AN ABSTRACT OF THE DISSERTATION OF

Robert L. Deal for the degree of Doctor of Philosophy in Forest Resources, presented on February 23, 1999. Title: The Effects of Partial Cutting on Stand Structure and Growth, and Forest Plant Communities of Western Hemlock-Sitka Spruce Stands in Southeast Alaska.

Abstract approved:

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John C. Tappeiner

This study evaluated the effects of partial cutting on stand structure and growth, patterns of conifer regeneration, stand mortality and disease, and understory plant diversity and abundance. Seventy-three 1/5 ha plots were established in 18 partially cut stands throughout southeast Alaska. These stands were partially cut 12 to 96 years ago removing 16 to 96 percent of the original stand basal area.

Partial cutting resulted in stands that had complex structures and these structures appear similar to uncut old-growth stands. Sitka spruce was maintained over a wide range of cutting intensities, and conversion to hemlock-dominated stands generally did not occur. New spruce regeneration was established in 23 of 55 partially cut plots compared with new spruce found in only 2 of the 18 uncut plots. The current stand basal area, tree species composition, and stand growth were strongly related to trees left after harvest. Trees that were 10 to 70 cm d.b.h. at time of cutting had the greatest tree diameter growth. Little of the

stand growth since harvest came from new regeneration or trees greater than 70 cm d.b.h. The diameter growth of residual hemlock and spruce trees were similar.

The species richness of vascular plants and bryophytes was similar among uncut and partially cut plots and did not significantly change with different cutting intensities. Overall, plant community structures were similar between the uncut and partially cut plots. However, moderate and heavy cutting intensities resulted in stands that had significantly different plant community composition. The abundance of most deer forage plants did not significantly change after partial cutting.

It appears that silvicultural systems that use single tree selection or small openings can be successful for timber management purposes in southeast Alaska. Concerns about changing tree species composition, lack of spruce regeneration, greatly reduced stand growth and vigor, increased dwarf mistletoe infection in hemlock trees, and higher incidence of tree wounding, decay, and mortality with partial cuts were largely unsubstantiated. Stand structural diversity, species richness and understory plant abundance were all greater in partially cut stands than in young-growth stands developing after clearcutting.

The Effects of Partial Cutting on Stand Structure and Growth, and Forest Plant Communities of Western Hemlock-Sitka Spruce Stands in Southeast Alaska

By

Robert L. Deal

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

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Robert L. Deal, Author

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CONTRIBUTION OF AUTHORS

Dr. John Tappeiner, my major professor, was involved in the analysis and writing of both the stand structure and growth manuscript, and the organization and writing of the new silvicultural systems manuscript. Louise Yount and Pat Palkovic contributed data and results to the silvicultural systems manuscript, and Paul Hennon and Mike McClellan provided ideas and direction for the silvicultural systems manuscript.

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Chapter 1

INTRODUCTION

Interest in new ways to manage forests

Forest managers are struggling to provide different and often conflicting products and values from forest lands including sustainable timber commodities, plant and animal conservation, wildlife and fisheries habitat, and public recreation and aesthetic values. In the western United States, there is increasing interest in developing new stand management strategies to provide for biodiversity and assure long-term sustainability of forests. To meet the challenge, various forms of silvicultural systems are being advocated to maintain late-succession and old-growth stand characteristics, and to promote biodiversity and other important non-commodity values. Some of these new stand management strategies have assumed several names including new forestry (Franklin 1989), green tree retention (North et al. 1996, Rose and Muir 1997, Acker et al. 1998), new perspectives (Salwasser 1991) and ecosystem management (Robertson 1992, Salwasser 1994). Most of these stand management practices are modifications of silvicultural systems long in use in other regions such as uneven-age management. However, these methods are being applied in new regions with different forest types, and there is a need to objectively evaluate the success of these methods before implementing any new region-wide silvicultural system.

Forest management on federal lands in the western United States has been very contentious, and conflicts between commodity and environmental interests have paralyzed agencies by polarization. A particularly controversial area of timber management has been the extensive use of clearcutting, because it is visually unacceptable and has resulted in the development of thousands of hectares of relatively uniform, even-aged stands in the Pacific Northwest and southeast Alaska. Recent region-wide forest-management plans (Record of Decision 1994, Record of Decision 1997) have prescribed specific silvicultural guidelines for management activities where new methods of management and alternatives to clearcutting will be implemented. However, little is known about these new systems, particularly in southeast Alaska where clearcutting has been the dominant regeneration method (Farr and Harris 1971, Harris and Farr 1974). There is a need to understand the effects of new systems on stand dynamics, plant diversity and abundance, regeneration and stand mortality.

Evaluation of partial cutting in southeast Alaska

Partial cutting of forests was a common practice in southeast Alaska before the establishment of pulp mills in the region during the 1950s (Figure 1.1). In this study, the term "partial cutting" refers to any harvesting practice where part of the original stand was cut and the remaining residual stand was left intact after logging. These partially cut stands were not part of any planned silvicultural system (such as shelterwood methods in an even-aged system or selection methods in an uneven-aged system), and generally little thought was given to management of the future stand. Usually these stands were partially cut to provide a particular product such as Sitka spruce sawtimber or western hemlock for dock pilings. Individual trees were selected for cutting or small groups of trees were harvested using small (0.05 to 0.5 ha) patch cuts. Also, partial cutting is not to be confused with commercial thinning of young-growth stands, and in this study, partial cutting refers to cutting of mature or old-growth stands that had never been previously harvested.

Objectives of this research

This study examines the effect of historical partial cutting on forest stand structure, stand and tree growth, and forest plant communities of hemlock-spruce stands in southeast Alaska. The results of this retrospective study are then synthesized and these results specifically address some of the biological concerns and management implications of partial cutting. Finally, the feasibility of using new silvicultural systems in hemlock-spruce stands in the region is examined using examples from partially cut stands.

The focus of chapter two is to assess the effect of partial cutting on forest stand structure and growth and the objectives are to:

- determine if partial cutting has led to changes in tree species composition, and specifically determine if spruce can be maintained in these partially cut stands within a wide range of cutting intensities.
- determine the effects of partial cutting and the intensity of cutting on tree age-cohort structure.
- describe the tree size distribution and growth of these stands after partial cutting, and determine if there are growth differences among tree-age cohorts, tree species, and residual trees of different size classes.

The focus of chapter three is to assess the effect of partial cutting on forest plant communities and the specific objectives of this chapter are to:

- determine the plant species diversity of partially cut and uncut stands and analyze the effect of cutting intensity on species richness.
- determine if partial cutting has led to changes in plant community structures.
- evaluate the presence and abundance of several key plant species for deer forage and determine if either partial cutting or the intensity of cutting has led to significant changes in abundance for these key species.

Chapter four is a synthesis of research findings for this study and discusses the feasibility of using new silvicultural systems in southeast Alaska. It incorporates my research on forest stand structure and growth, and forest plant communities following partial cutting. In addition I include results of companion work from Yount and Palkovic on patterns of conifer regeneration, stand mortality, tree wounding and disease. The chapter synthesizes results of partial cutting in these studies, examines management implications of the research using examples from partially cut stands, and assesses the feasibility of using new silvicultural systems in hemlock-spruce stands in the region.

Research methodology

This study used a retrospective approach to study the effects of partial cutting on stand structure and growth and forest plant communities. Retrospective studies have advantages to experimental studies in that the researcher can determine broad patterns of forest stand dynamics without waiting for decades for experimentally treated stands to develop. Retrospective studies establish baseline data and provide immediate information that can then be tested in a more rigorous experimental study. Researchers need to be careful not to make direct cause and effect conclusions using retrospective studies because they may not have pretreatment data nor do they have control of treatments, and they are required to report "after the fact." However, with detailed stand descriptions and careful stand reconstruction, forest researchers can accurately determine much of the former stand's history and development. This study incorporated descriptive analysis of current stand structures and reconstruction of former stand conditions.

Study areas and stand selection

Eighteen partially cut stands were selected to sample a range of time since cutting, intensity of cutting and geographic distribution throughout southeast Alaska. Study areas were selected from an available array of potential sites in the region with an identified pool of over 200 partially cut stands (Figure 1.1). This information came from a variety of sources including U.S. Forest Service district files, historical records and maps, and information from local residents. Aerial photography and field visits were then used to assess current stand conditions and to select study areas. Approximately sixty of the best candidate stands (Figure 1.1) were visited to select study areas using the following criteria: a) a range of "time since cutting" with study areas selected from stands cut at least ten years up to one hundred years ago, b) stands with only one harvest entry, c) a wide range of cutting intensity within each stand including an uncut area, d) a large partial cutting area of at least ten ha in size, e) relatively uniform topography, soils, forest type and plant associations within each stand, f) a geographic distribution throughout the three management areas of the Tongass National Forest. Following the field visits, the eighteen stands (Figure 1.1) that best met the study area selection criteria were used to fill a matrix of research sites. Study areas were generally close to saltwater, less than 100 meters in elevation, and located throughout southeast Alaska.

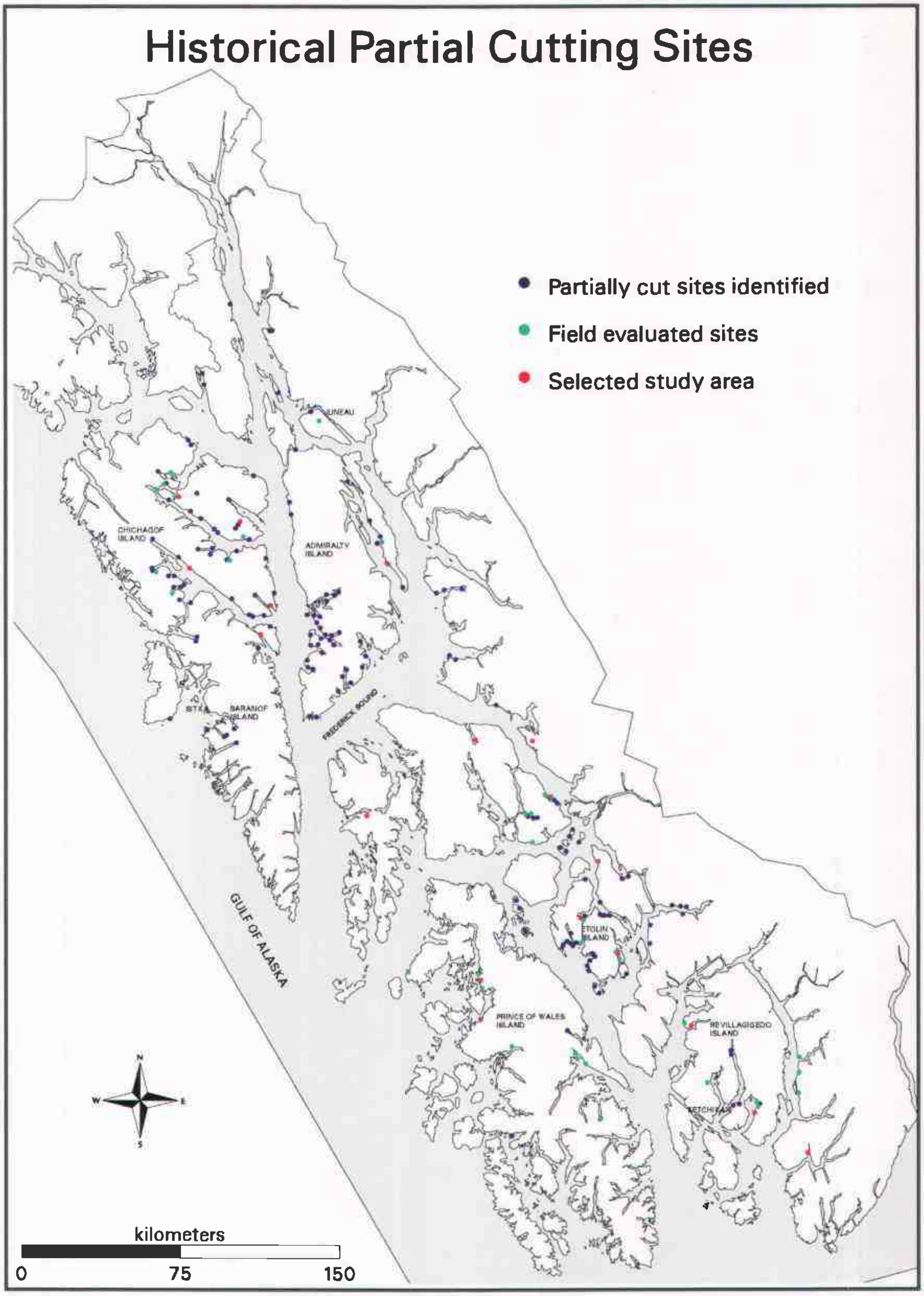

Figure 1.1. The location of identified, field evaluated, and selected partially cut stands in southeast Alaska.

Forests of southeast Alaska

The setting

Southeast Alaska consists of a large group of islands and a narrow mainland strip of land forming the border with British Columbia, Canada. The region is characterized by rugged coastal mountains and thickly forested islands. Southeast Alaska is a maritime region with cool summers, moderate winters, and considerable precipitation well distributed throughout the year (Harris et al. 1974). Southeast gales with hurricane force winds are not uncommon and are particularly intense during the autumn season (Harris 1989). Fire is rare or absent in southeast Alaska and the most important natural disturbances include small (single tree) to medium-sized (up to a hundred ha) wind disturbances (Harris 1989, Lertzman 1996, Ott 1997, Nowacki and Kramer 1998), and occasional mass wasting by landslides on steep slopes (Swanston 1974). In summary, moisture is generally not a limiting factor for tree regeneration, wildfire is rare, and windthrow and wind caused damage of trees is common.

Forest type and autecology of major tree species

The common tree species of Southeast Alaska include western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), Alaska-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) and western redcedar (*Thuja plicata* Donn ex D. Don). Western hemlock and Sitka spruce are the major tree species and comprise over 90% of the growing stock volume of the region (Hutchison 1967). The coastal western hemlock-Sitka spruce forests include some of the most productive forests in the world and the most productive in Alaska. Productivity is slightly less than in the spruce-hemlock forest type of the coastal Pacific Northwest, and Farr and Harris (1979) report that Sitka spruce site index decreases about 1 meter per degree of latitude. The most productive stands of timber are usually found near tidewater (Harris and Farr 1974) and the highest sites approach a site index of 36 (Farr 1984, base age 50, height in meters). The average volume of old-growth stands in southeast Alaska is about 400 m^3/ha (Ruth and Harris 1979).

Both western hemlock and Sitka spruce are prolific seed producers with some seed produced most years and good seed crops every five to eight years (Harris 1969). Seeds are light and are carried long distances by the wind (Harris 1967). Western hemlock is considered very shade tolerant (Minore 1979), and Sitka spruce is moderately shade tolerant. Western hemlock often regenerates on organic soils, and rotten wood makes an excellent microsite (Harris and Farr 1974, Christy and Mack 1984, Harmon and Franklin 1989). Sitka spruce is more likely than western hemlock to become established on mineral soil such as windthrow mounds and avalanche chutes (Taylor 1934, Andersen 1955, Gregory 1960, Harris and Farr 1974, Deal et al. 1991).

Abundant new regeneration of hemlock and spruce is usually established after both natural disturbances and after clearcutting. Analysis of a large, mile-square clearcut (James and Gregory 1959) showed that seedlings were well distributed over the entire cutting and natural regeneration was abundant. On most sites in southeast Alaska natural regeneration after clearcutting is adequate to assure successful reproduction. Tree planting after harvest is generally limited to site specific areas needing restocking, or to improve species composition by planting Sitka spruce or Alaska-cedar (Hennon 1992). Preexisting (advance) regeneration is common in stands established after clearcutting, and advance regeneration may be an important component of the future stand. In a reconstruction study of a stand established after a major wind disturbance, Deal et al. (1991) found small advance regeneration hemlock that were less than 2 meters tall at the time of disturbance; but this initial advantage over new hemlock and spruce was maintained for 120 years. Harris (1974) also noted that the initial advantage of advance regeneration hemlock was clearly evident in stands 15 years after clearcutting. Sitka spruce regeneration is abundant after major disturbances such as clearcutting (Andersen 1955, Harris 1974). However, the ability of Sitka spruce to survive as an understory tree is largely unknown. Ott (1997) found regeneration and rapid growth of some Sitka spruce in canopy gaps but he speculated that the long-term survival of spruce was doubtful in small gap-phase disturbance regimes.

Natural disturbance patterns

Early researchers determined the forests of southeast Alaska to be predominantly all-aged (Taylor 1932, Harris 1989). Frequently, small advance regeneration trees survive even large catastrophic disturbances. Deal et al. (1991) found advance regeneration hemlocks less than 2 meters tall that survived after a windstorm that destroyed all trees in the overstory stand. Partial stand blowdown is more frequent than major stand-replacing disturbances, and partial blowdown that occurs at irregular frequencies leads to multiple-cohort stands with complex size and age structures. However, recent studies on wind disturbances in the region (Kramer 1997, Nowacki and Kramer 1998) indicate that many stands are predominantly even-aged with wind disturbances occurring at regular intervals. Wind disturbance plays a fundamental role in shaping forest dynamics of southeast Alaska (Harris 1989, Ott 1997). The intensity, size and frequency of wind disturbances are highly variable and play a major role in determining the structure of these forests. Wind disturbance regimes range from exposed landscapes where recurrent large-scale events prevail to wind-protected landscapes where small-scale gaps predominate (Nowacki and Kramer 1998). The variable disturbance history of these forests creates complex stand age structures including patches of even-aged, multiple-aged, and all-aged stands (Deal et al. 1991, Nowacki and Kramer 1998).

Tree blowdown and exposure of mineral soil caused by tree uprooting has direct effects on forest composition. Harris (1989) concluded that if a stand had been partially blown down, the shaded seed bed would favor establishment and growth of the more shade tolerant western hemlock. New hemlock regeneration may also be favored over spruce when little soil disturbance has occurred. Harris also speculated that even-aged stands resulting from complete blowdown may contain a higher proportion of spruce. Many of the natural even-aged stands in the region have high proportions of spruce with tree density ranging from 30 to 100 percent spruce (Taylor 1932, unpublished data at the Juneau Forestry Sciences Laboratory). The process of mound & pit topography following tree windthrow has been described by many authors (van Hise 1904, Lutz and Griswold 1939, Lutz 1940, Stephens 1956, McIntosh 1961), and studies in southeast Alaska have shown that windthow mounds are important in facilitating Sitka spruce regeneration (Deal et al. 1991, Bormann et al. 1995). Summary of work from Ott (1997) also suggested that both established western hemlock and Sitka spruce saplings respond to gaps in the overstory with increased growth following small-scale disturbances. However, Sitka spruce regeneration occurred at only one of three sites, and the ability of spruce to maintain itself through gap-phase replacement appeared to be limited.

Logging may create conditions very different than natural disturbances. Clearcutting for instance, is probably a much more uniform disturbance than even major stand-replacing wind events. Following clearcutting in the region, stands naturally regenerate and form dense, generally uniform even-aged stands. Partial cutting may more closely resemble natural disturbances than clearcutting because residual trees left after cutting are more similar to the patchy blowdown common after wind disturbances. However, the lack of windthrow mounding may not provide the mineral soil that enhances spruce regeneration. Careful evaluation of partial cutting will be necessary to determine if changes occur in tree species composition, and if the intensity of partial cutting is important to maintaining spruce in these stands.

Forest management in southeast Alaska

Early logging history: use of partial or selective cutting

From the middle of the 1800s until the 1940s individual Sitka spruce and western hemlock trees were logged from forests along the shoreline (Harris and Farr 1974). Hemlock was used for dock pilings and lumber, and spruce was cut for salmon cases, barrels and buildings. Handlogging was the rule, and as late as 1902 there were only three steam donkeys using cable yarding in all of southeast Alaska (Rakestraw 1981). Harvested areas were generally less than 50 ha in size, close to shore or along river valleys, and generally lightly cut with individual tree selection. In the early 1900s timber operators from the Pacific Northwest brought mechanized logging to Alaska. Some Sitka spruce in Alaska was logged for airplane construction during World War I and cable logging had largely replaced handlogging by the 1920s. Clearcutting was limited to small stands of high quality Sitka spruce sawtimber and even-aged hemlock suitable for dock pilings[1]. The Alaska Spruce Log Program was established on June 4, 1942 and its immediate impact was a major increase in cutting for the region (Rakestraw 1981). Large A-frame operations were set up along the shoreline and probably for the first time larger-scale clearcutting began. The timber cut increased from about 12 million board feet in 1920 to over 80 million board feet (70 to 450 thousand cubic meters) in the mid 1940s (TLMP 1997). However, prior to the establishment of pulp mills in the region, most timber cutting was highly selective and confined to shorelines and river valleys with limited road access. The total yearly harvest in southeast Alaska from 1909-1952 averaged 40 million board feet (TLMP 1997).

Establishment of industrial logging: use of clearcutting

The beginning of industrial timber cutting in southeast Alaska began with the establishment of the first pulp mill in Ketchikan in 1951 with a 50-year contract giving this mill rights to 1.5 billion board feet of timber (8.5 million cubic meters). A second pulp mill opened in Sitka, Alaska in 1959. In addition, several other saw mills were operating in southeast Alaska and timber sales in the region increased from 50 million board feet cut in 1953 to a peak of 590 million board feet in 1973, and total yearly harvest during 1952-1995 averaged 358 million board feet. The opening of pulp mills in the region during the early 1950s led to significant changes in the way forests were managed. Road building opened up areas of previously inaccessible forests, and large blocks of forest land were clearcut. During the period of 1954-1995 harvested areas averaged 9500 acres/year (3900

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[1] R.R. Robinson. *Logging practices in Alaska.* Manuscript on file, Forestry Sciences Laboratory, Juneau, Alaska 49 p., April 26, 1938

ha/year), and virtually all timber cutting was done using clearcutting with natural regeneration. In the Pacific Northwest, clearcutting was accepted as necessary for regenerating Douglas-fir, and in southeast Alaska it was considered necessary for regenerating Sitka spruce (Harris and Farr 1974). Early experience with clearcutting in southeast Alaska was favorable to establish spruce regeneration and when industrial logging began with the opening of the pulp mills in the early 1950s clearcutting was used as the regeneration method. Andersen (1955) reported successful natural regeneration following clearcutting in mixed western hemlock-Sitka spruce stands. He found a higher proportion of spruce after clearcutting, and also increased stand growth rates compared with uncut stands or stands that had been partially cut, however, he did not provide any data to substantiate these results. Andersen also reported that partial cutting led to "practically pure hemlock reproduction which grows more slowly than reproduction originating on clearcuttings." However, it appears that this conclusion was also based on personal observation without any supporting data.

Current timber management using clearcutting

Clearcutting has been used extensively as an even-aged regeneration method for tree species well adapted to open-grown conditions where all of the overstory stand has been removed. Species in other regions of the United States that are commonly regenerated by clearcutting include some of the southern pines with short rotations (Trousdell 1959, Lotti 1961) such as loblolly pine (*Pinus taeda* L) and slash pine (*Pinus elliotti* Engelm.), closed-cone or serotinous pines such as jack pine (*Pinus banksiana* Lamb.) in the Great Lake Region (Eyre and LaBarron 1944), and lodgepole pine (*Pinus contorta* Dougl. Ex Loud.) in the Rocky Mountain Region (Crossley 1956, Lexen 1949), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) along the Pacific Northwest coast (Isaac 1938, 1943).

