaska Region. 9 pp.

HENNON, P.E.; DEMARS, D., 1997: Development of wood decay in wounded western hemlock and Sitka spruce in southeast Alaska. Can. J. For. Res. 27: 1971–1978.

HENNON, P.E.; MCCLELLAN, M.H., 2003: Tree mortality and forest structure in the temperate rain forests of southeast Alaska. Can. J. For. Res. 33: 1621–1634.

HOLSTEN, E.; HENNON, P.; TRUMMER, L.; SCHULTZ, M., 2001: Insects and diseases of Alaskan forests. U.S. Department of Agriculture, Forest Service, Alaska Region R10-TP-87. 242 pp.

IVERSON, G.C.; HAYWARD, G.D.; TITUS, K.; DEGAYNER, E.; LOWELL, R.E.; CROCKER-BEDFORD, D.C.; SCHEMPF, P.F.; LINDELL, J., 1996: Conservation and resource assessments for the Tongass land management plan revision: Conservation assessment for the Northern Goshawk in southeast Alaska. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Gen. Tech. Rep. PNW-GTR-387. 101 pp.

KNAPP, G., 1992: Native timber harvests in southeast Alaska. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Gen. Tech. Rep. PNW-GTR-284. 48 pp.

MARTIN, J.R.; TRULL, S.J.; BRADY, W.W.; WEST, R.A.; DOWNS, J.M., 1995: Forest plant association management guide: Chatham Area, Tongass National Forest. U.S. Department of Agriculture, Forest Service, Alaska Region R10-TP-57. (irregular pagination).

MCCLELLAN, M.H.; SWANSTON, D.N.; HENNON, P.E.; DEAL, R.L.; DE SANTO, T.L.; WIPFLI, M.S., 2000: Alternatives to clearcutting in the old-growth forests of southeast Alaska: study plan and establishment report. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Gen. Tech. Rep. PNW-GTR-494. 40 pp.

MILLER, J.M., 2000: Social acceptability of alternatives to clearcutting in southeast Alaska: an exploratory study of the factors affecting judgment. Master of Science thesis, University of Montana, Missoula. 122 pp.

NOWACKI, G.J.; KRAMER, M.G., 1998: The effects of wind disturbance on temperate rain forest structure and dynamics of southeast Alaska. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Gen. Tech. Rep. PNW-GTR-421. 25 pp.

NOWACKI, G.; SHEPHARD, M.; KROSSE, P.; PAWUK, W.; FISHER, G.; BAICHTAL, J.; BREW, D.; KISSINGER, E.; BROCK, T., 2001: Technical Publication: Ecological subsections of southeast Alaska and neighboring areas of Canada. U.S. Department of Agriculture, Forest Service, Alaska Region R10-TP-75. 306 pp.

PAWUK, W.H.; KISSINGER, E.J., 1989: Preliminary forest plant associations of the Stikine area, Tongass National Forest. U.S. Department of Agriculture, Forest Service, Alaska Region. Technical Publication R10-TP-72. 126 pp.

PERSON, D.K.; KIRCHHOFF, M.; VAN BALLENBERGHE, V.; IVERSON, G.C.; GROSSMAN, E., 1996: Conservation and resource assessments for the Tongass land management plan revision: The Alexander archipelago wolf: a conservation assessment. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Gen. Tech. Rep. PNW-GTR-384. 42 pp.

RAKESTRAW, L., 1981 (reprinted 1994): A history of the United States Forest Service in Alaska. U.S. Department of Agriculture, Forest Service, Alaska Region R10 FR-03.

RUTH, R.H.; HARRIS, A.S., 1979: Management of western hemlock-Sitka spruce forests for timber production. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 197 pp.

SAMSON, F.B.; ALABACK, P.; CHRISTNER, J.; FRANKLIN, J.F., 1991: Conservation of rain forests in southeast Alaska: report of a working group. In: RODIEK, J.E.; BOLEN, E.G. (eds) Wildlife and habitats in managed landscapes. Washington, DC. Island Press. 95–113.

TRUMMER, L.M.; HENNON, P.E.; HANSEN, E.M.; MUIR, P.M., 1998: Modeling the incidence and severity of hemlock dwarf mistletoe in 110-year-old wind-disturbed forests in Southeast Alaska. Can. J. For. Res. 28: 1501–1508.

USDA (U.S. Department of Agriculture) Forest Service, 1991: Tongass land management plan revision. Publication R10-MB-146. Juneau, AK: U.S. Department of Agriculture, Forest Service, Alaska Region.

USDA (U.S. Department of Agriculture) Forest Service, 1992: Ecosystem management strategy for Forest Service programs in Alaska. Unpublished report. On file with: Forestry Sciences Laboratory, Juneau, AK.

WIPFLI, M.S.; GREGOVICH, D.P., 2002: Export of invertebrates and detritus from fishless headwater streams in southeastern Alaska: implications for downstream salmonid production. Freshw. Biol. 47: 957–969.

WU, T.H.; SWANSTON, D.N., 1980: Risk of landslides in shallow soils and its relation to clearcutting in southeastern Alaska. For. Sci. 26: 495–510.

YOUNT, L.S., 1997: Sitka spruce and western hemlock regeneration after selective harvesting, Tongass National Forest, southeast Alaska. Master of Science Thesis, Oregon State University. 77 pp.

Accepted April, 9 2004