Clearcutting with natural regeneration has been the dominant regeneration method in the western hemlock-Sitka spruce forest type of southeast Alaska since the early 1950s (Andersen 1955, Harris and Farr 1974, Zasada and Packee 1995). Harris and Farr (1974) describe several reasons for the continued use of clearcutting in southeast Alaska:

1) old-growth stands contain defective timber (Kimmey 1956) and conversion to young-growth stands increases stand vigor (Godman 1952, Taylor 1933, Andersen 1955, Stephens et al. 1969);
2) windthrow is a serious problem with partial cutting (Wright et al. 1947, Ruth and Yoder 1953, Isaac 1956);
3) clearcutting is the most effective means of eliminating dwarf mistletoe and most old-growth stands have heavily infected western hemlock trees (Smith 1969);
4) clearcutting generally assures a higher percentage of Sitka spruce (Andersen 1955, Harris 1974), a more desirable timber species, and seedling growth is slower following partial cutting (Farr and Harris 1971).
5) both western hemlock and Sitka spruce are thin barked species and easily wounded during logging and partial cutting would increase wounding in residual trees (Wright et al. 1947, Wright and Isaac 1956).

Harris and Farr provide some compelling reasons for the continued use of clearcutting as an integral part of an even-aged silvicultural system in southeast Alaska. However, most of their conclusions regarding the adverse effects of partial cutting are speculative or based on research done in other regions. Current information on the effects of partial cutting on stand structure, growth, tree composition, regeneration, and patterns of disease and mortality in hemlock-spruce stands in southeast Alaska is largely unknown. In addition, there are also some serious concerns with the use of clearcutting on biological conservation, long-term maintenance of understory plants, wildlife habitat, and with the public acceptance of clearcutting. Many of these concerns are long-term consequences of clearcutting and may be best understood and appreciated in the context of forest stand development.

Stand development following clearcutting

In southeast Alaska stand development after clearcutting follows clearly defined stages of stand development after major disturbances (Oliver 1981). Immediately after clearcutting prolific new and advance conifer regeneration, shrubs and herbaceous plants become established (stand initiation). Understory plant biomass peaks around 15 to 25 years after clearcutting, and complete canopy closure occurs around 25 to 35 years after cutting (Alaback 1982a). Following canopy closure an intense period of inter-tree competition prevents new tree regeneration from becoming established (stem exclusion), and other understory vegetation is nearly eliminated. The developing young-growth stands are extremely dense, and stands have relatively uniform tree height and diameter distributions. This stage of stem exclusion is long lasting in southeast Alaska and can persist for 50 to 100+ years or longer (Alaback 1984). Stands during the stem exclusion stage are notably lacking the multi-layered, diverse structures found in old-growth or multi-aged stands common in the region. These even-aged stands develop into mature, highly productive stands with the highest plant biomass and wood volume of any stands in the region (Taylor 1934, Alaback 1982b, Farr unpublished data). Over time, disease, insect and wind disturbances in these stands (Kimmey 1956, Hard 1974, Harris 1989) creates gaps in the canopy resulting in reestablishment of new tree cohorts (understory reinitiation) and other understory vegetation.

Stand development described above has significant and long-term effects on understory plant development. Plant biomass peaks around 15 to 25 years after clearcutting followed by canopy closure with a near complete elimination of herbs and shrubs (Alaback 1982a). Species richness is also significantly reduced (Alaback 1982b), and attempts to reestablish understory herbs and shrubs with thinning dense young-growth stands has led to mostly conifer regeneration (Deal and Farr 1994) with little new herbaceous colonization. This intense stage of stem exclusion eliminates or significantly reduces the growth rate of understory vegetation for up to 100 years (Alaback 1982b, 1984, Tappeiner & Alaback 1989. The effect of a much reduced herb and shrub community for a long period of the stand rotation (100+ years) means that plant diversity and abundance is greatly reduced for over 70 percent of the stand rotation time period.

This long lasting stage of stem exclusion has significant implications for wildlife that depend on these plants as forage such as Sitka black-tail deer (Walmo and Schoen 1980, Schoen et al. 1988, Hanley 1993). For the first 15 to 25 years after clearcutting these young-growth stands provide greater understory plant biomass than old-growth stands (Alaback 1982a). However, deer energy costs associated with using these stands makes them much less useful for deer habitat in the winter (Rose 1984, Kirchhoff and Schoen 1987, Schoen and Kirchhoff 1990). The dense uniform canopy of young-growth hemlock/spruce stands, and the abundant conifer regeneration established after thinning, makes it difficult to manage these stands to improve wildlife habitat. The use of partial cutting rather than clearcutting old-growth stands needs to be evaluated to determine if partial cutting can provide the important stand structures for winter habitat for deer, greater plant diversity and abundance, and important plant species for wildlife.

Evaluation of new silvicultural systems

Silvicultural systems are designed to meet specific objectives including biological, physical and social considerations such as growing stock and species composition, logging problems, economics, wildlife, and protection of stands, soils and watersheds. Silvicultural systems are designed to fit a certain set of conditions and the system should be flexible enough to evolve over time as circumstances or conditions change. However, before implementing any new silvicultural system, a number of biological considerations need to be carefully evaluated including the autecology of important tree species, site specific conditions, and the maintenance of desired plant and animal populations.

Partial cutting in the Pacific Northwest - Examination of a case study

The management of forests in southeast Alaska has largely evolved from forest practices in the Pacific Northwest, and examination of the history of timber management in the Pacific Northwest has significance for southeast Alaska. The history of partial cutting in the coastal Douglas-fir region offers a good example of the need to understand stand dynamics and site specific conditions before implementing any new silvicultural system. Huge fires in the coastal forests of the Pacific Northwest during the 1800s and early 1900s, and regeneration problems following logging, led to early adoption of clearcutting using natural regeneration. The introduction of the tractor brought new flexibility to harvest operations in the late 1920s. Brandstrom (1930) advocated using "selective logging" with harvesting timber of economic value and reserving the uncut portions of the stand for future utilization. Kirkland and Brandstrom (1936) published a revolutionary treatise on the use of selective cutting in the Douglas-fir region. Contrary to later interpretations (Munger 1950, Isaac et al. 1952, Smith 1972), their proposal did not advocate individual tree selection, rather it advocated small 2 to 10 acre patch clearcuts after the initial light cuts (see Curtis 1998). Selective cutting was widely applied on the national forests in the Pacific Northwest from the middle of the 1930s until the late 1940s. However, the "loggers choice" system that was practiced rather than the patch cutting being advocated, led to serious stand mortality and growth reductions in logged stands (Englerth and Isaac 1944, Wright et al. 1947, Isaac 1956), and the hoped-for advantages of partial cutting were more than offset by undesirable consequences. Munger and Isaac concluded that selective cutting should be discontinued in favor of moderate-sized dispersed clearcut blocks, and the unfavorable results of partial cutting have been cited as proof that clearcutting is the only system suitable for Douglas-fir (Doig 1976).

Subsequently little research was conducted with regeneration methods other than clearcutting from 1950 to 1990. However, researchers have recently reported success in regenerating Douglas-fir in the Pacific Northwest under partial overstory canopies (Williamson 1973, Korpela et al. 1992, Tesch et al. 1993, Rose and Muir 1997, Acker et al. 1998, Zenner et al. 1998). The use of shelterwood systems may be most successful regeneration method when harvesting on hot and dry sites where partial shade reduces surface temperatures like interior southwest Oregon (Horton 1985, Tesch and Mann 1991). In summary, both forest type and site specific conditions need to be carefully considered when evaluating the success of different tree regeneration methods, but if properly implemented, it appears that different silvicultural systems can be successful for many tree species and forest types.

Use of shelterwood and selection methods in other regions

Shelterwood and selection cutting are regeneration methods where partial cutting removes some of the stand and leaves some overstory residual trees. Shelterwood is a method of regenerating an even-aged stand in which a new age class develops beneath the partial shade provided by the residual trees. Selection cuttings are methods of regenerating uneven-aged stands either by removing trees in small groups (group selection) or in which individual trees are removed more or less uniformly throughout the stand (individual tree selection) to achieve desired stand structural characteristics.

Shelterwood cutting is frequently used in the northern United States (Table 1.1) and has been successful in regenerating hardwoods (Cope 1948, Ondro and Love 1979, O'Hara 1986, Hannah 1991). Shelterwood has also been used to maintain conifer species in northern mixed conifer stands (Marshall 1927, Frank 1986, Seymour 1992, Fajvan and Seymour 1993). In the Great Lakes Region, both shelterwood and selection cuttings have been successful in regenerating hardwood stands (Eyre and Zillgitt 1953, Lorimer 1983, Perala and Alm 1989) and for maintaining important stand structures for a variety of wildlife habitat (McComb and Noble 1980, Goodburn and Lorimer 1998. In the Rocky Mountain Region shelterwood cutting in mixed conifer stands (Table 1.1) has been successful in releasing advance regeneration conifers and establishing new conifer regeneration (Roe and DeJarnette 1965, Alexander 1971, McCaughey and Schmidt 1982, McCaughey and Ferguson 1988, Gottfied 1992). McCaughey and Schmidt (1982) reported both understory spruce and fir responded by substantially increasing their height growth after adjusting to new conditions; height growth release began 1 to 7 years after treatment. In Idaho, Ferguson and Adams (1980) found that younger trees responded quicker than older trees and short trees more than taller trees after release. In California, existing advance regeneration trees released and rapidly grew following overstory removal (Gordon 1973). The release of advance regeneration depends on the physiological condition of the regeneration (Gordon 1979, Oliver 1985), and the rate of growth can be predicted from measurement of live crown ratio and annual height growth prior to release (Helms and Standiford 1985).

Table 1.1 Studies reporting on the use of partial cutting on new and advance tree regeneration, and tree damage in different forest types with focus on western hemlock and western conifer forest types.

	----------Forest Type----------		
Type of Study	Western Hemlock	Western Conifers	Northern Hardwoods And Conifers
Establishment Of New Regeneration	Herman 1962 Williamson 1966 Ruth 1967 Farr and Harris 1971 Williamson and Ruth 1976 Jaeck et al. 1984	Roe and DeJarnette 1965 Williamson 1973 Seidel and Head 1983 Tesch and Mann 1991 Gottfried 1992	Cope 1948 Eyre and Zillgit 1953 Perala and Alm 1989 Hannah 1991 Fajvan and Seymour 1992
Release Of Advance Regeneration	Meyer 1937 Farr and Harris 1971 Williamson and Ruth 1976 Oliver 1976 Tucker and Emmingham 1977 Wiley 1978 Hoyer 1980 Jaeck et al. 1984	Roe and DeJarnette 1965 Del Rio and Berg 1979 Ferguson and Adams 1980 McCaughey and Schmidt 1982 Helms and Standiford 1985 McCaughey and Ferguson 1988 Tesch and Korpela 1993 Tesch et al. 1993	Marshall 1927 Hough and Taylor 1946 Ondro and Love 1979 Lorimer 1983 O'Hara 1986 Fajvan and Seymour 1993 Brose and Van Lear 1998
Windthrow Wounding And Decay	Englerth and Isaac 1944 Wright et al. 1947 Foster and Foster 1951 Ruth and Yoder 1953 Isaac 1956 Wright and Isaac 1956 Wallis et al. 1971 Wallis and Morrison 1975	Munger 1950 Ruth and Yoder 1953 Isaac 1956 Wright and Isaac 1956 Alexander 1971 Gottfried 1992	

Partial cutting in western hemlock stands

Adequate regeneration is rarely a problem in hemlock-spruce stands following partial cutting; excessive regeneration is more of a concern. In a shelterwood cutting in Oregon, Ruth (1967) reported the successful establishment of a new hemlock-spruce stand, but overstocking was a problem. The overstory stand was too dense to maintain spruce in the understory and seedlings suffered shock from overstory removal. In other shelterwood studies in western Washington (Herman 1962, Williamson 1966, Williamson and Ruth 1976) overstocking of western hemlock was also reported to be a problem. In a hemlock shelterwood study Williamson and Ruth (1976) analyzed 12 different cutting intensities and they reported in all cases that excessive overstocking of hemlock occurred with reduced seedling growth as density and shade increased. This study was remeasured (Jaeck et al. 1984) and they found stocking in each treatment was similar and excessive ranging from 12,400 to 212,500 stems per hectare. Growth rates however varied among the different cutting treatments with the greatest diameter and height growth occurring in the lightest treatment (most open) and smaller trees in the denser overstory treatments. The new stand also showed patterns of stand differentiation with establishment of obvious crown classes. In the only study of partial cutting in southeast Alaska, Farr and Harris (1971) found all cutting treatments were overstocked with hemlock and spruce regeneration, and all regeneration in the uncut treatment was hemlock but partial cutting led to 15 to 20 percent spruce regeneration. They also found that hemlock regeneration was often advance regeneration while all spruce regeneration was new.

Advance regeneration is frequently found in mature hemlock stands and these trees may be an important component of the new stand after cutting (James and Gregory 1959, Harris 1974, Deal et al. 1991). Some researchers have shown that old hemlock advance regeneration may be able to respond to release following partial cutting (Meyer 1937, Wiley 1978, Oliver 1976, Deal et al. 1991) with shorter trees responding sooner and having greater height growth than taller trees (Oliver 1976, Hoyer 1980). Other authors have reported poor growth in advance regeneration hemlocks following partial cutting (Farr and Harris 1971, Williamson and Ruth 1976, Jaeck et al. 1984) and the advance regeneration tended to be scarred and crooked (Jaeck et al. 1984). Under partial cutting, the capacity of understory seedlings to respond to increasing levels of light is in accordance with generally accepted shade tolerance rankings (Minore 1979). Tucker and Emmingham (1977) found that western hemlock responds to increased light levels by shedding older needles and forming new smaller and thicker needles that are more efficient in absorbing higher radiation. They suggest that shelterwood cuttings provide greater protection, lower mortality and shock for understory hemlock trees than dramatic changes in light conditions created from clearcutting.

Concerns with partial cutting in hemlock-spruce stands

Both Sitka spruce and western hemlock are thin barked species and easily wounded (Farr et al. 1976), and trees in southeast Alaska often have shallow roots and are subject to windthrow (Ruth and Harris 1979, Harris 1989, Bormann et al. 1995). In partially cut hemlock-spruce stands in the Pacific Northwest, Isaac (1956) reported net losses in growth ten years after cutting, but the reasons for tree mortality were unexplained. Several studies in Washington, Oregon and British Columbia (Englerth and Isaac 1944, Wright et al. 1947, Foster and Foster 1951, Wright and Isaac 1956, Wallis et al. 1971) have shown a high correlation between wounding and decay for trees wounded following partial cutting operations. The resultant decay following wounding can cause significant losses in potential timber. Wallis and Morrison (1975) estimated an annual decay volume loss of 0.75% for trees severely injured during logging. In a 50-year-old western hemlock stand with 10-year-old logging injuries, Shea (1961) reported that decay was associated with 57 percent of the injuries, and the stand had a net volume loss of 10 cubic feet since date of logging. In a partially cut stand in southeast Alaska, (Farr and Harrris 1971) found that opening the stand stimulated epicormic branching in spruce, thus reducing the quality of trees in the stand. Epicormic branching was correlated with the intensity of cutting; 62 percent of the spruce trees in the heavy thinning treatment, 42 percent of spruce in light thinning, and 32 percent of spruce in the uncut control had epicormic branches.

Little work is documented on the effects of partial cutting in southeast Alaska. The region has a history of partially cutting where individual trees and groups of trees were selected for cutting, however, these partially cut stands were not part of a planned silvicultural system and generally little thought was given to management of the stand. More research is available on partial cutting in the western hemlock-Sitka spruce forest type of the Pacific Northwest (Table 1.1) and much of this information may be applicable to the same forest type in southeast Alaska. However, the response of hemlock-spruce stands in southeast Alaska may be different than in other regions, and the assumptions about the effects of partial cutting of stands in this region need to be evaluated before implementing any new region-wide silvicultural system.

Chapter 2.

THE EFFECTS OF PARTIAL CUTTING ON STAND STRUCTURE AND GROWTH OF WESTERN HEMLOCK-SITKA SPRUCE STANDS IN SOUTHEAST ALASKA.

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Introduction

Forest management of federal lands in the United States is mandated to provide a wide range of different and often conflicting products and services including sustainable timber production, productive wildlife and fisheries habitat, biological conservation, and forests for public recreation. Recent concerns that past forest management over emphasized timber production and undervalued other resources has created interest in developing new stand management practices that enhance biodiversity and assure the long-term sustainability of forest resources. A particularly controversial area of forest management has been the extensive use of clearcutting, and recent region-wide forest-management plans in the Pacific Northwest and Alaska (Record of Decision 1994; Record of Decision 1997) have prescribed specific silvicultural guidelines for forest management using alternatives to clearcutting. However, very little is known about the effects of partial cutting on forest stands, particularly in southeast Alaska where clearcutting has been the dominant regeneration method since the early 1950s (Farr & Harris 1971, Harris & Farr 1974). In this study, the term "partial cutting" refers to any harvesting practice where part of the original stand was cut and the remaining residual stand was left intact after logging. There is a great need to understand the effects of partial cutting on species composition, patterns of regeneration and mortality, plant diversity and abundance, and stand dynamics, before implementing any new silvicultural system.

Silviculture has traditionally been based on a combination of experience, in observation and experimental research. Most silvicultural research involves studies that test hypotheses and provide quantitative assessments of tree and stand response in relatively young stands. In contrast, the emerging new forestry (Franklin 1989) or ecosystem management approach (Salwasser 1994), is predominantly descriptive ecology, and most current proposals for specific practices are based on hypotheses derived therefrom, without manipulative or reconstruction studies to establish their validity (DeBell and Curtis 1993). Appropriate application of reconstruction studies and quantitative research are needed to resolve many questions related to benefits, risks and feasibility of new ecosystem management plans. Retrospective studies involve reconstruction of former stand conditions and can provide some immediate, albeit incomplete, information on stand development pathways following natural or man made disturbances. Stand reconstruction analysis has some limitations in that one cannot determine events for which all evidence has disappeared (Harper 1977). However, diligent reconstruction techniques which trace the growth and disturbance history of stands backward in time, can provide much useful information about the former stand (Stephens 1953, Henry and Swan 1974, Oliver and Stephens 1977, Bailey and Tappeiner 1998). Procedures for stand reconstruction include determining past growth patterns of living trees, determining changes in species composition from dead or cut trees, and determining past stand history by documenting frequency and type of disturbances (Oliver 1982, Lorimer 1985). Stand reconstruction is a valuable tool to assess possible successional pathways following a known disturbance.

Stand development in southeast Alaska after major disturbances follows a clearly defined pattern (Alaback 1982a, Deal et al. 1991). Following clearcutting or other major disturbances, dense prolific new and advance regeneration rapidly “fills” the site. At about 15-25 years old canopy closure occurs and an intense period of stem exclusion begins. During this period of stem exclusion, no new tree regeneration occurs and other understory vegetation is suppressed for up to 100 years (Alaback 1982b, 1984, Tappeiner & Alaback 1989). The developing young-growth stands are extremely dense, and have stand structures with relatively uniform tree height and diameter distributions. These stands are notably lacking the multi-layered, diverse structures found in old-growth or multi-aged stands common in the region.

The importance of both small-scale and large-scale disturbances on stand development has been well documented (Hough and Forbes 1943, Drury and Nisbet 1973, Oliver 1981, Lorimer 1985, Stewart 1986, Spies et al. 1990). Recent studies on small-scale disturbances and gap-phase stand dynamics have provided a greater appreciation of the role of small-scale disturbances on forest stand development (Lorimer 1980, Runkle 1982, Lertzman et al. 1996). Following small-scale disturbances, uneven-aged stands often develop that have multiple canopy layers and complex stand structures. The establishment and growth of conifer regeneration after small-scale disturbances varies widely among different forest types. Some trees including several pine species are relatively intolerant of shade and require more open grown conditions or stand replacing fires to germinate and become established (Eyre and LaBarron 1944, Lotti 1961), while other more shade tolerant trees including several true fir species and western redcedar (*Thuja plicata* Dunn ex D. Don) often become established from pre-existing "advance" regeneration (Roe and DeJarnette 1965, Ferguson and Adams 1980, Tucker and Emmingham 1977, McCaughey and Ferguson 1988).

Small-scale, low-intensity disturbances are common in the coastal regions of southeast Alaska (Alaback 1984, Alaback and Juday 1989, Harris 1989, Deal et al. 1991, Ott 1997), and the major tree species, Sitka spruce (*Picea sitchensis* (Bong.) Carr.), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), are moderately shade tolerant and very shade tolerant respectively (Minore 1979). The ability of western hemlock to release and rapidly grow following overstory removal is well documented (Meyer 1937, Oliver 1976, Tucker and Emmingham 1977, Hoyer 1980, Deal et al. 1991). The response of Sitka spruce to partial overstory removal is less well known, and it's ability to maintain itself in a gap-phase disturbance regime was reported by Ott (1997) to be substantially less than for western hemlock. However, in another study (Deal et al. 1991), Sitka spruce was able to regenerate in an all-aged stand with no major disturbances for over 300 years. The effects of partial cutting on the regeneration and growth of Sitka spruce and western hemlock are largely unknown, and research on this topic, as reported here, would provide valuable information to silviculturists in the region.

Partial cutting of forests was a common practice in southeast Alaska before the establishment of pulp mills in the region during the 1950s. These partially cut stands were not part of a planned silvicultural system, and generally little thought was given to the future management of the stand. Usually these stands were partially cut to provide a particular product such as Sitka spruce sawtimber or western hemlock for dock piling. The current age structure, species composition, and growth of these partially cut stands are unknown. There is considerable need to document current stand structures and assess patterns of growth in these stands. Understanding how these stands develop following partially cutting will be critical to develop new uneven-aged management prescriptions for the region.

This retrospective study on the effects of partial cutting on stand structure and growth is part of a large integrated study analyzing the effects of alternatives to clearcutting on forest stand structure, wildlife, hydrology, and socioeconomic concerns of people. The retrospective study includes collaborative work with other researchers on patterns of stand mortality, tree wounding and disease, plant community response, conifer regeneration, and stand structure and growth. In the work reported here, we described the current structures of partially cut stands, reconstructed these stands back to the date of cutting, and assessed growth of these stands since cutting. The objectives of this study were to determine the changes in tree species composition, tree age-cohort structure, tree size distribution, and growth of these stands after partial cutting. In particular, the distribution of Sitka spruce was analyzed to determine if spruce can be maintained in these partially cut stands over a wide range of cutting intensity.

Methods

Research methodology

I used a retrospective approach rather than installing a new experimental study to analyze the effects of partial cutting on forest stand structure. Retrospective studies have advantages in that the researcher can determine broad patterns of forest stand dynamics without waiting for decades for experimentally treated stands to develop. Retrospective studies establish baseline data and provide immediate information that can then be tested in a more rigorous experimental study. Researchers need to be careful not to make direct cause and effect conclusions using retrospective studies because they may not have pretreatment data nor do they have control of treatments, and they are required to report "after the fact." However, with detailed stand descriptions and careful stand reconstruction, forest researchers can accurately determine much of the former stand's history and development. This study incorporated descriptive analysis of current stand structures and reconstruction of former stand conditions.

Study areas and stand selection

Eighteen stands were selected to sample a range of time since cutting, intensity of cutting and geographic distribution throughout southeast Alaska. Study areas were selected from an available array of potential sites in the region with an initial pool of over 200 stands identified as being partially harvested. This information came from a variety of sources including U.S. Forest Service district files, historical records and maps, and information from local residents. Aerial photography and field visits were then used to identify stands and select study areas. Approximately sixty of the best candidate stands were visited to select study areas using the following criteria: a) a range of "time since cutting," with study areas selected from stands cut at least ten years up to one hundred years ago, b) stands with only one harvest entry, c) a wide range of cutting intensity within each stand including an uncut area, d) a large partial cutting area of at least ten ha in size, e) relatively uniform topography, soils, forest type and plant associations within each stand, f) a geographic distribution throughout the three management areas of the Tongass National Forest. Following the field visits, the eighteen stands that best met the study area selection criteria were used to fill a matrix of research sites. Study areas were installed during the summers of 1995 and 1996, and research sites were generally close to saltwater, less than 100 meters in elevation, and located throughout southeast Alaska in the north (Chatham), central (Stikine), and southern (Ketchikan) management areas of the Tongass National Forest (Figure 2.1).

Plot selection

Stand conditions were thoroughly assessed by walking through the entire stand and noting the number and size of cut stumps, the number of obvious residual overstory trees,

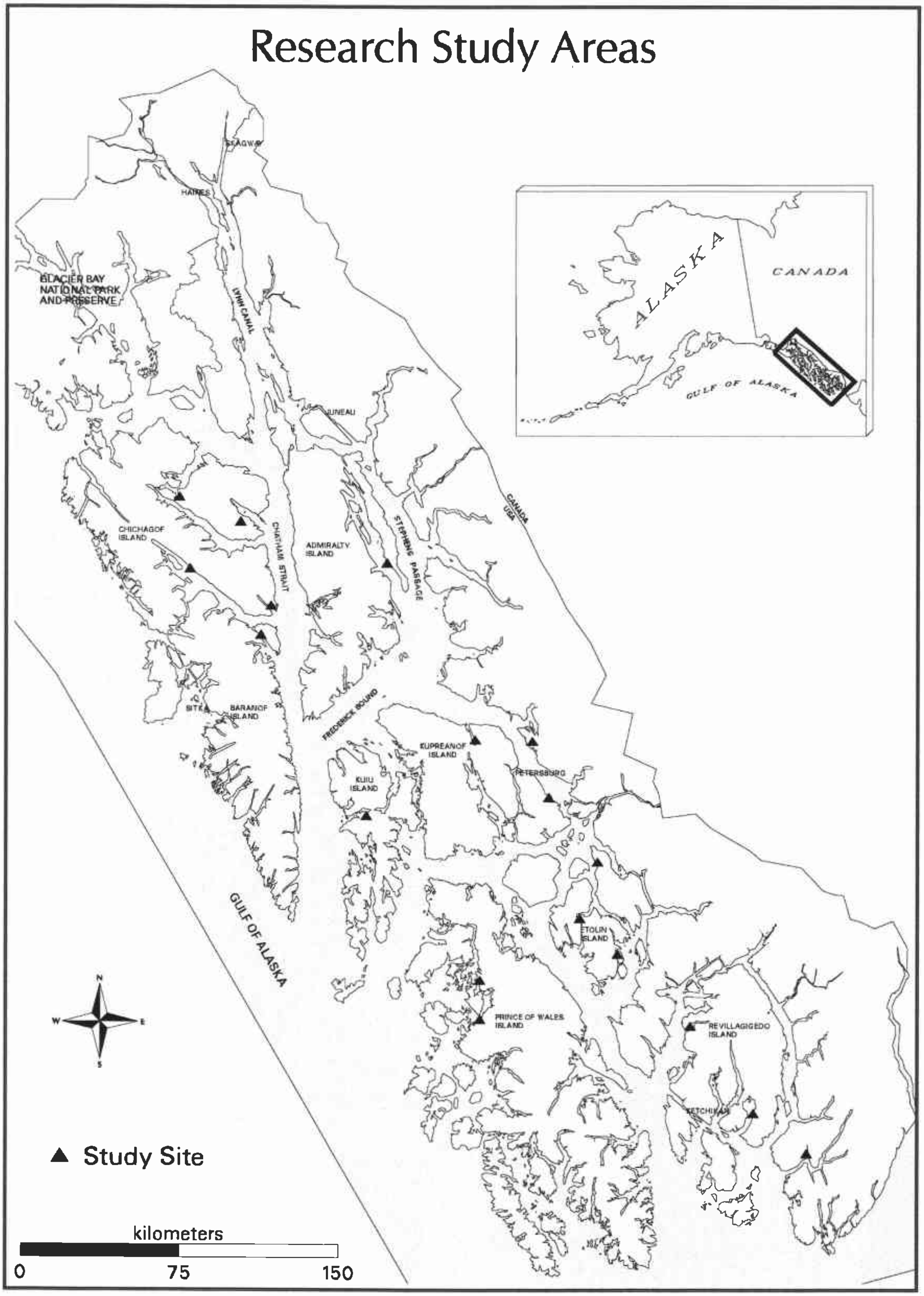

Figure 2.1. The location of 18 partially cut stands in southeast Alaska that were selected for study sites.

stand stocking, size of cutting area, and general stand conditions. Generally three partially cut plots and an uncut control plot were established per stand. Within each stand, relative cutting treatments were designated as light, medium and heavy, according to the number and size of cut stumps, and the number of obvious residual trees. Plots were centrally located within these designated cutting treatments with no preconceived bias. These cutting treatments were established to sample the range of cutting intensities within each stand; however, the actual basal area cut and proportion of stand cut was determined later through stand reconstruction. I sampled a wide range of cutting intensity within each stand in order to evaluate stand response in relation to density. Elevation, slope, aspect, plant association and soil type of stands were recorded (Table 2.1). A total of seventy-three 0.2 ha plots were installed in eighteen different stands.

Plot installation and measurement

Each 0.2 ha plot contained three circular nested plots using a nested plot sampling design (Avery and Burkhart 1994) to sample trees in different size classes (Figure 2.2). All trees, snags and cut stumps greater or equal to 2.5 cm d.b.h. (1.3 m) were measured in the 0.02 ha plot ("a" plot). Trees, snags and stumps greater than 24.9 cm d.b.h. were measured in the 0.05 ha plot ("b" plot). Trees, snags and stumps greater than 49.9 cm d.b.h. were measured in the 0.2 ha plot ("c" plot). These plot sizes were based on a pilot study I established in 1994 to determine plot sample size, and plot sizes and were chosen to provide a minimum of 10-15 trees per plot in each tree diameter size class. The "a" plots had greater variability in tree sample size, and based on the pilot study data, I added two additional "a" plots in each of the large "c" plots to increase sample size and improve

Table 2.1 Descriptions of research sites listed chronologically by cutting date. Elevation, slope and aspect were averaged by location. The plant association and soil series are the predominant site types.

Research Site	Tongass Area[1]	Cutting Date	Elev. (m)	Slope (%)	Aspect	Plant[2] Association	Soil Series	Site[3] $Index_{50}$
Thomas Bay	Stikine	1984	15	2	NW	hemlock/blueberry/shield fern	Fanshaw	30
Granite	Stikine	1983	30	5	NW	hemlock/blueberry/shield fern	Kupreanof-Mosman	27
Pavlof River	Chatham	1977	20	5	W	spruce/blueberry/devil's club	Tuxekan	30
Big Bear Creek	Stikine	1958	20	10	NW	spruce/blueberry/devil's club	Mitkof-Mosman	23
Margarita Bay	Ketchikan	1958	20	50	NE	hemlock/blueberry	Traitors	30
Rainbow Falls	Stikine	1942	20	15	SW	spruce/red alder	Kupreanof-Mitkof	27
Finger Creek	Chatham	1941	5	3	W	hemlock/blueberry/shield fern	Tuxekan	30
Winter Harbor	Ketchikan	1932	5	2	N	spruce/blueberry	Aeric-Cryaquepts	29
Salt Lake Bay	Chatham	1928	10	5	NE	spruce/devil's club	Tuxekan	30
Canoe Passage	Stikine	1927	100	25	NW	hemlock/blueberry	Kupreanof-Mosman	27
Elf Point	Ketchikan	1927	30	35	NW	hemlock-redcedar/blueberry	St. Nicholas	24
Sarkar	Ketchikan	1925	60	20	W	hemlock/blueberry	Ulloa-Sarkar	30
Hanus Bay	Chatham	1922	25	20	SW	spruce/devil's club	Kupreanof	30
Kutlaku Lake	Stikine	1920	5	3	N	spruce/devil's club	Tuxekan	32
Portage Bay	Stikine	1918	35	15	W	hemlock/blueberry/shield fern	Kupreanof-Mitkof	27
Florence Bay	Chatham	1914	10	4	S	spruce/blueberry	Tuxekan	32
Glass Peninsula	Chatham	1911	20	15	W	spruce/devil's club	---	29
Weasel Cove	Ketchikan	1900	30	40	E	spruce/devil's club	---	24

[1] Management areas of the Tongass National Forest including the Chatham (north), Stikine (central), and Ketchikan (south).
[2] Forest Plant Association Management Guides Alaska Region.
[3] Farr's potential site index, base age 50, height in meters (Farr 1984).

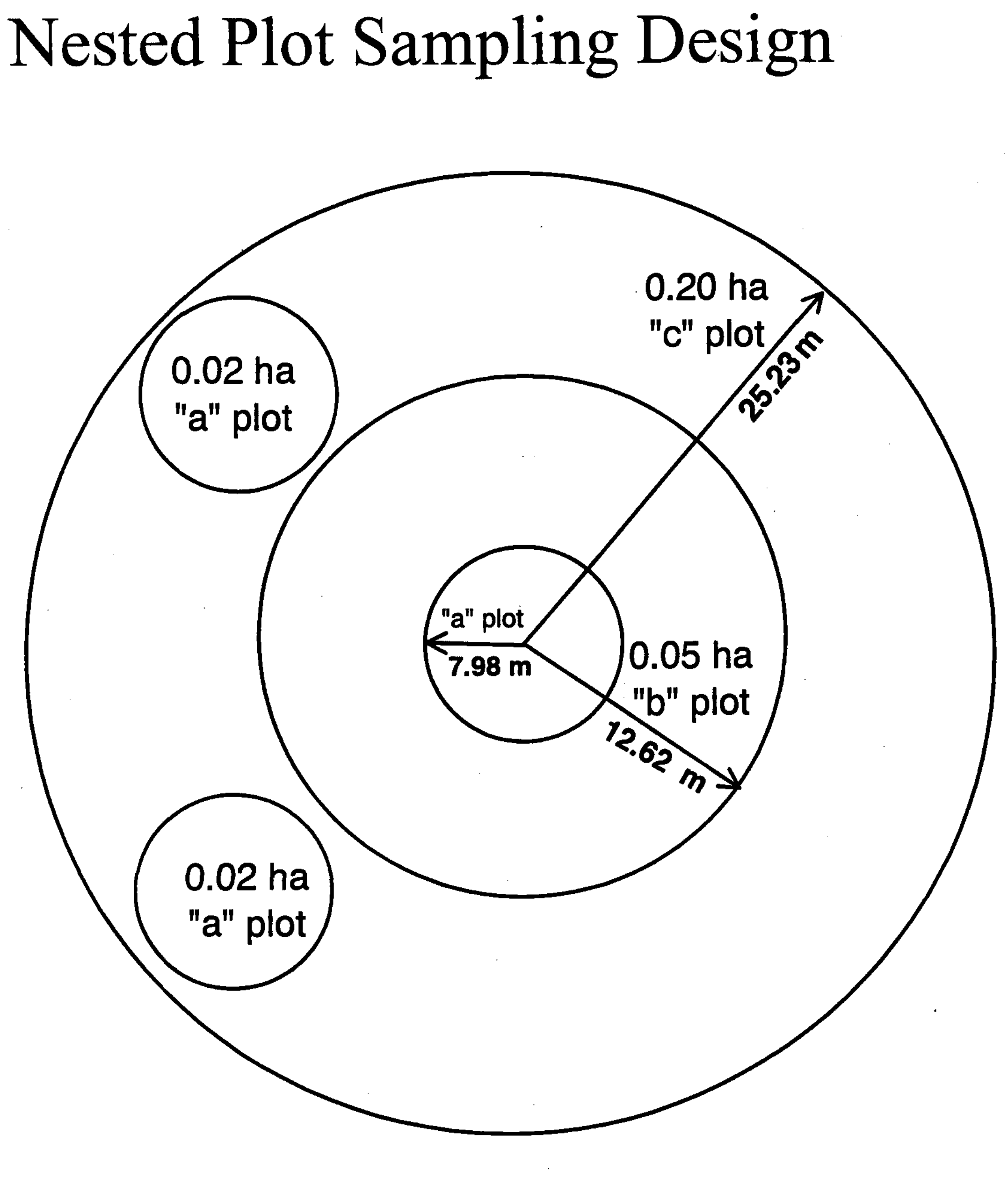

Figure 2.2 Nested plot sampling design including three "a" plots (0.02 ha) with all trees, snags and cut stumps greater or equal to 2.5 cm d.b.h. measured, one "b" plot (0.05 ha) with trees, snags and stumps greater than 24.9 cm d.b.h measured, and one "c" plot (0.20 ha) with trees, snags and stumps greater than 49.9 cm d.b.h measured.

reliability of samples. The additional "a" plots were located at a random bearing 17 m from plot center (Figure 2.2).

For each plot, tree species, crown position, and d.b.h. were measured for all live trees to provide current stand structural information. Snag species, d.b.h. and decay class data were collected to provide information on tree mortality. The diameter of cut stumps at a height of 0.5 m was measured to determine basal area of cut trees. Stumps were often cut at different heights above ground level and the height of 0.5 m was used as the highest common stump height. Tree height, percent live crown, and tree condition data such as top damage and dwarf mistletoe were measured for 10-20 trees on each plot. Height trees were randomly selected from each crown class with two dominant, two codominant, and 1-2 intermediate, suppressed and understory trees measured for each tree species. A minimum of 10 dominant and codominant height trees were selected from each "c" plot. Tree increment cores or stem sections were taken from all height trees for tree-ring analysis to determine tree age, changes in diameter growth (tree release and suppression), cutting date and cutting intensity for each stand.

Determination of cutting date

The date of cutting was determined using stand reconstruction techniques (Lutz 1928, Stephens 1953, Henry & Swan 1974; Oliver 1982; Lorimer 1985; Deal et al. 1991) and verified by historical data if available. Patterns of tree release indicating an abrupt and sustained increase in growth (Lorimer 1980, Lorimer et al. 1988) were used to determine the date of partial cutting. In addition, other indicators of a cutting disturbance such as new tree cohorts near the cutting date, decay classes of cut stumps and logs, and tree scar ages were used. One of the best methods for determining the date of a cutting event was dating the onset of callus wound tissue development around tree scars caused by logging. However, since tree scars were not always present in stands, the most dependable method for determining the cutting date was from identifying patterns of tree release (Lorimer 1980) from tree increment core and stem section data. The estimated cutting date from stand reconstruction was then compared with historical records that were available for twelve of the eighteen stands. Nine of the twelve stands with historical records had cutting dates match within one year of the cutting date determined from stand reconstruction. The other three stands with historical records were cut at least 70 years ago and the historical dates were unreliable. Thus, in all cases the final cutting date was determined from stand reconstruction data.

Determination of cutting intensity

Stands were reconstructed back to the date of cutting using cut stumps, current live trees, and snag information. Data on basal area cut, current live tree basal area at cutting date, and stand mortality since cutting were combined to determine the proportion of basal area cut for each stand cutting treatment.

I used stem taper equations to determine tree d.b.h. from cut stumps. Tree stumps were often cut at different heights, and to standardize stump height measurements, all stump diameters were measured at the highest common height of 0.5 m above ground level. I then developed stem taper equations to predict tree d.b.h. from the stump diameter using forward stepwise regression analysis (Snedecor and Cochran 1980) on a large unpublished tree data set from southeast Alaska (Appendix, Table 1). The stump basal area was then multiplied by the appropriate tree expansion factor to determine basal area cut per ha for each plot.

I reconstructed the basal area of each stand at the date of cutting using a regression model approach. Tree increment cores and stem sections from 986 western hemlock, Sitka spruce, western redcedar, and Alaska-cedar were used to develop regression equations to predict tree d.b.h. at cutting date. Data from all cutting treatments in each stand were combined and analyzed together, with stand specific regression equations developed to predict tree d.b.h. at cutting date (Appendix, Table 2). I used forward stepwise regression analysis (Snedecor and Cochran 1980) to predict tree d.b.h. at cutting date using a number of tree and stand predictor variables. The most significant variables included current tree d.b.h., basal area, tree species, and cutting intensity. These stand-specific regression equations were then applied to all live trees in the current stand to predict tree d.b.h. at cutting date and estimate former stand basal area per ha using the appropriate tree expansion factor (excluding basal area cut and mortality estimates).

I used snag class and snag age data to determine the snag d.b.h. at cutting date, and then estimate stand mortality since cutting. Each snag was given a snag decay class (Appendix, Table 3, scale 1-5, Palkovic) with an average age for each decay class. Overall, mortality in the stands was light with no significant differences in mortality among the partially cut and uncut plots (Palkovic unpublished data). The live-tree regression equations were then applied to snags, and the snag's d.b.h. was predicted at the date of cutting. Stand periodic mortality estimates included only trees that died since date of cutting (new snags). If the snag age was younger than the date of cutting, then these snags were grown back as live trees from the estimated snag creation date (from snag age class data) to the date of cutting. Periodic basal area mortality per ha. was estimated for each plot using the tree diameter at time of cutting and the appropriate tree expansion factor.

Procedures for tree ring data

Tree increment cores and stem sections were collected and transported back to the laboratory for analysis. Cores were mounted on narrow grooved boards with wood glue and secured for drying by binding with string. Cores were aligned so the tracheids were vertical to give a cross-sectional surface for better resolution of individual cells and tree ring boundaries (Stokes and Smiley 1968). Cores twisted during extraction were straightened by steaming and gently torqueing the cores (Swetnam et al. 1988). Once the glue was dry, the cores were sanded with progressively finer sandpaper grits producing a smooth surface with fine details apparent such as microrings, tree injuries, and false rings.

Prepared cores were examined under a binocular dissection microscope and rings were counted from inner pith to outer bark. Dates were assigned to rings from bark to pith, and tree rings were counted from pith to bark. The relationship of decadal marks from dating was compared to decadal marks from counting to verify accuracy of tree-ring years. Pointer years were used to help ensure dating consistency between cores (Schweingruber et al. 1990). Rings were counted and measured from at least 30 years prior to cutting date. Stem sections were sanded and examined as above. Two radii per section (at approximately 90 degrees apart) were counted, measured, and dated as with the cores. Ring widths of the two stem section radii were then averaged.

Rings were measured on a tree ring measuring system with a linear encoder and digital display unit. To facilitate measuring, a digital signal processing color camera was mounted on the binocular dissection scope and connected to a large video monitor. Data were recorded using the software MEDIR (Krusic and Holmes 1995) and edited using Program EDT within the international Tree-Ring Data Bank program library (Holmes 1995).

Data were transferred to a spreadsheet and each tree's radial growth was summarized. All trees were then combined and analyzed by plot. Several equations were used to determine the tree d.b.h. at date of cutting. First, I calculated the stem radius inside bark (RADBH) from:

$$RADBH = (DBH - (BT*2))/2 \quad (1)$$

where DBH is the field measured tree diameter at breast height (1.3 m), and BT is the species specific bark thickness based on an equation developed for southeast Alaska trees (Appendix, Table 1). Next I calculated the previous tree d.b.h. at time of cutting (PDBH) from:

$$PDBH = (RADBH - RADGR) + (BT*2) \quad (2)$$

where RADGR is the measured radial growth from tree increment cores. However, piths of many trees were off center (common on hemlock trees), and whenever a tree's pith was found, I used a tree-ring-width proportionality adjustment. This proportionality adjustment provided a better estimate of previous tree d.b.h. than an unproportioned d.b.h. (Herman et al. 1975). First, I calculated the measured tree increment core diameter (MDIA) from:

$$MDIA = ((MRAD – RADGR)*2) + (BT*2) \quad (3)$$

where MRAD is the total measured radius from tree increment cores. I then calculated the proportionally adjusted tree d.b.h. (PROPDBH) from:

$$PROPDBH = MDIA/(MRAD/RADBH) \quad (4)$$

Data analysis

Stand structure

I analyzed stand structure and growth by describing current stand conditions and by reconstructing the former stand at time of cutting. Tree diameter distributions, the number of trees, snags, and cut stumps per ha, tree species composition, and stand basal areas were calculated using the appropriate tree expansion factor. The cutting intensity, current stand density, and species composition of each stand was described using tables and histograms. Tree-ring analyses were used to investigate the effects of partial cutting on the growth of hemlock and spruce trees, different tree-age cohorts, and size classes of residual trees.

The stands response to partial cutting was probably related to the intensity of cutting and several different measures of cutting intensity were evaluated. The intensity of cutting was initially determined using absolute basal area cut, residual basal area left after cutting, and the proportion of stand basal area cut. However, using only the absolute basal area cut or the residual basal area did not provide an accurate assessment of the stand cutting intensity. Some stands had very high densities before cutting and stand basal area growth was closely related to initial stand basal area prior to cutting. The proportion of stand basal area cut combined both the absolute basal area cut and the initial stand basal area to determine a proportion of the stand removed by cutting. I found that the proportion of stand basal area cut was a more accurate indicator of cutting intensity than either absolute basal area cut or residual basal area, and the proportion of basal area cut was more closely related to the major stand structural responses I was investigating. For this reason, I used the proportion of stand basal area cut to determine the effects of cutting intensity on stand structure and growth.

I determined the proportion of stand basal area cut (PROPCUT) for each plot from:

$$PROPCUT = [CUTBA/(RESBA + CUTBA + MORTBA)]*100 \qquad (5)$$

where CUTBA is the absolute basal area cut, RESBA is the current live tree basal area at cutting date, and MORTBA is the periodic basal area mortality since cutting date. I then used the proportion of stand basal area cut as a continuous variable in regression analyses to analyze changes in tree species composition, tree-age cohorts, stand growth and stand structure after cutting. The proportion of western hemlock and Sitka spruce trees by tree number and basal area were used to determine if changes in species composition were related to cutting intensity. The tree age structure was analyzed according to the proportion of stand basal area cut to determine if changes in age structure were related to cutting intensity. Stand basal area growth was also determined and analyzed according to the proportion of stand basal area cut to look for patterns of growth associated with cutting intensity. I also analyzed the growth of residual trees of different species and size classes to examine how tree species and size influenced subsequent growth. Tree diameter distributions for current stands were then compared with diameter distributions of stands before cutting to analyze changes in stand structure.

Stand density

Stand density was calculated using both Stand Density Index (SDI) and Crown Competition Factor (CCF). The Stand Density Index (Reineke 1933) is the number of trees per acre (*TPA*) based on a quadratic mean diameter (*Dq*) of 10 inches. Given the actual *TPA* and *Dq*, SDI can be calculated from:

$$\mathrm{SDI} = TPA(Dq/10)^{1.6} \qquad (6)$$

The SDI is based on the number of 10-inch-diameter trees that occur per acre and is designed primarily for use in even-aged stands. A different measure of stand density was calculated using the Crown Competition Factor (Krajicek et al. 1961). The crown competition factor reflects the area available to the average tree in a stand in relation to the maximum area it could use if it were open-grown. The CCF is a unit-less ratio based on the open-grown tree condition and a calculated stand CCF of 100 is an open-grown stand whose tree crowns fully occupy all available area. This stand density measure uses individual tree diameters rather than the quadratic mean diameter, and the relationship of crown radial width of the open grown tree to tree diameter is of the form: crown width = $a + b\mathrm{D}i$. I used a metric unit equation developed for Sitka spruce and western hemlock in southeast Alaska (Farr et al. 1989). The tree maximum crown width (MCW) of open-grown trees was first calculated from:

$$\mathrm{MCW} = 1.07 + 0.334(\mathrm{D}^{0.8263}) \qquad (7)$$

where D is tree d.b.h. in centimeters. The maximum crown area is then calculated assuming that crowns are circular in shape by squaring MCW, and then a proportion of area per hectare calculated from:

$$\mathrm{CCF} = \pi(\mathrm{MCW}^2)*100/(4*10{,}000) \qquad (8)$$

All of the trees on a particular plot were then summed using the appropriate tree diameter expansion factor and CCF was calculated on a per hectare basis.

Species composition

To determine if tree species composition may be different in stands after partial cutting, I first tested the hypothesis of no difference in species composition between uncut and partially cut plots (H_o: NCUT SPEC = PCUT SPEC). I blocked plots by stand, and tested for differences in western hemlock and Sitka spruce tree density and basal area among cut and uncut plots using contrast analysis (SAS Institute, Inc.). I also blocked plots by stand, and tested separate hypotheses relating to species composition not being a function of cutting intensity (H_o: SPEC $\neq$ f(PROPCUT). Lastly, I regressed the proportion of tree density and basal area for both spruce and hemlock on stand variables including the intensity of cutting, absolute basal area cut, total stand residual basal area, and residual basal area of different tree species.

Tree-age cohorts

To determine if tree-age cohorts are different in stands after partial cutting, I first tested the hypothesis that the proportion of tree-age cohorts (new tree-C1, or residual tree-C2 cohorts) are the same in uncut and in partially cut plots (H_o: NCUT C-1 = PCUT C-1). I confined my statistical analysis to the C-1 trees (all trees are either C-1 or C-2). I blocked plots by stand, and then tested for differences in C-1 tree density and basal area among cut and uncut plots using contrast analysis. To determine if tree-age cohorts are a function of stand cutting intensity, I blocked plots by stand, and tested hypotheses that the proportion of C-1 tree density and basal area, are not a function of cutting intensity (H_o: PROP C-1 $\neq$ f(PROPCUT). Lastly, I regressed the proportion of C-1 tree density and basal area for both hemlock and spruce on stand variables including the intensity of cutting, absolute basal area cut, total stand residual basal area, and residual basal area of different tree species.

Stand growth

I also determined if there are differences in stand growth following partially cutting. First, I blocked plots by stand, and tested for differences in stand basal area growth between cut and uncut plots using contrast analysis. I then blocked plots by stand, and tested the hypothesis that stand basal area growth is not a function of cutting intensity (H_o: BAGRTH $\neq$ f(PROPCUT). I also tested the hypothesis that stand basal area growth is the same for C-1 and C-2 trees (H_o: C-1 BAGRTH = C-2 BAGRTH). Then, I regressed the proportion of stand basal area growth (arcsin square-root transformation) for C-1 trees in each stand on stand variables including the intensity of cutting, absolute basal area cut, total stand residual basal area, and residual basal area of different tree species.

Lastly, I determined if there were differences in tree diameter growth between residual western hemlock and Sitka spruce, and also if there were differences in diameter growth among different residual-tree (C-2) size classes. To accomplish this, regression models were developed in a similar fashion as in the model used to predict tree d.b.h. at cutting date (Appendix, Table 2). I then plotted the average tree diameter growth for each decade since cutting by 20 cm diameter classes for C-1 and C-2 trees, and compared the growth of trees in cut and uncut plots. I limited my analysis to the eleven stands that were cut at least sixty years ago, and estimated growth for six decades since the date of cutting. I tested for average diameter growth differences (cut vs. uncut plots) for each diameter class using a paired-sample t-test, alpha = 0.05 (Zar 1996). I also tested for average diameter growth differences (western hemlock vs. Sitka spruce) in the partially cut plots for each diameter class using a paired-sample t-test, alpha = 0.05 (Zar 1996).

Results and Discussion

Cutting date and cutting intensity

The time from cutting date to sampling date ranged from 12 years for the stands at Thomas Bay and Granite, to 96 years for Weasel Cove (Table 2.2). Twelve of the 18 research sites were cut between 1900 and 1942. It was difficult to find recent partially cut stands (only 6 stands were cut since 1950) and most stands were cut in the 1910's and 1920's. The intensity of cutting varied both within stands and among stands. The different cutting intensities within stands at Florence Bay and Salt Lake Bay were relatively similar both in absolute basal area cut and the proportion of basal area cut (Table 2.2). Other stands had wide ranges in cutting intensity both for the absolute basal area cut (e.g. Margarita Bay) and in the proportion of basal area cut (e.g. Elf Point and Granite). Overall, in this study, cutting intensity varied from an absolute basal area cut of 84.8 m^2/ha (96.4% of BA cut) at Hanus Bay, to a basal area cut of 7.0 m^2/ha (26.3% of BA cut) at Portage Bay (Table 2.2). However, some stands had higher initial basal areas and relatively high residual basal areas left after cutting (e.g. Winter Harbor). Other stands had relatively small amounts of absolute basal area cut but grew vigorously after cutting. The current stand basal area was more closely related to the proportion of stand basal area cut than to the absolute basal area cut or the amount of residual basal area left after cutting.

Table 2.2 Cutting intensity and current stand density of stands listed by plot cutting intensity at each research site.

		---Cutting Intensity---			---Current Stand Density---			
							Density Index	
Research Site	Plot Cutting Intensity	BA Cut (m^2/ha)	BA Left (m^2/ha)	Prop. Cut (% BA)	Trees[1] (no./ha)	BA (m^2/ha)	SDI[2]	CCF[3]
Thomas Bay	Medium	17.5	42.4	29.2	766	49.4	376	162
	Light	18.8	76.9	19.7	237	68.7	389	191
	Uncut	0.0	77.2	0.0	383	70.2	435	214
Granite	Heavy	51.2	8.5	85.7	1440	12.6	142	83
	Medium	9.3	23.4	28.5	1650	22.0	228	133
	Light	10.7	50.3	17.5	1970	57.9	515	250
	Uncut	0.0	66.6	0.0	368	70.4	432	228
Pavlof River	Heavy	42.7	31.0	58.0	413	37.4	266	139
	Medium	30.6	47.4	39.2	448	58.7	389	195
	Medium	28.3	46.3	37.9	288	54.7	336	169
	Light	21.2	38.5	35.5	823	48.0	373	172
	Uncut	0.0	62.6	0.0	882	69.3	508	266
	Uncut	0.0	48.4	0.0	387	60.0	384	201
Big Bear Creek	Heavy	27.1	49.2	35.5	754	61.6	447	246
	Medium	20.4	63.3	24.4	270	78.9	446	222
	Light	9.3	46.8	16.6	676	52.7	387	201
	Uncut	0.0	49.7	0.0	430	54.6	364	185
Margarita Bay	Heavy	48.0	9.9	82.9	1115	41.1	349	206
	Medium	27.7	12.9	68.2	2695	44.3	442	298
	Light	8.8	30.1	22.5	1658	63.3	534	304
	Uncut	0.0	47.2	0.0	694	58.6	423	232
Rainbow Falls	Heavy	25.0	16.2	60.7	775	45.8	355	206
	Medium	22.8	25.4	47.2	682	66.3	465	233
	Light	15.1	29.0	34.3	348	58.2	367	197
	Uncut	0.0	40.3	0.0	1108	44.4	371	208
Finger Creek	Heavy	32.5	45.9	41.5	522	74.8	486	266
	Medium	30.5	43.9	41.0	405	58.3	379	219
	Light	11.0	51.0	17.7	373	66.4	413	234
	Uncut	0.0	44.9	0.0	331	58.8	366	195
Winter Harbor	Heavy	33.8	55.7	37.8	785	84.3	580	300
	Medium	38.9	69.7	35.8	1126	74.4	563	260
	Light	19.0	60.1	24.0	1311	95.3	708	336
	Uncut	0.0	72.7	0.0	1124	73.3	557	253
Salt Lake Bay	Heavy	35.2	28.9	54.9	642	68.0	469	256
	Medium	28.9	29.8	49.3	437	62.6	407	217
	Light	28.4	31.3	47.5	295	69.5	410	201
	Uncut	0.0	53.0	0.0	158	87.0	434	224

Table 2.2 (Continued)

Research Site	Plot Cutting Intensity	Cutting Intensity: BA Cut (m²/ha)	BA Left (m²/ha)	Prop. Cut (% BA)	Current Stand Density: Trees (no./ha)	BA (m²/ha)	Density Index: SDI	CCF
Canoe Passage	Heavy	57.2	18.9	75.2	815	43.9	346	192
	Medium	20.6	20.5	50.1	1235	65.9	521	298
	Medium	27.4	27.4	50.0	1183	57.6	463	242
	Light	9.0	46.1	16.4	2452	56.0	523	306
Elf Point	Heavy	35.2	12.7	73.4	453	42.0	298	157
	Medium	35.5	29.7	54.5	641	58.3	415	235
	Light	12.0	57.4	17.3	1397	89.7	683	326
	Uncut	0.0	92.9	0.0	1443	115.6	843	388
Sarkar	Heavy	27.6	19.0	59.2	583	57.7	404	230
	Medium	21.2	20.9	50.3	1163	64.2	504	258
	Light	13.8	37.0	27.1	1067	68.5	522	256
	Uncut	0.0	65.4	0.0	467	76.4	484	239
Hanus Bay	Heavy	84.8	3.2	96.4	1180	65.1	511	286
	Medium	71.1	14.4	83.1	413	84.3	511	264
	Light	23.9	24.6	49.2	760	56.1	416	214
	Uncut	0.0	42.6	0.0	460	82.8	515	260
Kutlaku Lake	Heavy	30.8	18.4	62.6	305	57.8	356	189
	Medium	20.0	33.7	37.3	525	108.4	656	318
	Light	16.9	37.4	31.1	372	91.6	535	282
	Uncut	0.0	94.0	0.0	325	139.1	729	338
Portage Bay	Heavy	25.9	14.2	64.5	1202	52.6	432	258
	Medium	28.5	25.3	52.9	920	54.1	420	242
	Light	7.0	19.6	26.3	935	47.1	377	210
	Uncut	0.0	26.8	0.0	459	56.3	377	198
Florence Bay	Heavy	34.8	26.2	57.0	120	55.6	286	152
	Medium	32.5	28.4	53.4	215	70.0	388	208
	Light	37.8	38.1	49.8	360	82.9	491	270
	Uncut	0.0	79.3	0.0	195	62.2	346	189
Glass Peninsula	Heavy	38.4	17.1	69.2	331	60.1	373	185
	Medium	40.8	29.8	57.8	397	74.3	458	241
	Light	14.5	47.3	23.5	147	84.4	417	212
	Uncut	0.0	43.7	0.0	350	81.6	482	254
Weasel Cove	Heavy	22.6	21.5	51.2	1015	63.0	486	254
	Medium	17.8	43.0	29.3	1220	53.3	439	219
	Light	9.2	44.7	17.1	450	72.6	461	250
	Uncut	0.0	41.6	0.0	1196	74.6	571	303

[1] Trees = the number of trees per hectare that are at least 2.5 cm d.b.h.
[2] SDI = $TPA(Dq/10)^{1.6}$ (Reineke 1933) where (*TPA*) is trees per acre and (*Dq*) is the quadratic mean diameter.
[3] CCF = $\pi(MCW^2)*100/(4*10,000)$ (Krajicek et al. 1961) where MCW = $1.07 + 0.334(D^{0.8263})$ for southeast Alaska (Farr et al. 1989) and (D) is tree diameter.

Stand density

The current stands have complex structures with highly variable stand densities both within and among stands. Tree density varies from only a few hundred trees/ha at some of the earliest cut sites such as Kutlaku Lake, Florence Bay and Glass Peninsula (Table 2.2), to nearly two thousand trees/ha at some of the recently cut sites such as Granite and Margarita Bay.

Many of these stands are highly productive with high stand basal areas. Thirteen stands have basal areas greater than 70 m^2/ha and are examples of the extremely high basal areas of hemlock/spruce forests in this region. Stand densities are also very high with several partially cut plots above a stand density index (SDI) of 500, and several cut plots with a crown competition factor (CCF) of nearly 300. These stand density indices are very high for this forest type and approaching the maximum SDI and CCF indices used in even-aged forest simulators in the region (Stage 1973, SEAPROG 1992). Tree growth in the partially cut plots has generally been greater than in the uncut plots, and many of the cut plots in the earliest cut stands has current basal areas equal to or greater than the uncut plots (Table 2.2).

Effects of partial cutting on tree species composition

To determine the effects of partial cutting on tree species composition, I confined my analyses to the responses of western hemlock and Sitka spruce, which are the dominant tree species in all of the stands. However, other species such as western redcedar, Alaska cedar, and red alder were frequently a minor component of some stands, and their potential interaction with hemlock and spruce required testing separate responses for both spruce and hemlock.

The species composition of trees and basal areas was highly variable both among and within stands (Table 2.3). Some current stands were very heavily stocked (e.g. Margarita Bay) with small new regeneration (C-1 trees), while other stands had high current stand basal areas predominantly from large residuals (C-2 trees) left after cutting (e.g. Winter Harbor). The C-2 spruce and hemlock tree density varied widely among stands. The density of C-2 spruce trees ranged from zero in several plots to a maximum of 480 trees/ha at the heaviest cutting plot at Finger Creek (Table 2.3). There were more C-2 hemlock trees than spruce trees in almost all plots. Overall, in the 55 partially cut plots, the spruce tree density in the current stand increased in 21 plots, decreased in 19 plots, and was unchanged in 15 plots (Table 2.3). However, the tree densities and basal areas varied widely among stands, and to assess changes in tree species composition, I used proportions of hemlock and spruce to account for the highly variable stocking differences among stands.

The proportions of western hemlock and Sitka spruce trees were similar in both uncut and partially cut plots. The proportions of western hemlock trees were generally higher than for spruce; however, the proportions of hemlock and spruce varied widely among stands. The average proportion of hemlock is 79.4 (SE = 4.9) in the uncut plots, and 78.8 (SE = 2.7) in the partially cut plots, and the average proportion of spruce in the uncut plots is 15.2 (SE =4.4) and in the partially cut plots was 17.5 (SE = 2.4). After accounting for potential species composition differences among stands through blocking

Table 2.3 Tree species composition in stands after cutting and in current stands listed by plot cutting intensity for each research site.

Research Site	Cutting Intensity Prop. Cut (% BA)	Tree Species Composition: Stand after cutting: Trees[1] per hectare: Spruce	Hemlock	Other	Stand after cutting: Basal area per hectare: Spruce	Hemlock	Other	Current stand: Trees per hectare: Spruce	Hemlock	Other	Current stand: Basal area per hectare: Spruce	Hemlock	Other
Thomas Bay	29.2	117	622	0	0.1	43.7	0	133	633	0	0.3	49.1	0
	19.7	10	272	0	14.0	65.3	0	5	232	0	5.8	62.8	0
	0.0	5	458	0	4.6	72.6	0	5	378	0	4.8	65.3	0
Granite	85.7	0	190	0	0	8.5	0	0	1440	0	0	12.6	0
	28.5	10	1250	0	1.0	22.4	0	110	1540	0	1.9	20.1	0
	17.5	0	1980	0	0	50.2	0	0	1970	0	0	57.9	0
	0.0	25	365	0	2.5	64.4	0	25	343	0	3.2	67.2	0
Pavlof River	58.0	5	297	0	1.9	29.1	0	17	397	0	0.1	37.3	0
	39.2	47	352	0	23.1	24.4	0	47	402	0	26.6	32.1	0
	37.9	25	235	0	21.2	25.0	0	25	263	0	24.1	30.6	0
	35.5	79	295	117	26.8	11.7	0.1	145	528	150	31.1	16.4	0.6
	0.0	137	338	203	42.1	19.5	1.0	107	372	403	39.2	27.7	2.4
	0.0	113	257	17	32.8	15.0	0.5	113	257	17	38.9	20.3	0.8
Big Bear Creek	35.5	225	639	0	32.1	17.1	0	182	572	0	30.4	31.2	0
	24.4	40	268	0	31.6	31.7	0	40	230	0	36.8	42.2	0
	16.6	163	698	0	11.2	35.6	0	108	568	0	10.4	42.3	0
	0.0	274	253	0	35.4	14.3	0	202	228	0	39.9	14.7	0
Margarita Bay	82.9	42	787	0	0.5	9.3	0	42	1073	0	2.6	38.4	0
	68.2	77	438	0	0.2	12.8	0	310	2385	0	6.8	37.5	0
	22.5	276	633	0	7.5	18.2	4.3	293	1313	52	17.4	36.7	9.2
	0.0	167	293	0	24.4	22.8	0	167	527	0	27.8	30.8	0
Rainbow Falls	60.7	0	182	80	0	15.6	0.6	0	695	80	0	41.0	4.8
	47.2	70	137	75	13.5	8.3	3.6	190	427	65	40.7	16.8	8.7
	34.3	0	546	0	0	29.0	0	0	348	0	0	58.2	0
	0.0	103	1502	0	13.1	27.1	0	48	1060	0	17.0	27.4	0
Finger Creek	41.5	480	239	0	31.4	14.5	0	315	207	0	57.5	17.2	0
	41.0	20	540	0	4.4	37.8	0	20	385	0	10.7	47.6	0
	17.7	58	731	0	15.6	35.4	0	20	353	0	13.2	53.1	0
	0.0	101	413	0	3.5	41.4	0	68	263	0	13.2	45.5	0
Winter Harbor	37.8	300	315	0	37.8	17.9	0	262	523	0	62.8	21.4	0
	35.8	89	565	0	20.1	49.7	0	58	1068	0	15.3	59.0	0
	24.0	101	951	0	10.4	49.7	0	48	1263	0	12.2	83.0	0
	0.0	10	448	0	16.0	56.8	0	27	1097	0	19.2	54.1	0
Salt Lake Bay	54.9	25	441	0	0.5	39.0	0	112	530	0	6.2	61.8	0
	49.3	106	669	0	5.7	24.2	0	73	363	0	16.0	46.6	0
	47.5	55	140	0	11.7	19.7	0	55	240	0	26.1	43.4	0
	0.0	173	43	0	51.2	1.7	0	115	43	0	83.3	3.7	0

Table 2.3 (Continued)

Research Site	Cutting Intensity Prop. Cut (% BA)	Tree Species Composition: Stand after cutting: Trees per hectare: Spruce	Hemlock	Other	Basal area per hectare: Spruce	Hemlock	Other	Current stand: Trees per hectare: Spruce	Hemlock	Other	Basal area per hectare: Spruce	Hemlock	Other
Canoe Passage	75.2	17	225	17	0.1	27.4	0.1	62	703	50	5.6	38.0	0.2
	50.1	287	920	170	4.8	4.8	10.9	160	910	165	15.6	27.8	22.6
	50.0	60	240	0	9.9	9.0	0	33	1083	67	1.1	55.4	1.0
	16.4	55	2210	462	2.7	14.0	14.7	50	1945	457	0.3	27.2	28.5
Elf Point	73.4	20	200	0	3.3	3.4	0	20	433	0	13.5	28.5	0
	54.5	15	468	58	0.7	9.5	3.3	15	568	58	4.4	46.2	7.8
	17.3	30	848	102	1.4	7.3	43.3	30	1265	102	6.0	24.3	59.4
	0.0	30	873	323	2.2	17.1	66.4	63	1040	340	6.2	28.2	81.2
Sarkar	59.2	30	250	0	0.1	19.0	0	65	518	0	12.3	45.4	0
	50.3	10	240	0	1.7	19.2	0	0	1163	0	0	64.2	0
	27.1	0	844	0	0	37.0	0	0	1067	0	0	68.5	0
	0.0	15	627	0	10.6	54.7	0	15	452	0	15.9	60.5	0
Hanus Bay	96.4	35	55	0	2.8	0.4	0	732	448	0	41.5	23.6	0
	83.1	105	208	0	2.2	12.3	0	122	292	0	33.2	51.0	0
	49.2	0	844	0	0	37.0	0	375	385	0	5.9	50.2	0
	0.0	15	627	0	10.6	54.7	0	27	433	0	21.9	60.8	0
Kutlaku Lake	62.6	15	80	0	0.4	17.9	0	148	107	50	17.2	38.6	1.9
	37.3	30	115	0	14.9	18.7	0	63	442	20	34.8	71.5	2.1
	31.1	40	215	20	11.5	26.0	0.1	40	312	20	26.2	63.4	2.0
	0.0	32	286	0	24.5	69.7	0	15	310	0	35.0	104.1	0
Portage Bay	64.5	218	555	0	3.3	10.9	0	402	800	0	13.2	39.4	0
	52.9	65	707	0	1.9	23.4	0	82	838	0	6.3	47.8	0
	26.3	142	514	0	4.7	31.8	0	88	847	0	1.8	45.3	0
	0.0	22	430	0	8.7	18.1	0	22	437	0	11.3	45.0	0
Florence Bay	57.0	30	40	0	12.6	13.6	0	90	30	0	34.2	21.3	0
	53.4	60	132	0	6.0	22.4	0	120	95	0	32.1	38.0	0
	49.8	272	490	0	6.6	31.3	0	155	205	0	35.1	47.8	0
	0.0	40	367	0	14.7	64.6	0	35	160	0	27.8	34.6	0
Glass Peninsula	69.2	35	110	0	7.1	9.8	0	108	223	0	26.7	33.4	0
	57.8	74	110	177	10.5	18.1	1.2	92	112	193	27.0	26.6	20.7
	23.5	93	82	20	30.3	16.1	0.9	50	77	20	50.3	30.8	3.3
	0.0	67	317	20	23.3	19.6	0.1	40	290	20	36.8	43.8	1.0
Weasel Cove	51.2	15	783	0	1.4	16.0	0	0	1015	0	0	63.5	0
	29.3	280	602	88	5.9	24.8	10.9	217	898	105	0.6	29.6	23.2
	17.1	149	446	50	31.0	12.1	1.6	107	303	40	37.5	27.0	8.1
	0.0	37	862	182	5.6	17.1	12.5	20	978	198	9.7	29.6	35.2

[1] Trees = the number of trees per hectare that are at least 2.5 cm d.b.h.

by stand, I found no significant difference between cut and uncut plots in either the proportion of hemlock trees ($p = 0.842$) or spruce trees ($p = 0.460$).

The proportions of western hemlock and Sitka spruce basal areas also showed non-significant differences between uncut and partially cut plots. However, the basal areas of hemlock and spruce varied widely among stands. The average proportion of hemlock basal area in the uncut plots is 57.8 (SE = 6.0) and 69.291 (SE = 3.241) in the partially cut plots, and the average spruce proportion in the uncut plots is 35.4 (SE = 5.9) and 25.3 (SE = 3.0) in the partially cut plots. After accounting for potential species composition differences among stands through blocking by stand, I found no significant difference between cut and uncut plots in the proportion of hemlock basal area ($p = 0.064$) or spruce basal area ($p = 0.126$).

In summary, there was insufficient evidence to reject the null hypothesis that tree species composition is the same in uncut and partially cut plots. Partial cutting did not lead to significant changes in the composition of either Sitka spruce or western hemlock. These results are in sharp contrast to conventional knowledge stating that partial cutting leads to hemlock-dominated stands. Anderson (1955) reported that partial cutting led to practically pure hemlock reproduction and a significantly lower proportion of spruce than after clearcutting. Harris and Farr (1974) also stated that one of the major reasons for the continued use of clearcutting in the region was concern that partial cutting would lead to a higher proportion of hemlock (a less desirable timber species). Some of the stands in this study had high proportions of hemlock but species composition generally did not change following partial cutting.

The proportions of western hemlock trees and basal area were not closely related to cutting intensity (Figure 2.3). The proportion of hemlock trees decreased slightly with increasing cutting intensity but cutting intensity explained very little of the variation (adjusted $R^2 = 0.0303$). The proportion of hemlock basal area increased with increasing cutting intensity but hemlock basal area appeared unrelated to cutting intensity (adjusted $R^2 = 0.0127$). After blocking by stand, I found no significant correlation between cutting intensity and the proportion of hemlock trees ($p = 0.722$) or hemlock basal area ($p = 0.282$). In summary, the intensity of partial cutting did not cause significant changes in the composition of hemlock.

Both the proportions of Sitka spruce trees and basal area were not closely related to cutting intensity (Figure 2.4). The proportion of spruce trees increased slightly with increasing cutting intensity but cutting intensity explained very little of the variation in spruce trees (adjusted $R^2 = 0.0506$). The proportion of spruce basal area also increased slightly with increasing cutting intensity but spruce basal area appeared unrelated to cutting intensity (adjusted $R^2 = 0.0134$). After blocking by stand, I found no significant correlation between cutting intensity and the proportion of spruce trees ($p = 0.417$) or spruce basal area ($p = 0.691$). In summary, the intensity of partial cutting did not cause significant changes in the composition of Sitka spruce.

Overall, there was insufficient evidence to reject the null hypothesis that tree species composition is not a function of cutting intensity. The intensity of partial cutting did not lead to significant changes in the composition of either Sitka spruce or western hemlock.

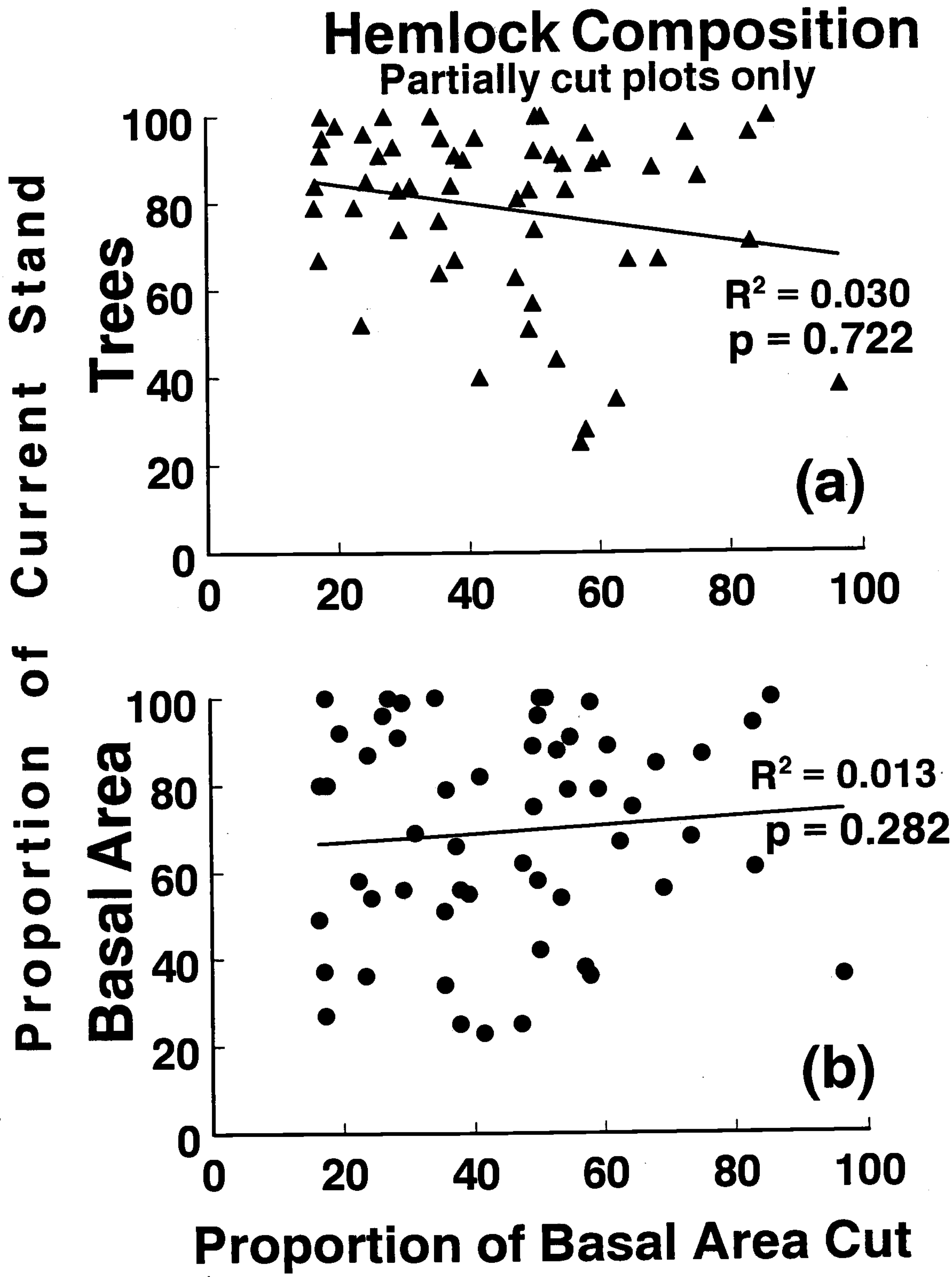

Figure 2.3. The proportion of hemlock tree density (a) and basal area (b) in the current stand, as a function of cutting intensity in the 55 partially cut treatment plots. Tree density and basal area includes data from all trees 2.5 cm d.b.h. and greater.

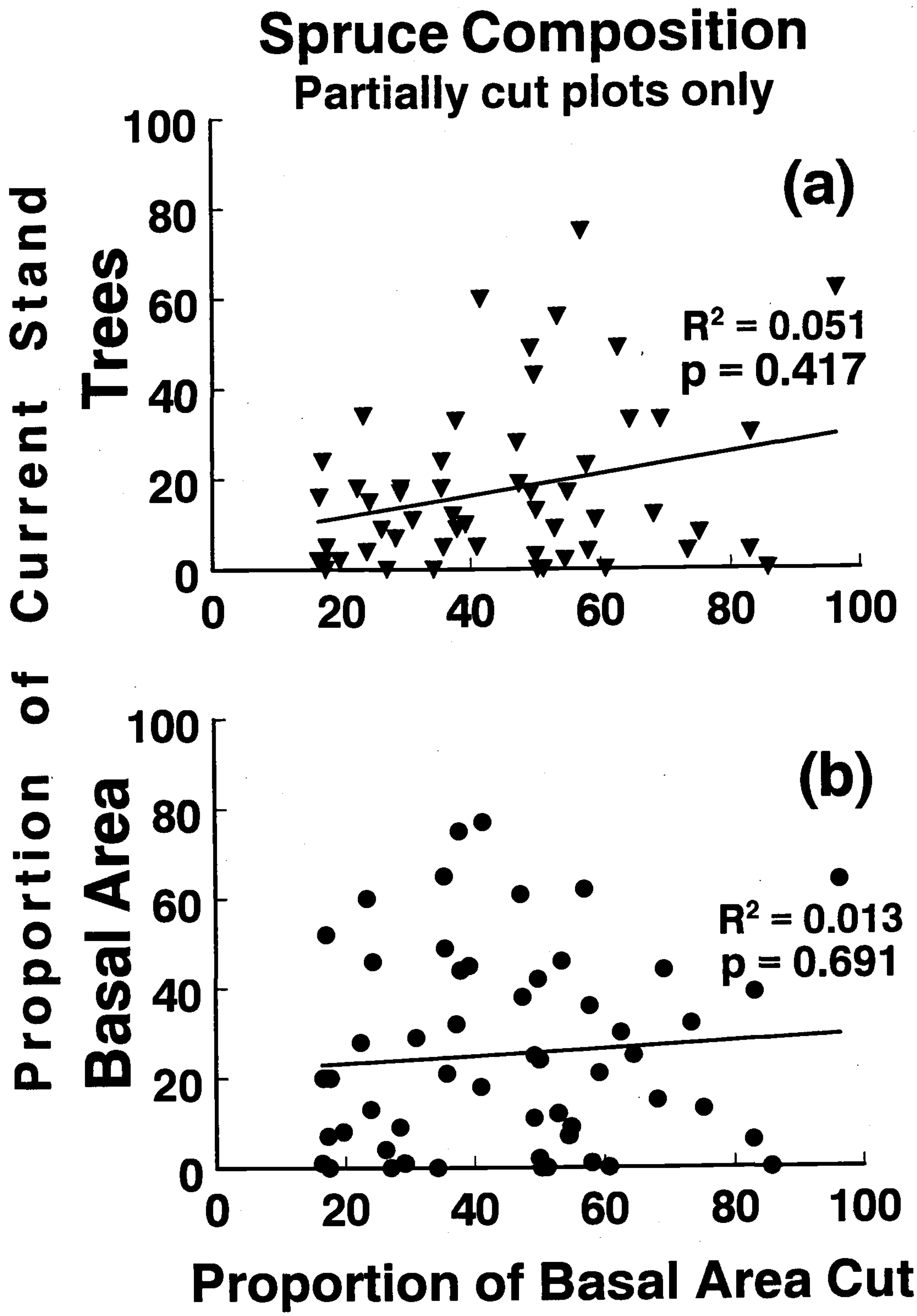

Figure 2.4. The proportion of spruce tree density (a) and basal area (b) in the current stand, as a function of cutting intensity in the 55 partially cut treatment plots.
Tree density and basal area includes data from all trees 2.5 cm d.b.h. and greater.

The species composition of spruce and hemlock was highly variable both among and within different stands, and tree composition was not closely related with different measures of cutting intensity including the proportion of basal area cut, the absolute basal area cut, and the total residual basal area left after cutting. However, I found that the wide variation in current species composition in stands was largely explained by the amount of hemlock and spruce basal area left after cutting. The proportion of hemlock trees was highly positively correlated with the amount of C-2 hemlock basal area (adjusted $R^2 = 0.7005$, $p = 0.0001$, Table 2.4). I found that more than 84 percent of the variation in the proportion of hemlock basal area among and within stands was explained by the amount of C-2 hemlock basal area and total stand C-2 basal area (adjusted $R^2 = 0.8445$, $p = 0.0001$, Table 2.4). The C-2 trees were even more important for predicting current stand spruce composition. The proportion of spruce trees was highly negatively correlated with hemlock C-2 basal area (adjusted $R^2 = 0.7583$, $p = 0.0001$, Table 2.4). My best model for predicting the proportion of spruce basal area was the amount of C-2 spruce basal area and C-2 total stand basal area, and this model explained almost 85 percent of the variation among and within stands (adjusted $R^2 = 0.8453$, $p = 0.0001$, Table 2.4). Overall, most of the variation in hemlock and spruce composition both within and among stands was explained by the amount of C-2 basal area of a particular species left after cutting. In lightly cut stands the larger C-2 trees were the dominant structural component of the stand, and in heavily cut stands small advance regeneration were more important. It appears that the C-2 trees (either large C-2 trees or small advance regeneration) were an important part of the future stand, and explained a large amount of the variation in tree species composition among stands.

Table 2.4. The current stand species composition, tree-age cohorts, and stand growth regressions fitted to the data to predict the proportion of western hemlock and Sitka spruce tree density and basal area for all trees, for only new trees (C-1 cohorts), and C-1 trees net basal area growth in the 55 partially cut plots.

Dependent variable	n	B_0	B_1	X_1	B_2	X_2	R^2	P
All trees								
Western hemlock								
Tree density[1]	55	69.8850	0.7627	HMRESBA			0.7005	0.0001
Basal area[2]	55	90.6425	2.1961	HMRESBA	-1.5493	TRESBA	0.8445	0.0001
Sitka spruce								
Tree density[1]	55	23.5659	-0.6982	HMRESBA			0.7583	0.0001
Basal area[2]	55	9.9892	2.2066	SPRESBA	-0.5630	TRESBA	0.8453	0.0001
C-1 trees only								
Western hemlock								
Tree density[3]	55	0.2197	0.0099	PROPCUT			0.6948	0.0001
Basal area[4]	55	-0.0118	0.0043	PROPCUT			0.6494	0.0001
Sitka Spruce								
Tree density[3]	55	0.2096	-0.0058	TRESBA			0.5553	0.0095
Basal area[4]	55	0.0642	0.0010	PROPCUT	-0.0027	TRESBA	0.4777	0.0887
C-1 basal area growth								
Net BAGR[5]	55	0.1883	0.0040	PROPCUT	-0.0046	TRESBA	0.6437	0.0010

[1] The proportion of trees in the stand.
[2] The proportion of basal area in the stand.
[3] The arcsin square-root transformation of the proportion of trees in the stand.
[4] The arcsin square-root transformation of the proportion of basal area in the stand.
[5] The arcsin square-root transformation of the proportion of net basal area growth.
Note: n is the number of observations; B_0 is the intercept and B_1–B_2 are the slope coefficients of the regression line; R^2 is the adjusted coefficient of determination; P is the probability value using the F-statisitic; HMRESBA is the hemlock residual basal area left after cutting; SPRESBA is the spruce residual basal area left after cutting; TRESBA is the total residual basal area for all trees left after cutting; PROPCUT is the proportion of stand basal area cut.

Changes in stand structure following partial cutting

Tree species compositions in mixed hemlock and spruce stands were generally very resilient to partial cutting. However, I found different patterns of tree density, species composition and conifer regeneration in "hemlock-dominated stands" than in "spruce/hemlock stands," and these stand types were described separately. Hemlock-dominated stands had much higher proportions of hemlock and higher tree densities and regeneration than spruce/hemlock stands. Also, the amount of C-2 hemlock basal area was closely associated with the proportion of hemlock and spruce trees in the current stand (Table 2.4). The total tree density (Table 2.2) and density of hemlock trees (Table 2.3) considerably increased in stands with hemlock trees comprising at least 85% of the established trees. These stands were designated as hemlock-dominated stands. Conversely, the total tree density and density of hemlock trees was substantially less in stands with spruce comprising at least 12% of the trees. These stands were designated as spruce/hemlock stands.

Throughout this study, most trees cut were large diameter spruce trees and there were more C-2 hemlock trees left in almost all plots (Table 2.3). For example, in the heaviest cutting plot in a spruce/hemlock stand at Big Bear Creek (Figure 2.5), many of the larger-diameter spruce trees were cut. However, a number of C-2 spruce trees in the 40-80 cm size class were left after cutting, and these smaller-diameter spruce have grown and replaced the larger cut trees. Overall, the spruce-hemlock stand at Big Bear Creek showed changes in diameter class distributions following partial cutting, but the species compositions remained relatively stable. A critical factor to maintaining spruce in these partially cut stands may be leaving smaller diameter C-2 spruce trees. This was generally

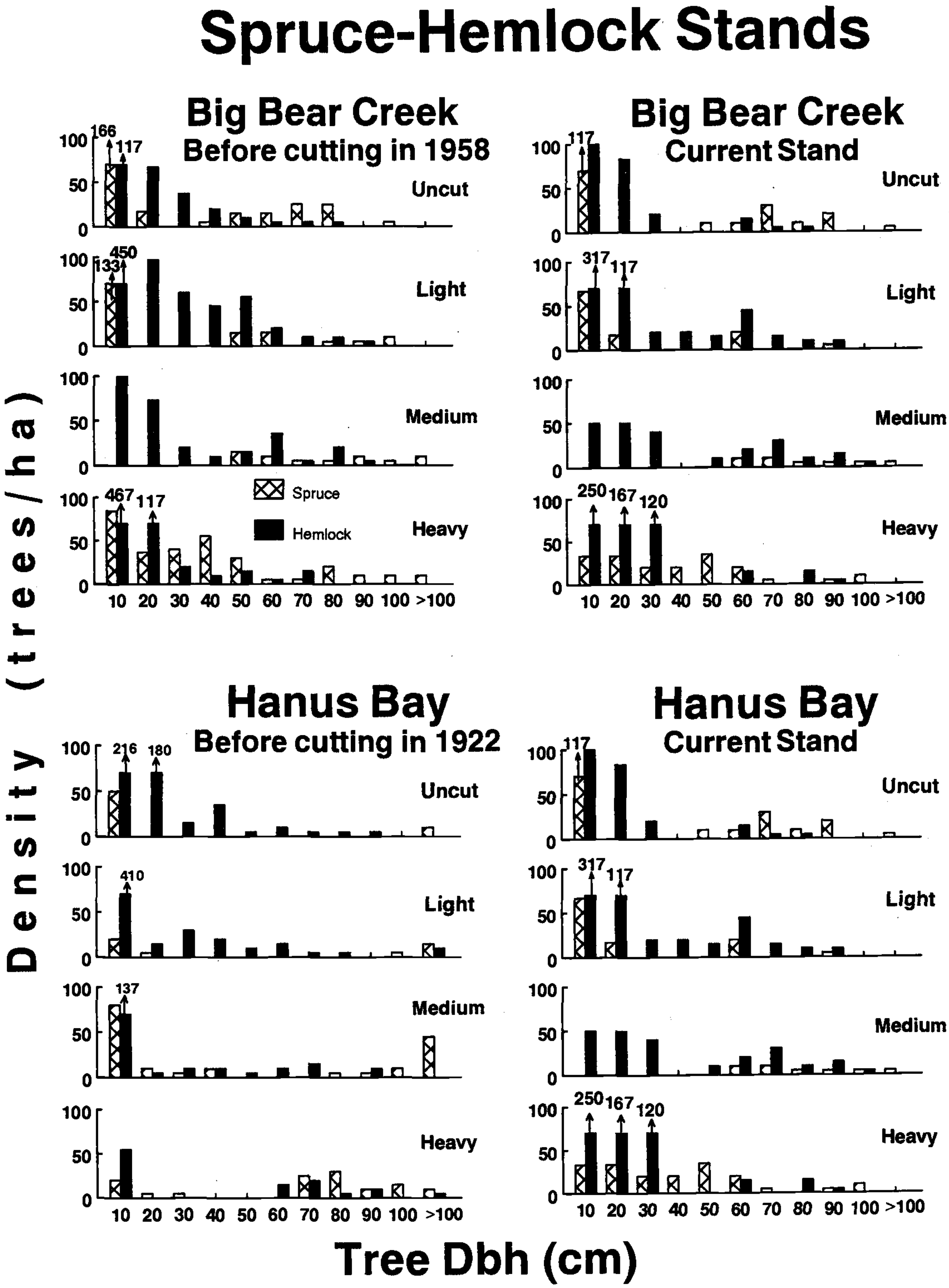

Figure 2.5. The former and current stand diameter distributions for a recently-cut (Big Bear Creek) spruce/hemlock stand, and for an older-cut (Hanus Bay) spruce/hemlock stand.

not a problem in spruce/hemlock stands for any of the cut plots, and the smaller-diameter C-2 spruce trees were able to replace the overstory spruce removed during partial cutting.

The older-cut spruce/hemlock stand at Hanus Bay (Figure 2.5) also has maintained spruce in all cut plots. Cutting was very heavy in two plots (medium-83%, and heavy-96% basal area cut) and the current stand diameter distributions are very different than before cutting (Figure 2.5). The small-diameter C-2 spruce trees grew rapidly and replaced the larger previously cut spruce. In the light cutting plot, some smaller diameter C-2 spruce trees grew into larger diameter size classes, and also some new C-1 spruce trees became established. Prior to this study, the response of C-2 trees to partial cutting was largely unknown in this region, and it was unclear whether smaller C-2 spruce trees would release after cutting overstory trees. However, following natural disturbances such as tree windthrow, Ott (1997) reported that Sitka spruce seedlings in the presence of canopy gaps rapidly grew in height, and in another reconstruction study Deal et al. (1991) reported the establishment and rapid growth of some spruce trees after partial stand blowdown. Overall, these spruce/hemlock stands have maintained the former stand's spruce component over a wide range of cutting intensities, and tree species composition appears very resilient to partial cutting.

The hemlock-dominated stands show different species successional pathways. The recently-cut hemlock-dominated stand at Thomas Bay (Figure 2.6) had very little spruce in any of the plots before cutting, but some spruce has been maintained in all of the cutting treatments. In the light cutting plot a few of the larger-diameter C-2 spruce were left. In the medium cutting plot some smaller-diameter C-2 spruce trees were left, and also some new C-1 spruce trees were established. This stand was purposely managed to maintain

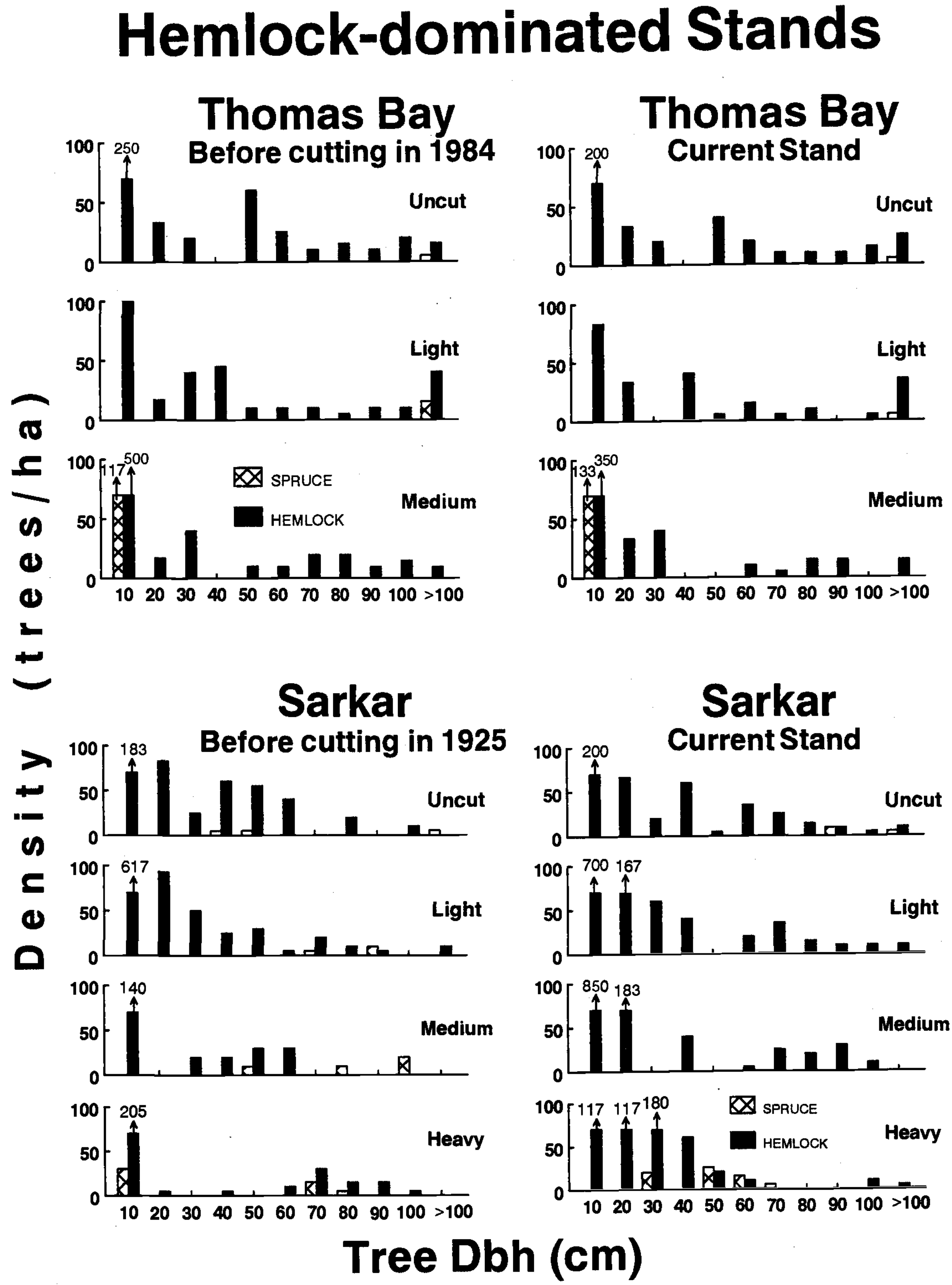

Figure 2.6. The former and current stand diameter distributions for a recently-cut (Thomas Bay) hemlock-dominated stand, and for an older-cut (Sarkar) hemlock-dominated stand.

spruce, and although spruce is only a minor part of the current stand, C-1 spruce regeneration was established in all the cut plots. The older-cut hemlock-dominated stand at Sarkar (Figure 2.6) is an example of a hemlock-dominated stand that has been converted into a nearly pure hemlock stand. In the light and medium cutting plots, all of the larger-diameter spruce trees were cut or died soon after cutting, and no new C-1 spruce were established (Table 2.3, Figure 2.6). In the heavy cutting plot, some smaller-diameter C-2 spruce trees were left and these trees have grown into the 30-70 cm diameter classes. Also, the removal of all overstory spruce trees and the lack of a seed source may explain some of the species changes in this stand as there has been no C-1 spruce regeneration in any of the cut plots. Partial cutting in hemlock-dominated stands may be a challenge if the management goal is to maintain spruce in the stand. To maintain spruce in these stands it is important to leave smaller-diameter understory spruce for release into the overstory, and probably some overstory spruce as a seed source for spruce regeneration.

The establishment of C-1 spruce trees was highly variable both within and among stands, and some of the unexplained variation in species composition was probably related to differences in new regeneration among stands. My best model for predicting C-1 trees was much less reliable than for all trees, particularly for Sitka spruce (Table 2.4). Some stands such as Margarita Bay and Hanus Bay had large increases in both hemlock and spruce C-1 trees following partial cutting (Table 2.3). Other stands such as Big Bear Creek and Finger Creek had C-2 trees fill in the growing space with the exclusion of C-1 trees (Table 2.3). The high variation in C-1 spruce trees may be explained by differences among stands in seed availability, seed predators such as red squirrels, or differences in regeneration due to site factors such as suitable rooting substrate, logging disturbance, competition for light or other resources.

In conclusion, tree species composition generally did not change following partial cutting. The composition of hemlock and spruce was also unrelated to cutting intensity. Species composition in these stands was very resilient to partial cutting. Hemlock-dominated stands remained hemlock stands and spruce/hemlock stands remained spruce/hemlock stands. It appears that the C-2 stand component (either large C-2 trees or small advance regeneration) is an important part of the future stand, and explains a large amount of the variation in tree species composition among stands. The only situation where spruce was completely replaced by hemlock following partial cutting, was following light-to-moderate cutting in hemlock-dominated stands, where all of the overstory spruce was cut and no C-2 spruce were left after cutting. However, in all of the spruce/hemlock stands, and in most of the hemlock-dominated stands, there were generally sufficient numbers of spruce to maintain spruce in the future stand. Overall, it appears that the more valuable timber species, Sitka spruce, can maintain it's abundance within a wide range of partial cutting intensity.

Effects of partial cutting on tree-age cohorts

The proportion of C-1 trees was greater in the partially cut plots than in the uncut plots. This was apparent from analysis of the proportion of trees in different plot cutting intensity classes (Figure 2.7a). The average proportion of C-1 trees in uncut plots was 12.4 (SE = 4.1), and in cut plots was 35.0 (SE = 3.7). After blocking by stand, I found a highly significant difference in C-1 tree density between the uncut and cut plots (p=0.0001).

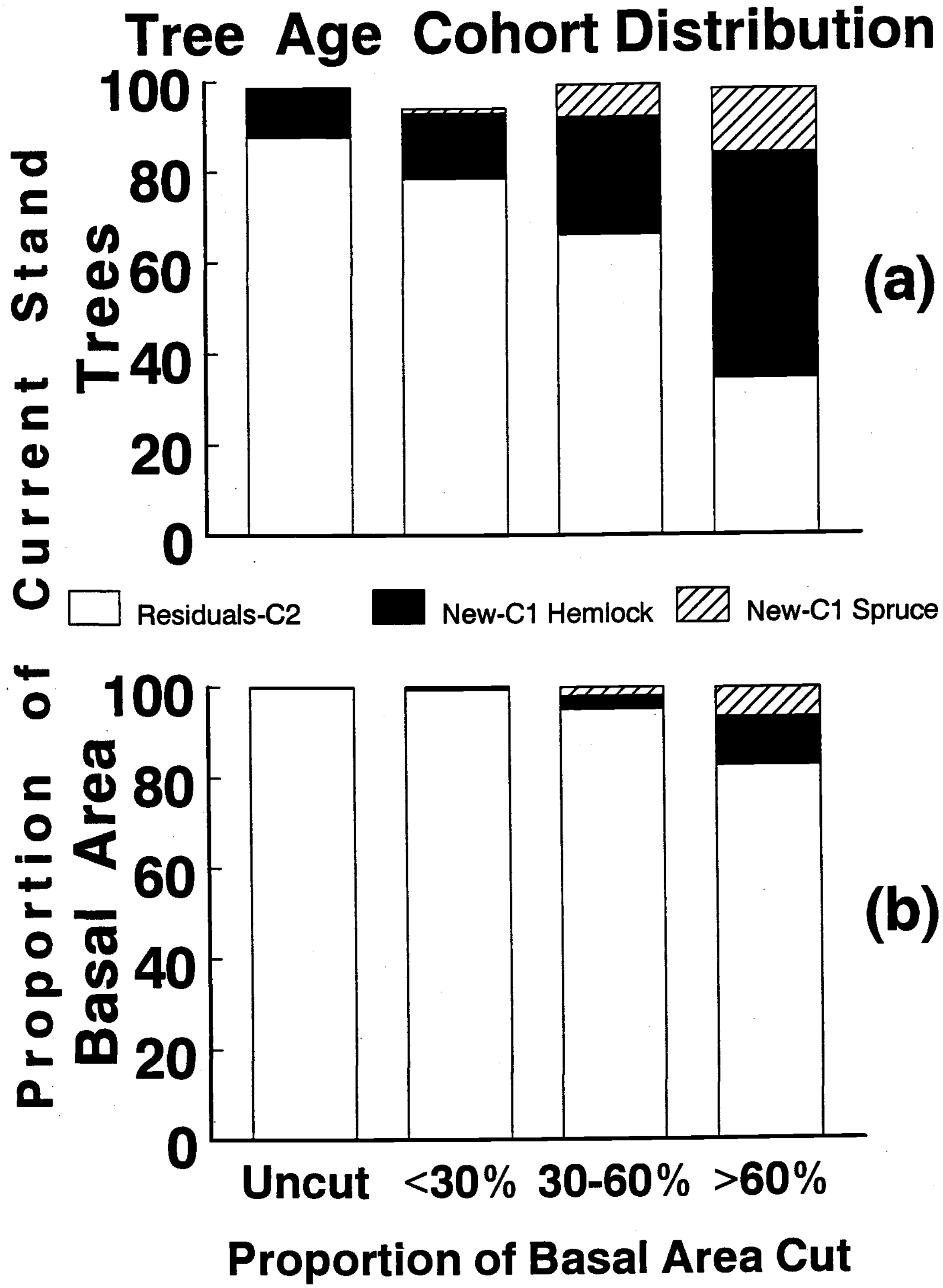

Figure 2.7. The proportion of tree density (a) and basal area (b) in the current stand by plot cutting intensity classes. The three tree-age cohorts shown include all the residual-tree cohorts (C-2), the hemlock new-tree cohorts (C-1) and the spruce new-tree cohorts (C-1).

The proportion of C-1 basal area was also greater in the partially cut plots than in uncut plots. However, C-2 basal area dominated in all plot cutting intensity classes, with over 99 percent of stand basal area in C-2 trees for plots with less than 30 percent of the basal area cut (Figure 2.7b). There was a statistically significant difference in the proportion of tree-age cohort basal area among uncut and cut plots. The average proportion of C-1 basal area in the uncut plots was only 0.3 (SE = 0.1), and in the cut plots it was 6.3 (SE = 1.4). After blocking by stand, I found a highly significant difference in C-1 basal area between the uncut and cut plots (p=0.0002).

In summary, there was convincing evidence to reject the null hypothesis that the proportion of C-1 trees was the same in uncut and partially cut plots. Partial cutting led to a larger component of C-1 trees. The fact that there was an increase in the proportion of C-1 trees following partial cutting was no surprise. I had expected an increase in C-1 tree density in these stands. I had also expected a higher proportion of C-1 basal area following partial cutting. Although there was a statistically significant difference among cut and uncut plots, the proportion of C-2 basal area was high in all the plots, and that made differences in C-1 basal area among cut and uncut plots appear less conspicuous.

The proportion of C-1 trees generally increased with increasing cutting intensity. However, there were several cut plots with no C-1 trees, particularly in stands that were lightly cut (Figure 2.8). After blocking by stand, I found a statistically significant increase in the proportion of C-1 trees with increasing cutting intensity (adjusted $R^2 = 0.675$ for transformed tree density, $p < 0.001$, Figure 2.8a).

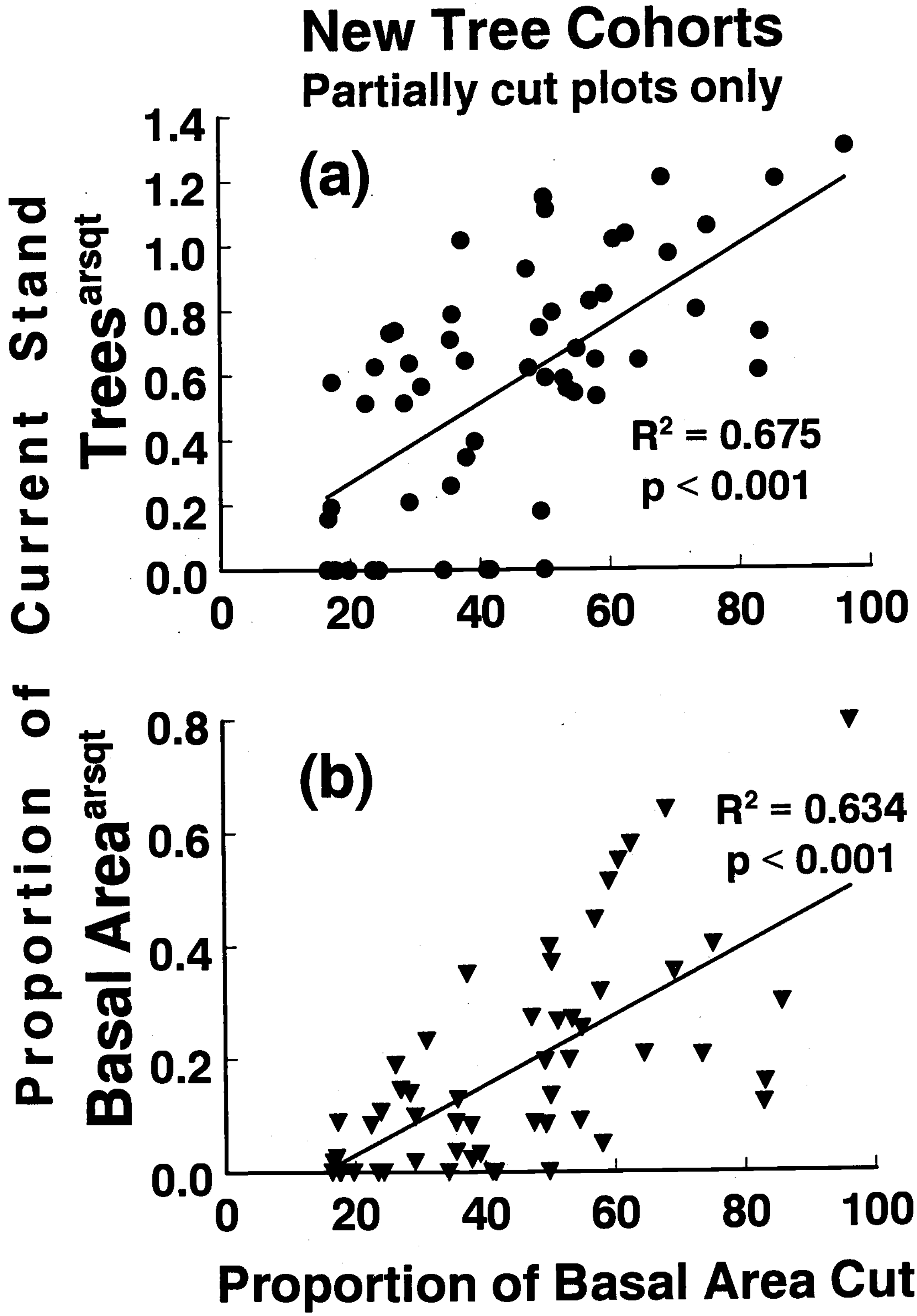

Figure 2.8. The proportion of new-tree cohorts (C-1) in the current stand as a function of cutting intensity for the 55 partially cut plots. The proportion of tree density (a) and basal area (b) on the Y-axis is the arc-sin square root transformation.

The proportion of C-1 basal area also increased with increasing cutting intensity. However, the C-1 basal area was a minor component in all the cut plots, and the C-2 basal area was the dominant part of the stand (Figure 2.7b). Even in the heaviest cutting plot (96 percent basal area removal) about half of the current basal area was from C-2 trees. I found a statistically significant increase in the proportion of C-1 basal area with increasing cutting intensity (adjusted $R^2 = 0.634$ for transformed basal area, $p < 0.001$, Figure 2.8b). Overall, there was compelling evidence to reject the null hypothesis that the proportion of C-1 trees was not a function of cutting intensity. The proportion of C-1 tree density and basal area increased with increasing intensity of cutting.

Overall, the proportion of C-1 tree density and basal area was positively correlated with the intensity of cutting but the response of C-1 hemlock trees was much more predictable than for C-1 spruce trees. My best models for predicting the proportion of C-1 hemlock tree density and basal area was based only on the proportion of basal area cut (hemlock trees adjusted $R^2 = 0.6948$ for transformed tree density, $p < 0.0001$; hemlock basal area adjusted $R^2 = 0.6494$ for transformed basal area, $p < 0.0001$, Table 2.4). However, the C-1 spruce tree density and basal area was also negatively correlated with the amount of total stand residual basal area. My best model for predicting the proportion of C-1 spruce tree density was based on total stand residual basal area (spruce trees adjusted $R^2 = 0.5553$ for transformed tree density, $p = 0.0095$, Table 2.4). The best model for predicting the proportion of spruce basal area included both the proportion of basal area cut and total stand residual basal area (spruce basal area adjusted $R^2 = 0.4777$, for transformed basal area, $p = 0.0887$, Table 2.4). These models used to predict C-1 spruce tree density and basal area were much less reliable than for hemlock, with lower predictive power largely explained by the absence of new spruce regeneration in some stands.

Partial cutting increased the proportion of C-1 trees. Partial cutting also increased the proportion of C-1 basal area, but most of the basal area was in the C-2 trees. The proportion of C-1 tree density and basal area also increased with cutting intensity. However, the C-1 basal area was a minor component of most partially cut stands, and accounted for only 0 to 51 percent of the total stand basal area for all cut plots. The C-2 basal area was a significant and surprisingly dominant component of even heavily cut stands. However, the establishment of the C-1 cohorts is also important, and although the C-1 cohorts are not a significant component of the current stand, they could potentially have long-term consequences in the future stand. These smaller C-1 trees may eventually become a significant component of the future stand given enough time, or if another natural disturbance or secondary cutting were to occur in these stands, these cohorts could respond and grow up into an overstory canopy layer.

Effects of partial cutting on stand growth

There were no significant differences in tree species composition but there were significant differences in tree-age cohorts between cut and uncut plots and as a function of cutting intensity. The C-2 trees were an important structural component and contain most of the current stand basal area. However, it was unclear how much of the current stand basal area was from the growth of C-1 versus C-2 trees.

The net basal area growth was greater in the partially cut plots than in uncut plots. This was apparent from analysis of the net basal area growth for all plots (Figure 2.9a). The growth response was variable among the different stands and plot cutting intensities. Some of the uncut and lightly cut plots had negative net growth due to tree mortality, and

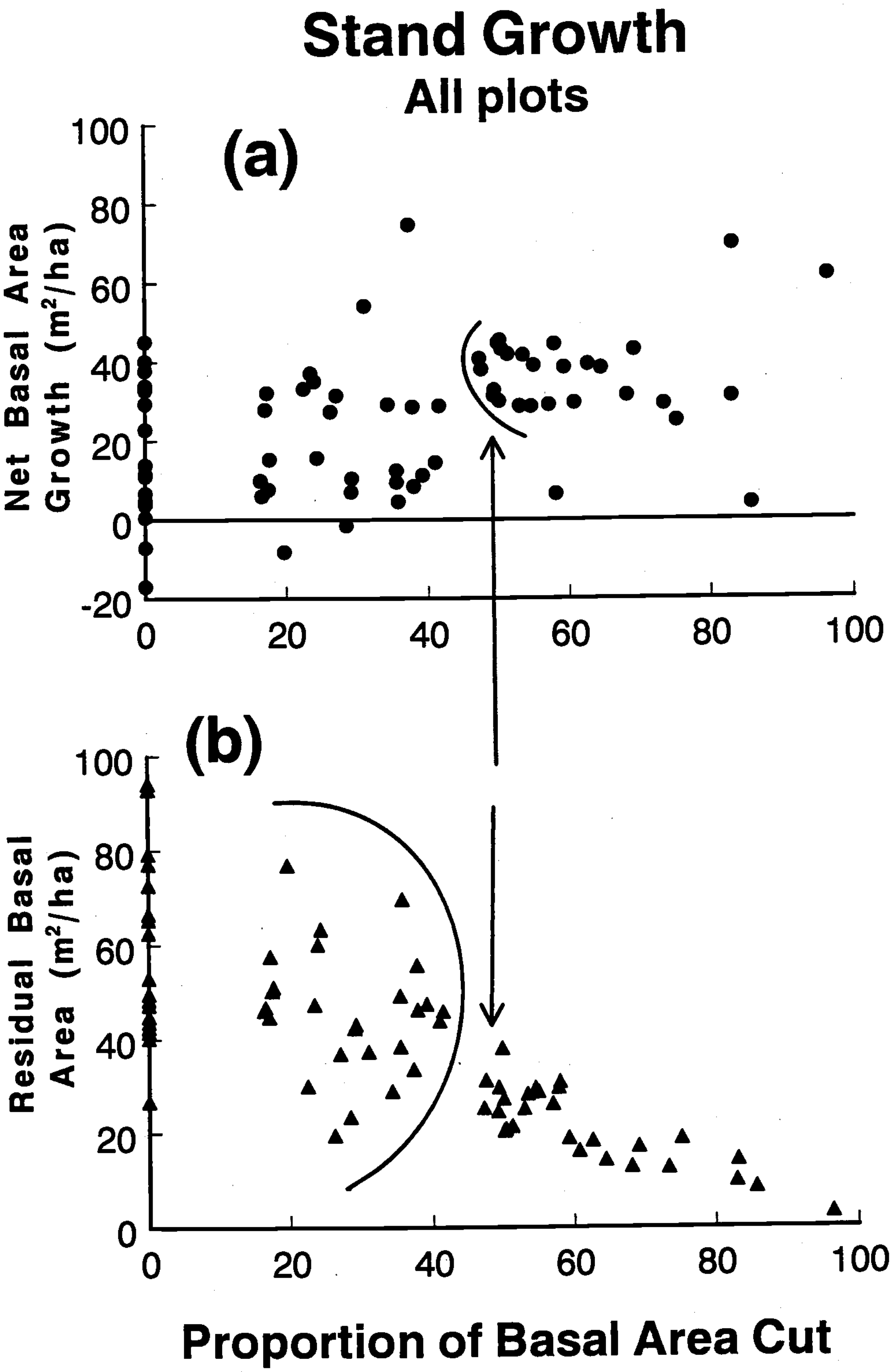

Figure 2.9. The stand net basal area growth since time of cutting by the proportion of basal area cut (a), and the relationship between residual basal area and the proportion of basal area cut (b), for the 73 partially cut and uncut plots.

overall, the net basal area growth was highly variable (Figure 2.9a). Much of this variation is from growth differences among stands, and differences in time since cutting among stands. However, after accounting for differences in basal area growth among stands through blocking by stand, I found a significant difference in net basal area growth between uncut and partially cut plots ($p = 0.0004$).

The stand net basal area growth generally increased with increasing cutting intensity. However, the growth response was irregular and some of the lightest cutting intensity plots had negative net growth. The differences in net basal area growth among stands were highly significant ($p < 0.001$), and the differences in time since cutting among stands explained part of the variation in stand growth ($p = 0.0256$ when year since cutting included). However, after blocking by stand, I found a statistically significant increase in net basal area growth with increasing cutting intensity (adjusted $R^2 = 0.769$, $p < 0.001$). Overall, there was strong evidence to reject the null hypothesis that net basal area growth was not a function of cutting intensity, and stand basal area growth generally increased with increasing cutting intensity.

There also appeared to be a minimum cutting intensity level after which net basal area growth consistently increased. Several plots showed a noticeable increase in growth when at least 50% of the basal area was cut (cluster of plots with arrow in Figure 2.9a). The net basal area growth for plots below this "50% of the basal area cut" level was highly variable and similar to the range in growth for the uncut plots. Comparing the proportion of basal area cut with the residual basal area left after cutting (Figure 2.9b) also showed a marked change in plot basal area at this "50% of the basal area cut" level. Plots cut below this level had a wide range of residual basal areas (wide semi-circle in Figure 2.9b), and these residual basal areas were only slightly less than the range in basal areas for the uncut plots. However, cutting above this "50% of the basal area cut" level showed a sharp linear decrease in residual basal area (arrow in Figure 2.9b). New tree regeneration also consistently increased above this "50% of the basal area cut" level (Figure 2.8a). This cutting intensity level may represent an important threshold, and cutting above this level appears to lead to increasing stand growth and the establishment of new regeneration. There may also be minimum residual basal area threshold (e.g. 20 m^2/ha), and leaving less basal area may result in a significant increase in stand growth and tree regeneration. This residual basal area threshold needs to be further investigated.

Effects of partial cutting on growth of different tree-age cohorts

The proportion of stand basal area growth in different tree-age cohorts was important to determine if the different tree-age cohort structures in the current stand were a legacy of the original stand, or were more related to the growth of the stand since cutting. Also, quantifying the growth of both C-1 and C-2 trees provided information for predicting where future stand growth might occur.

The proportion of stand basal area growth was significantly less for C-1 than for C-2 trees (Figure 2.10). The C-2 tree growth was much greater than the C-1 tree growth, accounting for over 98% of the basal area growth for stands with less than 30 percent of the basal area cut, and over 93% of the growth for stands with 30-60 percent of the basal area cut (Figure 2.10b). The proportion of stand basal area growth in the C-2 trees on the heaviest cutting intensity plots was particularly impressive. In plots where over 60 percent of the original stand basal areas were cut, almost 80% of the stand basal area growth

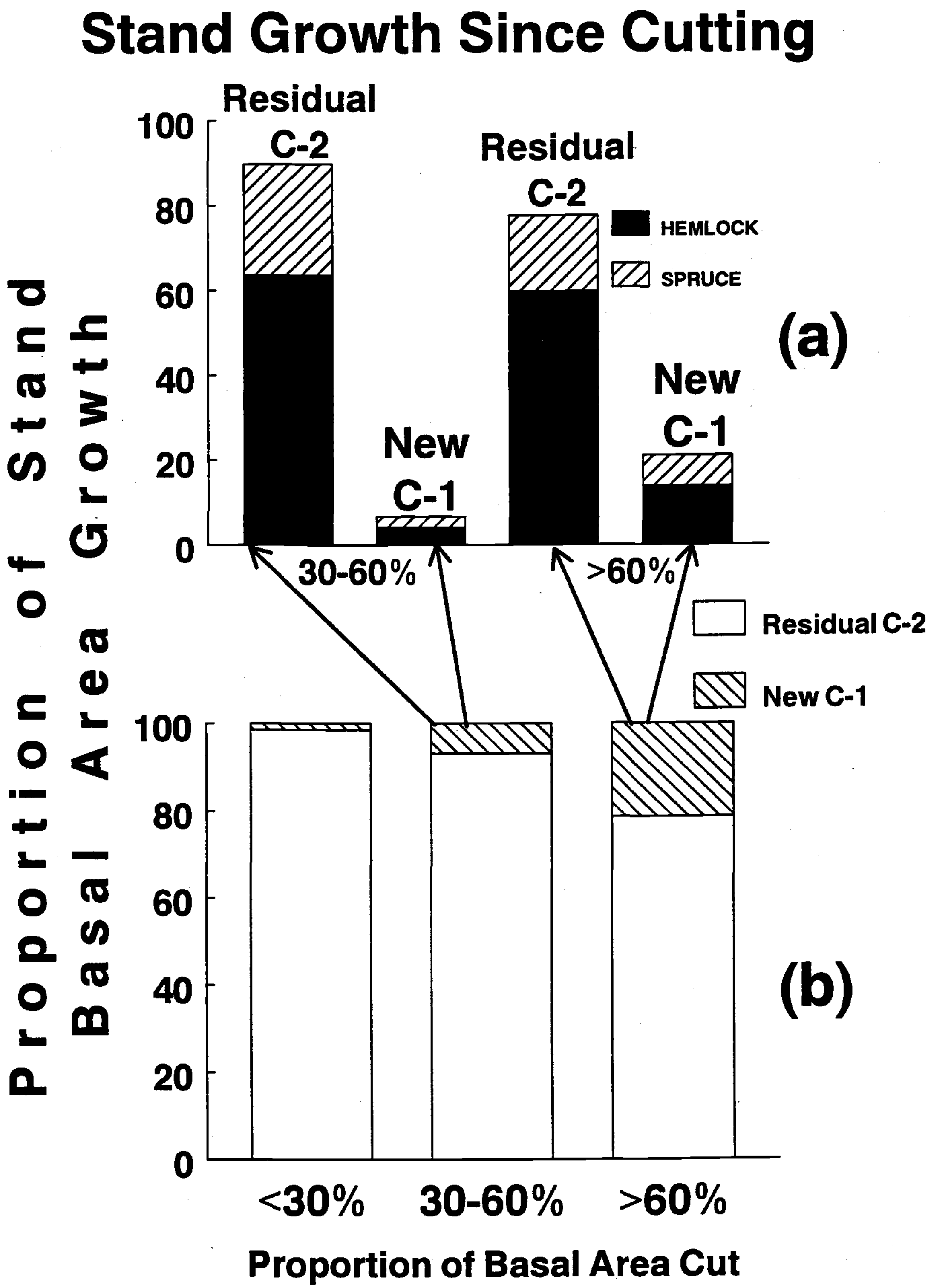

Figure 2.10. The proportion of stand basal area growth by the proportion of basal area cut for the 55 partially cut plots. The distribution of C-1 and C-2 trees is shown by three cutting intensity classes (b), and the tree species and tree-age cohort distributions are shown for the two heaviest cutting intensity classes (a).

occurred in C-2 trees (Figure 2.10b). The average proportion of stand basal area growth in C-2 trees for the fifty-five partially cut plots was 91.8 (SE = 1.6), and after blocking by stands, I found a statistically significant difference ($p < 0.001$), in growth among C-1 and C-2 trees.

The proportion of C-1 basal area growth increased with increasing cutting intensity (Figure 2.11). However, the C-1 basal area growth was much lower than the C-2 basal area growth in almost all cut plots (C-1 proportion of net basal area growth ranged from 0 to 54%), and stand basal area growth was dominated by C-2 trees (Figure 2.10b). After blocking by stands, I found a statistically significant increase in the proportion of C-1 net basal area growth with increasing cutting intensity (adjusted $R^2 = 0.6271$ for transformed basal area, $p = 0.001$, Figure 2.11a). The amount of residual basal area was also negatively correlated with C-1 tree growth. My best model for predicting the proportion of C-1 net basal area growth was the proportion of basal area cut and the total stand C-2 basal area (adjusted $R^2 = 0.6437$ for transformed net basal area growth, $p = 0.0010$, Table 2.4).

Thus, partial cutting increased the proportion of C-1 net basal area growth and there was convincing evidence to reject the null hypothesis that the proportion of stand basal area growth was the same for C-1 and C-2 trees. However, the current stand C-1 basal area and the C-1 net basal area growth were a minor component of most partially cut stands. The dominant component of C-2 basal area in partially cut stands appears to be a combination of legacy C-2 trees left after cutting, and a surprisingly strong growth response of C-2 trees following cutting.

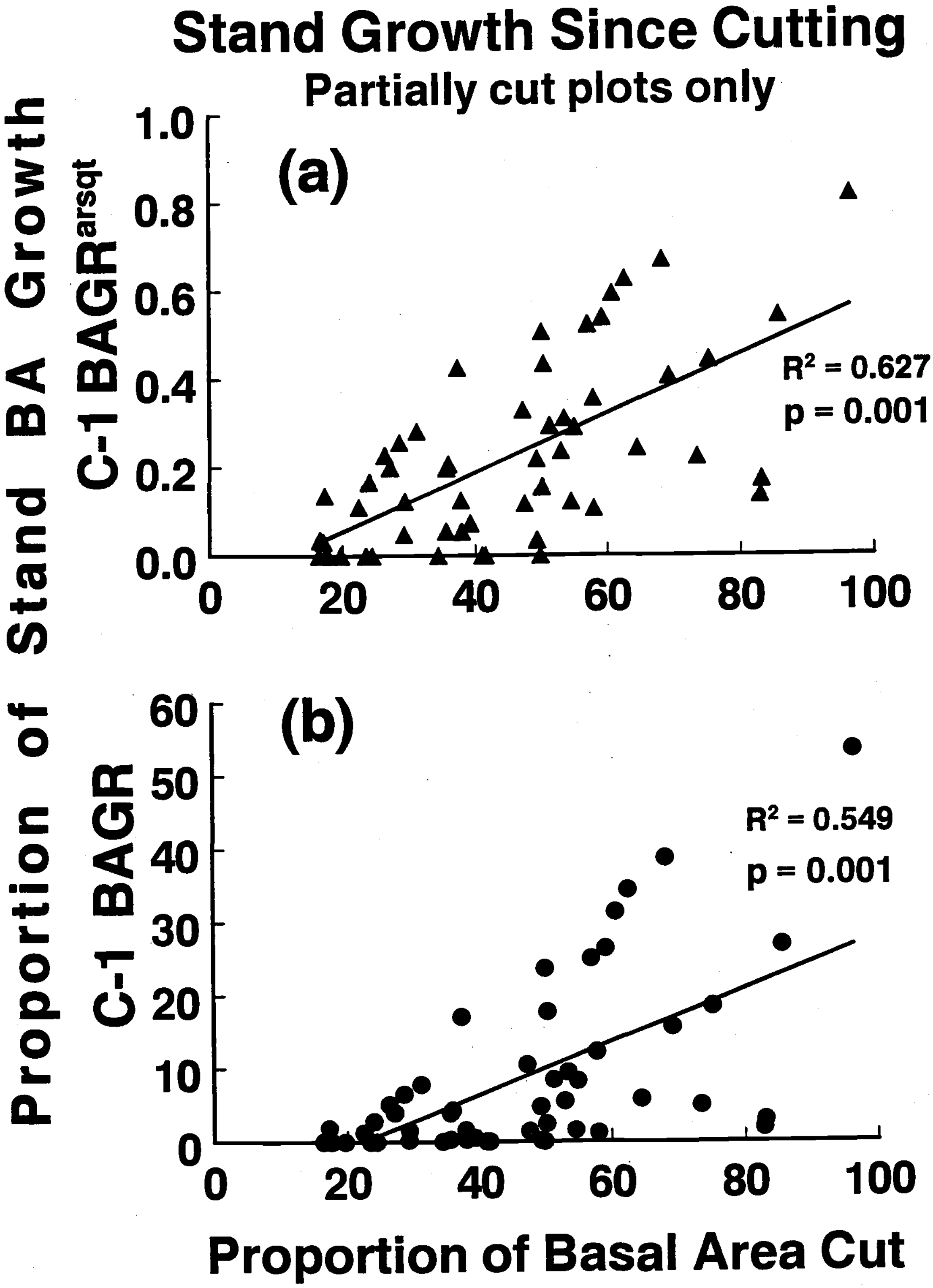

Figure 2.11. The proportion of stand basal area growth for new-tree cohorts since cutting date by the proportion of basal area cut. The C-1 BAGR^{arsqrt} (a) is the arc-sin square root transformation of the proportion of stand basal area growth, and C-1 BAGR (b) is the untransformed proportion of stand basal area growth.

Effects of partial cutting on growth of western hemlock and Sitka spruce

The tree diameter growth of Sitka spruce and western hemlock was generally similar following partial cutting. Spruce diameter growth was slightly greater than hemlock growth for all tree diameter classes, but the growth differences between hemlock and spruce were not statistically significant for any of the tree diameter classes (Figure 2.12). The C-1 trees had the least growth of any tree diameter class during the sixty year growth period, averaging 84.3 mm (SE = 15.5) for hemlock and 149.4 mm (SE = 32.1) for spruce, with a non-significant difference among hemlock and spruce ($p = 0.091$). Overall, the C-2 tree diameter growth rates were generally consistent for both hemlock and spruce in all tree diameter classes averaging about 200 to 300 mm during the growth period (Figure 2.12).

The release of residual western hemlock trees after overstory removal has been well documented (Meyer 1937, Williamson and Ruth 1976, Oliver 1976, Wiley 1978, Hoyer 1980, Jaeck et al. 1984, Deal et al. 1991, Ott 1997). Some researchers have reported poor height growth of residual hemlock trees (Williamson and Ruth 1976, Jaeck et al. 1984) and the advance regeneration tended to be crooked and of poor quality (Jaeck et al. 1984). Other authors have reported rapid height growth of advance regeneration hemlocks and that shorter trees responded sooner and had greater height growth than taller trees (Oliver 1976, Hoyer 1980). Little work has been documented on the ability of advance regeneration Sitka spruce to respond to release. Ott (1997) showed that residual Sitka spruce seedlings responded and grew in canopy gaps created from natural disturbances but growth rates were not reported. Results from the release of advance regeneration of more shade tolerant species like Douglas-fir and Ponderosa pine (Helms and Standiford 1985,Tesch and Korpela 1993, Korpela et al. 1992, Oliver and Dolph 1992)

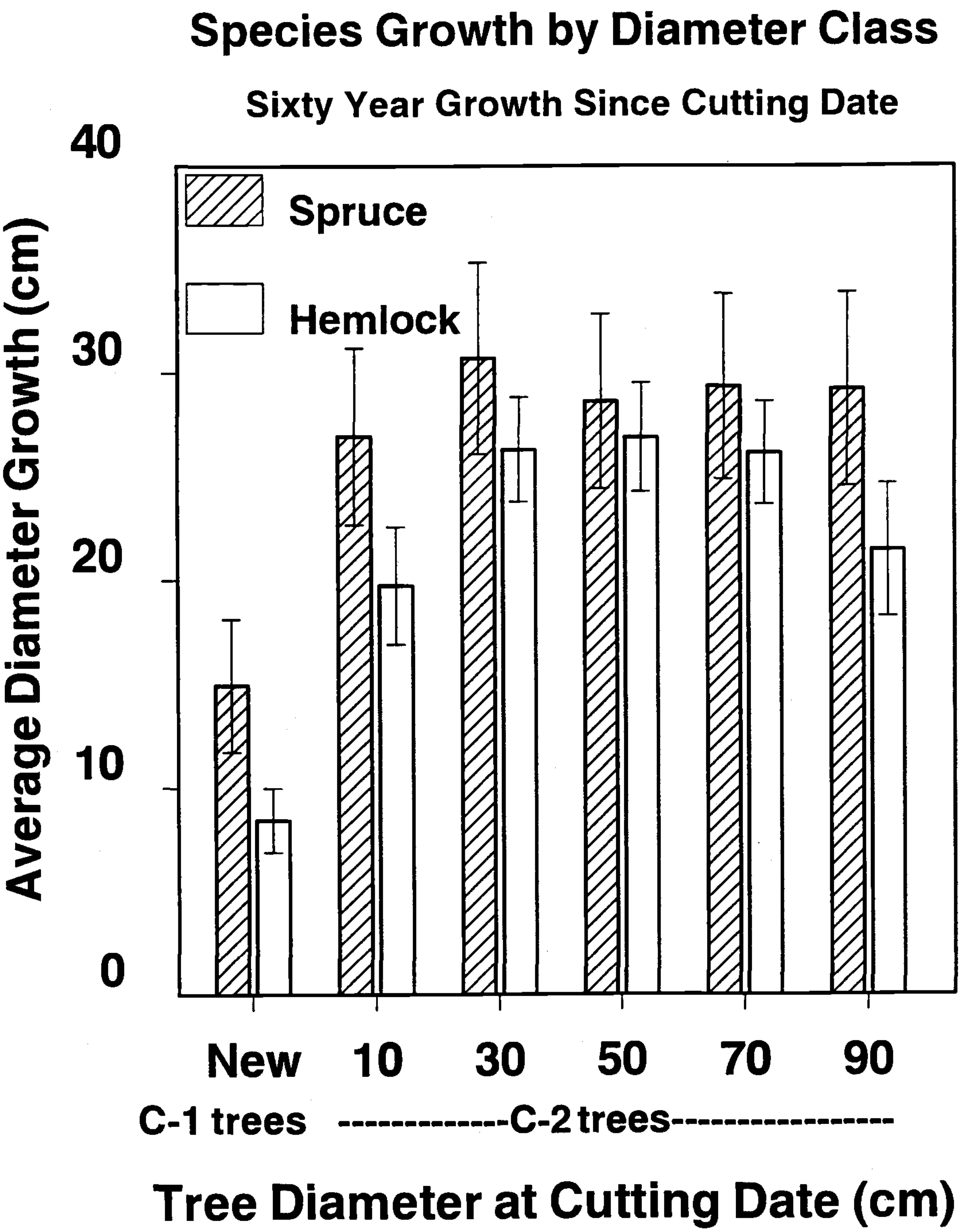

Figure 2.12. The average tree diameter growth of Sitka spruce and western hemlock trees in the partially cut plots by tree diameter classes. The tree diameters at cutting date are the midpoints of trees by 20-cm-diameter classes for new tree cohorts (C-1), and residual tree cohorts (C-2). Vertical lines represent standard error.

show that these species can respond in height growth and become dominant components of future stands. Height growth of spruce and hemlock was not reconstructed, but tree diameter growth in this study showed that both spruce and hemlock trees respond to release following partial cutting.

The proportion of stand basal area growth was also consistent for hemlock and spruce. In the medium and heavy cutting treatments, for both C-1 and C-2 trees, about 60-75% of stand basal area growth was hemlock, and the remainder was spruce and other species (Figure 2.10a). Overall, tree species composition was not an important predictor of stand growth or current stand structure, and species proportions were consistent over a wide range of cutting intensity.

Effects of partial cutting on growth of residual trees by tree-size class

There were no significant basal area growth differences between hemlock and spruce, and thus, these tree species were combined to analyze growth response by tree-size class. Analysis of tree diameter growth for the uncut and partially cut plots showed that the best diameter growth was in the small- to medium-sized C-2 trees (Figure 2.13). The smallest growth occurred in the C-1 trees with an average diameter growth for trees in the cut plots of only 12.9 cm for the 60-year-growth period (Figure 2.14). The largest growth was in C-2 trees that were in between 10 and 70 cm in size at cutting date with an average diameter growth of between 23 and 27 cm for trees in the cut plots during the 60-year-growth period (Figures 2.13 and Figure 2.14). The larger-diameter trees contributed much more to basal area growth than the smaller-diameter trees; however, there were many more

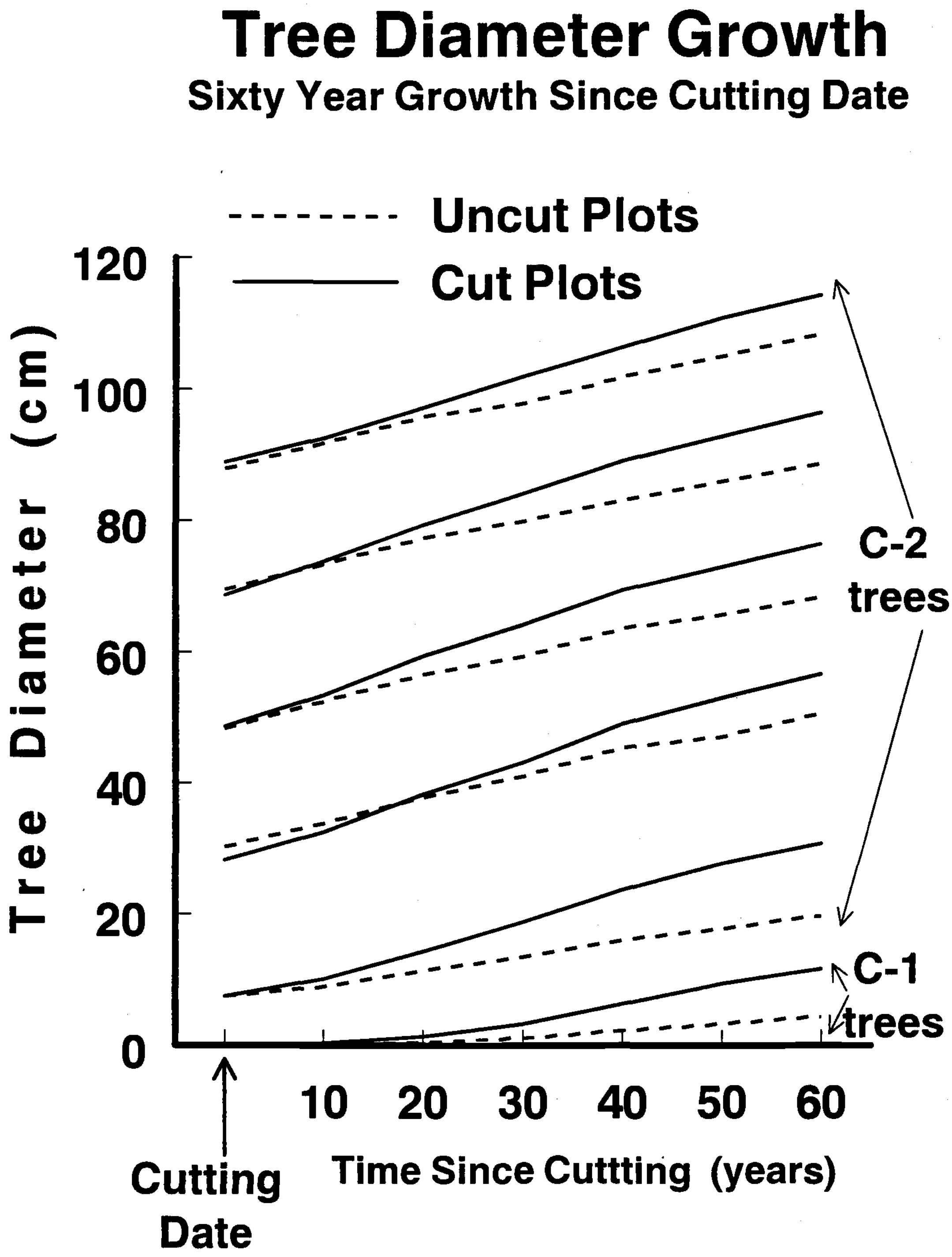

Figure 2.13. The average diameter growth by tree diameter classes for 60 years since cutting date, for both uncut and partially cut plots. The tree diameters at cutting date are the midpoints of trees by 20-cm-diameter classes for new tree cohorts (C-1), and residual tree cohorts (C-2).

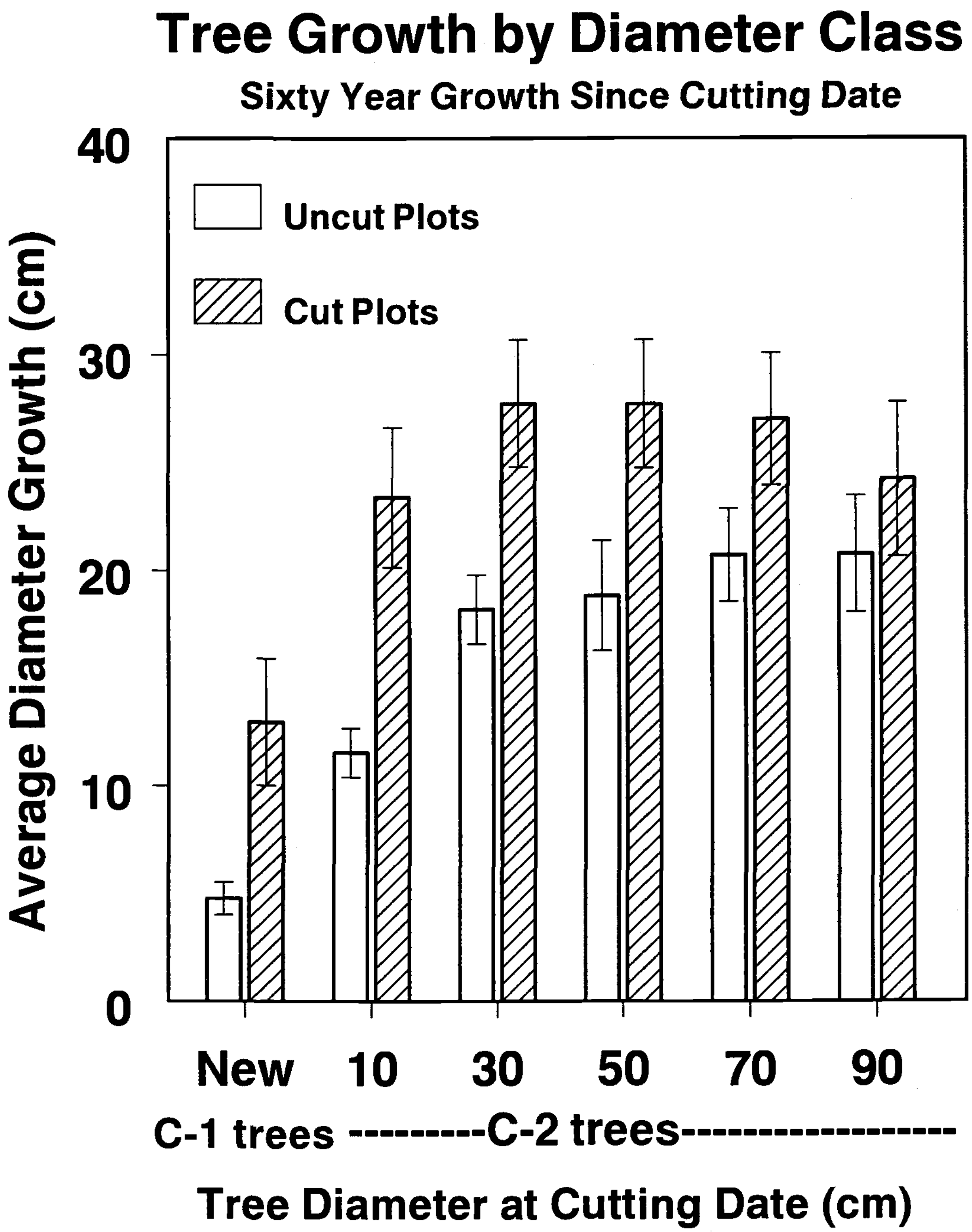

Figure 2.14. The average diameter growth of trees in uncut and partially cut plots by tree diameter classes. The tree diameters at cutting date are the midpoints of trees by 20-cm-diameter classes for new tree cohorts (C-1), and residual tree cohorts (C-2). Vertical lines represent standard error.

small-sized trees than larger-sized trees in the stands. Overall, about half of the stand basal area growth in the partially cut plots was from small-diameter trees that were less than 30 cm in diameter at cutting date.

The tree diameter growth was also consistently higher in the cut plots than in the uncut plots for all tree diameters (Figures 2.13 and 2.14). The average diameter growth for C-1 trees was 4.8 cm (SE = 0.7) in the uncut plots compared with 12.9 cm (SE = 0.7) in the cut plots, with a statistically significant difference among treatments ($p = 0.022$). The average diameter growth for the C-2 trees 10 cm in size at cutting date was 11.5 cm (SE = 1.1) in the uncut plots compared with 23.4 cm (SE = 3.2) in the cut plots, with a statistically significant difference among treatments ($p = 0.005$). The average diameter growth for C-2 trees in the 30- and 50-cm size classes also was significantly higher in the cut plots than in the uncut plots. The growth of C-2 trees in the 70- and 90-cm size classes did not differ significantly between the cut and uncut plots ($p = 0.118$, and $p = 0.494$, respectively).

Thus, partial cutting increased the growth of small-to-medium-sized C-2 trees and there is strong evidence that tree diameter growth is not the same for all tree-size classes. The smaller diameter trees appeared to respond to increased growing space and showed significant increases in growth after partial cutting compared to uncut plots. The larger diameter trees (greater than 50 cm in diameter at cutting date) were probably overstory trees at the time of cutting, and although they increased in growth, these trees did not grow significantly faster than comparable overstory trees in the uncut treatments. The best growth response in partially cut stands appeared to be in the small-to-medium-sized C-2 trees.

Conclusions

The partially cut stand structures were very complex. Tree stocking, stand basal area and density, and tree diameter distributions varied widely among stands. Individual stands had their own distinctive structures and partial cutting generally maintained these unique structures over a wide range of cutting intensity.

Tree species composition was highly variable both among and within stands. Some current stands were very heavily stocked with small new regeneration (C-1 trees), while other stands had high current stand basal areas predominantly from large residuals (C-2 trees) left after cutting. The C-2 stand component (either large C-2 trees or small advance regeneration) was an important part of the future stand, and explained a large amount of the variation in tree species composition among stands. The establishment of C-1 spruce trees was highly variable both within and among stands, and some of the unexplained variation in species composition was probably related to differences in new spruce regeneration among stands. However, partial cutting did not lead to significant changes in the relative abundance of either Sitka spruce or western hemlock, nor did the intensity of partial cutting cause significant changes in tree species composition.

Species composition within stands was very resilient to partial cutting. Hemlock-dominated stands remained hemlock stands, and spruce/hemlock stands remained spruce/hemlock stands. In order to maintain spruce in a hemlock-dominated stand, it was important to leave some large overstory spruce and smaller-diameter understory spruce in the stand after cutting, both as a potential seed source for new regeneration, and to allow the smaller spruce trees to grow up into the overstory. However, in all of the spruce/hemlock stands, and in most of the hemlock-dominated stands, there were generally sufficient numbers of spruce to maintain spruce in the future stand. It appears that Sitka spruce can be maintained in mixed western hemlock-Sitka spruce stands within a wide range of partial cutting intensity.

Current stand structures and growth was largely dictated by the tree-age cohort structure. Stand basal area, tree species composition, and stand structures were dominated by C-2 trees left after partial cutting. Most stand growth for all cutting treatments was from C-2 trees. The majority of growth was from small-to-medium-sized trees at time of cutting, with little of the stand growth from larger-diameter trees. Stand basal area growth of hemlock and spruce were proportional to species composition left after cutting, and there were no significant differences in growth between species as a function of tree-size classes or cutting intensities. The C-2 component was a critical structure of developing stands, and the importance of C-2 trees in partially cut stands has been underestimated.

Overall, partial cutting created diverse and highly complex stand structures and these structures appear comparable to uncut, multi-aged stands. Sitka spruce was maintained over a wide range of cutting intensity, and species conversion to hemlock-dominated stands generally did not occur. The development and implementation of new silvicultural systems has excellent potential to alleviate some of the problems associated with conventional clearcutting in southeast Alaska. These alternative silvicultural systems could provide a sustainable timber resource including more valuable spruce trees, while also maintaining stand structural diversity, and enhancing late-successional or old-growth stand conditions that are an important component of current region-wide forest management plans.

Chapter 3.

THE EFFECTS OF PARTIAL CUTTING ON FOREST PLANT COMMUNITIES OF WESTERN HEMLOCK-SITKA SPRUCE STANDS IN SOUTHEAST ALASKA.

Robert L. Deal

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Introduction

Clearcutting has been the dominant regeneration method in the western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) -Sitka spruce (*Picea sitchensis* (Bong.) Carr.) forests of southeast Alaska since the early 1950s when pulp mills were established in the region (Harris and Farr 1974, Zasada and Packee 1995). Regardless of the success of clearcutting as a regeneration method for even-aged forests, recent concerns over the use of clearcutting have generated considerable interest in the development and use of new silvicultural systems in the region. Research on alternatives to clearcutting is currently being conducted in southeast Alaska[1]. However, very little is known about the effects of partial cutting on forest stand development and understory plant diversity and abundance, particularly in southeast Alaska where clearcutting has been the dominant regeneration method. In this study, the term "partial cutting" refers to any harvesting practice where part of the original stand was cut and the remaining residual stand was left intact after logging. There is considerable need to understand the effects of partial cutting on stand structure, forest overstory-understory interactions and plant communities before implementing any new silvicultural system.

Southeast Alaska is a temperate rain forest region, and part of the hemlock-spruce forest type that occupies a narrow 3000 km long band along the Pacific coast from Coos Bay, Oregon to Prince William Sound, Alaska (Ruth and Harris 1979). The region of Southeast Alaska is characterized by rugged steeply rising coastal mountains and numerous densely forested islands. Proximity to the north Pacific Ocean results in cool summers and mild winters; the annual precipitation is abundant and extended periods without

[1] Alternatives to clearcutting in the old-growth forests of southeast Alaska. 1994. Study plan on file at the Juneau Forestry Sciences Laboratory, Juneau, Alaska.

precipitation are rare (Farr and Hard 1987). Much of the precipitation occurs in the autumn season along with occasional hurricane force winds. The significance of this climate for the forest is that moisture is generally not a limiting factor for tree regeneration, wildfire is rare, and windthrow and wind caused damage of trees is common. (Harris et al. 1974, Harris 1989, Deal et al. 1991, Nowacki and Kramer 1998).

In southeast Alaska stands developing after major disturbances such as clearcutting follow clearly defined stages of stand development (Alaback 1982a, Deal et al. 1991). Immediately after clearcutting prolific new and advance conifer regeneration, shrubs, and herbaceous plants become established (stand initiation). Understory plant biomass peaks around 15 to 25 years after clearcutting, and complete canopy closure occurs about 25 to 35 years after cutting (Alaback 1982a). Following canopy closure an intense period of inter-tree competition prevents new tree regeneration from becoming established (stem exclusion), and other understory vegetation is nearly eliminated. The developing young-growth stands are extremely dense, and stands have relatively uniform tree height and diameter distributions. This stage of stem exclusion is long lasting in southeast Alaska and can persist for 50 to 100+ years or longer (Alaback 1984). Stands during the stem exclusion stage are notably lacking the multi-layered, diverse structures found in old-growth or multi-aged stands common in the region. Over time, disease, insect and wind disturbances in these stands (Kimmey 1956, Hard 1974, Harris 1989) creates gaps in the canopy resulting in reestablishment of new tree cohorts (understory reinitiation) and other understory vegetation.

Stand development described above has significant and long-term effects on understory plant development. Understory plant biomass peaks soon after clearcutting followed by canopy closure with a nearly complete elimination of herbs and shrubs (Alaback 1982a). Species richness is also significantly reduced (Alaback 1982b), and attempts to reestablish understory herbs and shrubs through thinning dense young-growth stands has led to mostly conifer regeneration with little new herbaceous colonization (Deal and Farr 1994). This intense stage of stem exclusion eliminates or significantly reduces the growth rate of understory vegetation for up to 100 years (Alaback 1982b, 1984, Tappeiner & Alaback 1989. The effect of a much reduced herb and shrub community for a long period of the stand rotation (100+ years) means that plant diversity and abundance is greatly reduced for over 70 percent of the stand rotation time period.

This long lasting stage of stem exclusion has significant implications for wildlife and other biota that depend on these plants as forage such as Sitka black-tailed deer (Walmo and Schoen 1980, Schoen et al. 1988, Hanley 1993). For the first 15 to 25 years after clearcutting these young-growth stands provide greater understory plant biomass than old-growth stands (Alaback 1982a). However, deer energy costs associated with using these stands makes them much less useful for deer habitat in the winter (Rose 1984, Kirchhoff and Schoen 1987, Schoen and Kirchhoff 1990). The dense uniform canopy of young-growth hemlock/spruce stands, and the abundant conifer regeneration established after thinning, makes it difficult to manage these stands to improve wildlife habitat. The use of partial cutting rather than clearcutting old-growth stands needs to be evaluated to determine if partial cutting can provide the critical stand structures for winter deer habitat, greater plant diversity and abundance, and important plant species for wildlife forage.

The effects of partial cutting on forest plant communities in hemlock-spruce stands of southeast Alaska are unknown. This study is part of large integrated study analyzing the effects of alternatives to clearcutting on forest stand structure, plant communities, wildlife, stand regeneration and mortality, hydrology and socioeconomic concerns of people. The major objectives of this study were to analyze plant species diversity and abundance in partially cut stands and to determine if changes in forest plant communities occur after partial cutting. Specifically I assess the plant species diversity of partially cut and uncut stands and analyze the effect of cutting intensity on species richness. I also determined if partial cutting leads to changes in plant community structures, and assessed the effect of cutting intensity on community composition. Lastly, I evaluated several key plant species that are important for deer forage, and determined if either partial cutting or the intensity of cutting led to significant changes in abundance of these plants.

Methods

I used a retrospective approach to study the effects of partial cutting on forest stand structure and plant communities. Partial cutting of forests was a common practice in southeast Alaska before the establishment of pulp mills in the region during the 1950s. These partially cut stands were not part of a planned silvicultural system, and generally little thought was given to the future management of the stand. Usually these stands were partially cut to provide a particular product such as Sitka spruce sawtimber or western hemlock for dock piling.

Study areas

Eighteen stands were selected to sample a range of time since cutting, intensity of cutting and geographic distribution throughout southeast Alaska. Study areas were selected from an available array of potential sites in the region with an initial pool of over 200 stands identified as being partially harvested. This information came from a variety of sources including U.S. Forest Service district files, historical records and maps, and information from local residents. Aerial photography and field visits were then used to assess current stand conditions and to select study areas. Approximately sixty of the best candidate stands were visited to select study areas using the following criteria: a) a range of "time since cutting," with study areas selected from stands cut at least ten years up to one hundred years ago, b) stands with only one harvest entry, c) a wide range of cutting intensity within each stand including an uncut area, d) a large partial cutting area of at least 10 ha in size, e) relatively uniform topography, soils, forest type and plant associations within each stand, f) a geographic distribution throughout the three management areas of the Tongass National Forest. Following the field visits, the eighteen stands that best met the study area selection criteria were used to fill a matrix of research sites. Study areas were installed during the summers of 1995 and 1996, and research sites were generally close to saltwater, less than 100 meters in elevation, and located throughout southeast Alaska in the north (Chatham), central (Stikine), and southern (Ketchikan) management areas of the Tongass National Forest (Figure 3.1, Table 3.1).

Plot selection

Stand conditions were thoroughly assessed by walking through the entire stand and noting the number and size of cut stumps, the number of obvious residual overstory trees, stand stocking, size of cutting area, and general stand conditions. Generally three partially cut plots and an uncut control plot were established per stand. In each stand, relative within-stand cutting treatments were designated as light, medium and heavy, according to

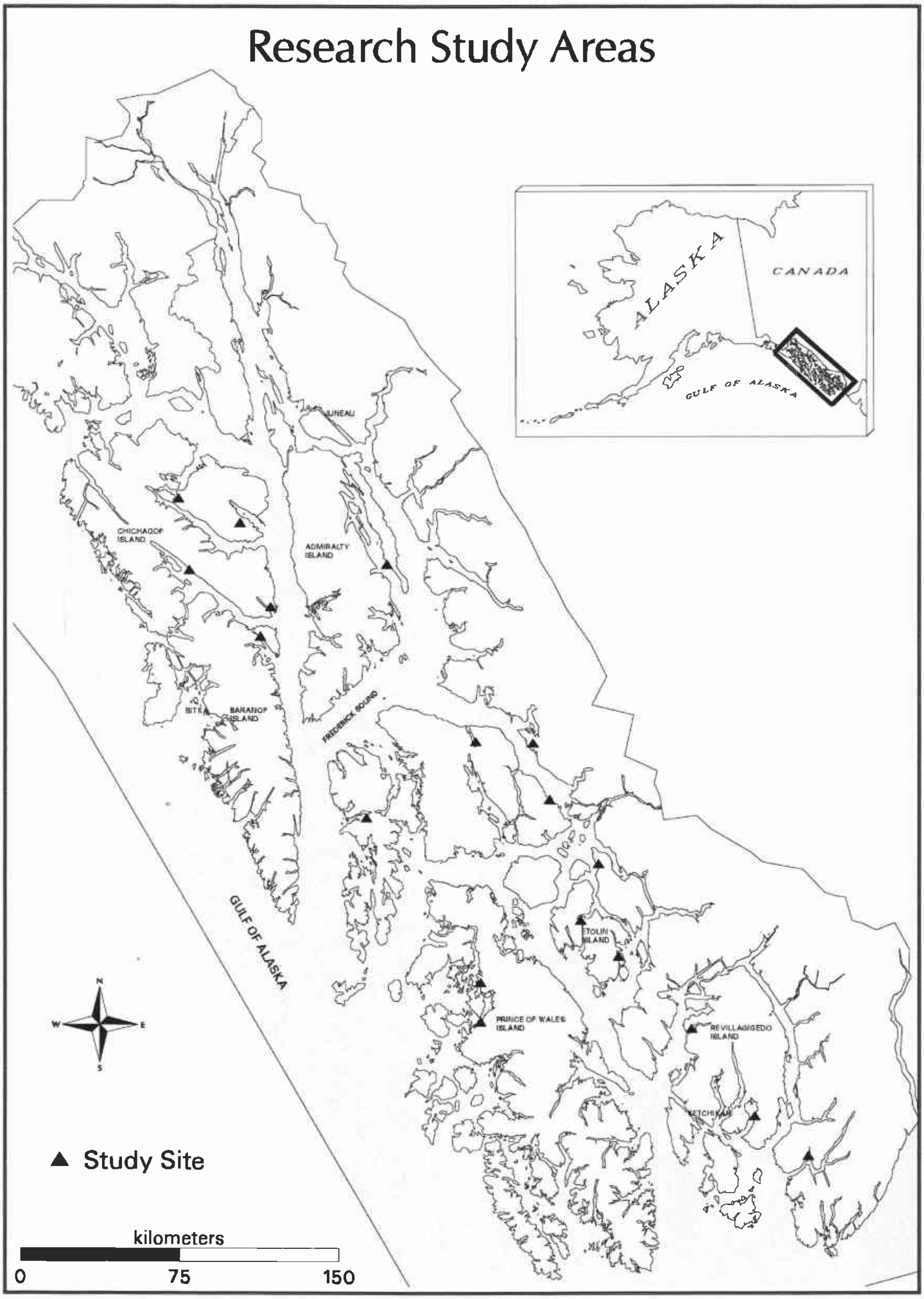

Figure 3.1. The location of 18 partially cut stands in southeast Alaska that were selected for study sites.

Table 3.1 Descriptions of research sites listed chronologically by cutting date. Elevation, slope and aspect were averaged by location. The plant association is the predominant site type. Forest type is the major tree species for all plots at each site.

Research Site	Tongass Area[1]	Cutting Date	Elev. (m)	Slope (%)	Aspect	Plant[2] Association	Forest Type	Site[3] Index$_{50}$
Thomas Bay (TB)	Stikine(2)	1984	15	2	NW	hemlock/blueberry/shield fern	western hemlock	30
Granite (GR)	Stikine(2)	1983	30	5	NW	hemlock/blueberry/shield fern	western hemlock	27
Pavlof River (PR)	Chatham(1)	1977	20	5	W	spruce/blueberry/devil's club	Sitka spruce	30
Big Bear Creek (BB)	Stikine(2)	1958	20	10	NW	spruce/blueberry/devil's club	Sitka spruce	23
Margarita Bay (MB)	Ketchikan(3)	1958	20	50	NE	hemlock/blueberry	Hemlock, spruce	30
Rainbow Falls (RF)	Stikine(2)	1942	20	15	SW	spruce/red alder	hemlock, spruce	27
Finger Creek (FC)	Chatham(1)	1941	5	3	W	hemlock/blueberry/shield fern	hemlock, spruce	30
Winter Harbor (WH)	Ketchikan(3)	1932	5	2	N	spruce/blueberry	spruce, hemlock	29
Salt Lake Bay (SB)	Chatham(1)	1928	10	5	NE	spruce/devil's club	spruce	30
Canoe Passage (CP)	Stikine(2)	1927	100	25	NW	hemlock/blueberry	hemlock, redcedar	27
Elf Point (EP)	Ketchikan(3)	1927	30	35	NW	hemlock-redcedar/blueberry	hemlock, spruce, redcedar	24
Sarkar (SK)	Ketchikan(3)	1925	60	20	W	hemlock/blueberry	hemlock	30
Hanus Bay (HB)	Chatham(1)	1922	25	20	SW	spruce/devil's club	spruce	30
Kutlaku Lake (KL)	Stikine(2)	1920	5	3	N	spruce/devil's club	spruce, hemlock	32
Portage Bay (PB)	Stikine(2)	1918	35	15	W	hemlock/blueberry/shield fern	hemlock	27
Florence Bay (FB)	Chatham(1)	1914	10	4	S	spruce/blueberry	spruce	32
Glass Peninsula (GP)	Chatham(1)	1911	20	15	W	spruce/devil's club	Spruce	29
Weasel Cove (WC)	Ketchikan(3)	1900	30	40	E	spruce/devil's club	spruce, redcedar, hemlock	24

[1] Management areas of the Tongass National Forest including the Chatham (north), Stikine (central), and Ketchikan (south).
[2] Forest Plant Association Management Guides Alaska Region.
[3] Farr's potential site index from soil series (Farr 1984), base age 50, height in meters.

the number and size of cut stumps, and the number of obvious residual trees. Plots were centrally located within these designated cutting treatments with no preconceived bias, and plots generally had a minimum of 50 meter buffer between treatments. These cutting treatments were established to sample the range of cutting intensities within each stand; however, the actual basal area cut and proportion of stand cut was determined later through stand reconstruction. I sampled a wide range of cutting intensity within each stand in order to evaluate stand overstory and plant understory response in relation to density. Elevation, slope, aspect, plant association and forest type of stands were recorded (Table 3.1). A total of seventy-three 0.2 ha plots were installed in eighteen different stands.

Stand reconstruction

Stands were reconstructed back to the date of cutting using cut stumps, current live trees, and snag information. Data on basal area cut, current live tree basal area at cutting date, and stand mortality since cutting, were combined to determine the proportion of basal area cut for each stand cutting treatment. Tree increment cores and stem sections from 986 western hemlock, Sitka spruce, western redcedar, and Alaska-cedar were used to develop regression equations to predict tree diameter at breast height (d.b.h.) at cutting date (Appendix, Table 2). Data from all cutting treatments in each stand were combined and analyzed together, with stand specific regression equations developed to predict tree d.b.h. at cutting date. I used forward stepwise regression analysis (Snedecor and Cochran 1980) to predict tree d.b.h. at cutting date using a number of tree and stand predictor variables. The most significant variables included current tree d.b.h., basal area, tree species, and cutting intensity. These stand-specific regression equations were then applied to all live trees in the current stand to predict tree d.b.h. at cutting date and estimate former stand basal area (excluding basal area cut and mortality estimates). I used stem taper equations to determine tree d.b.h. from cut stumps. I then developed equations to predict tree d.b.h. from the stump diameter using forward stepwise regression analysis on a large tree data set from southeast Alaska (Appendix, Table 1). I used snag class and snag age data (Appendix, Table 3) to determine the snag d.b.h. at cutting date, and then estimated stand mortality since cutting.

Overstory plot data

For each overstory plot, tree species, d.b.h., tree height and crown position were measured for all live trees to provide current stand structural information. Stand reconstruction provided data on the date and the intensity of cutting. The overstory plot data included stand structural data on the total stand basal area cut, residual basal area retained, proportion of stand basal area cut, stand density, and the proportion of spruce and hemlock in the stand (Table 3.2). Environmental data included elevation, slope, aspect, forest type, site index, geographic area and time since cutting (Table 3.1).

Vegetation data

Understory vegetation was sampled with ten 1m-by-1m vegetation quadrats (1.0 m^2), and ten 2m-radius shrub plots (12.57 m^2) within each of the seventy-three 0.2 ha overstory plots (Figure 3.2). Canopy cover classes for all herbs, mosses, lichens, liverworts, and tree seedlings less than 0.1 m tall were estimated within each vegetation quadrat. The canopy cover classes were estimated, and shrub and tree seedlings greater than 0.1 m tall were

Table 3.2 Range of cutting intensity and current stand structures for plots at the eighteen research sites. The current stand structural data includes both uncut and cut plots. The cutting intensity data is for only the partially cut plots.

	----------Cutting Intensity----------			----------Current Stand Structures----------					
Research Site	-------Basal Area--------		Proportion	Basal	Density		---------Species Proportion--------		
	Cut (m^2/ha)	Left (m^2/ha)	Cut % BA	Area (m^2/ha)	Index CCF[1]	Trees[2] (no./ha)	Spruce	Hemlock	Other
Thomas Bay	17.5-18.8	42.4-76.9	19.7-29.2	49.4-70.2	162-214	237-766	1-17	83-99	0
Granite	9.3-51.2	8.5-50.3	17.5-85.7	12.6-70.4	83-250	368-1970	0-7	93-100	0
Pavlof River	21.2-42.7	31.0-47.4	35.5-58.0	37.4-69.3	139-266	288-882	4-29	42-96	0-46
Big Bear Creek	9.3-27.1	46.8-63.3	16.6-35.5	52.7-78.9	185-246	270-754	15-47	53-85	0
Margarita Bay	8.8-48.0	9.9-30.1	22.5-82.9	41.1-63.3	206-304	694-2695	4-24	76-96	0
Rainbow Falls	15.1-25.0	16.2-25.4	34.3-60.7	44.4-66.3	197-233	348-1108	0-28	63-100	0-10
Finger Creek	11.0-32.5	43.9-51.0	17.7-41.5	58.3-74.8	195-266	331-522	5-60	40-95	0
Winter Harbor	19.0-38.9	55.7-69.7	24.0-37.8	73.3-95.3	260-336	785-1311	2-33	67-98	0
Salt Lake Bay	28.4-35.2	28.9-31.3	47.5-54.9	62.6-87.0	201-256	158-642	17-73	27-83	0
Canoe Passage	9.0-57.2	18.9-46.1	16.4-75.2	43.9-65.9	192-306	815-2452	2-13	74-92	6-19
Elf Point	12.0-35.5	12.7-57.4	17.3-73.4	42.0-115.6	157-388	453-1443	2-4	72-96	0-24
Sarkar	13.8-27.6	19.0-37.0	27.1-59.2	57.7-76.4	230-258	467-1163	0-11	89-100	0
Hanus Bay	23.9-84.8	3.2-24.6	49.2-96.4	56.1-82.8	214-286	413-1180	6-62	38-94	0
Kutlaku Lake	16.9-30.8	18.4-37.4	31.1-62.6	57.8-139.1	189-338	305-525	5-49	35-95	0-16
Portage Bay	7.0-28.5	14.2-25.3	26.3-64.5	47.1-56.3	198-258	459-1202	5-33	67-95	0
Florence Bay	32.5-37.8	26.2-38.1	49.8-57.0	55.6-82.9	152-270	120-360	18-75	25-82	0
Glass Peninsula	14.5-40.8	17.1-47.3	23.5-69.2	60.1-84.4	185-254	147-397	11-34	28-83	0-49
Weasel Cove	9.2-22.6	21.5-44.7	17.1-51.2	53.3-74.6	219-303	450-1220	0-24	67-100	0-17

[1] $CCF = \pi(MCW^2)*100/(4*10{,}000)$ (Krajicek et al. 1961) where $MCW = 1.07 + 0.334(D^{0.8263})$ for southeast Alaska (Farr et al. 1989) and (D) is tree diameter.
[2] Trees = the number of trees per hectare that are at least 2.5 cm d.b.h.

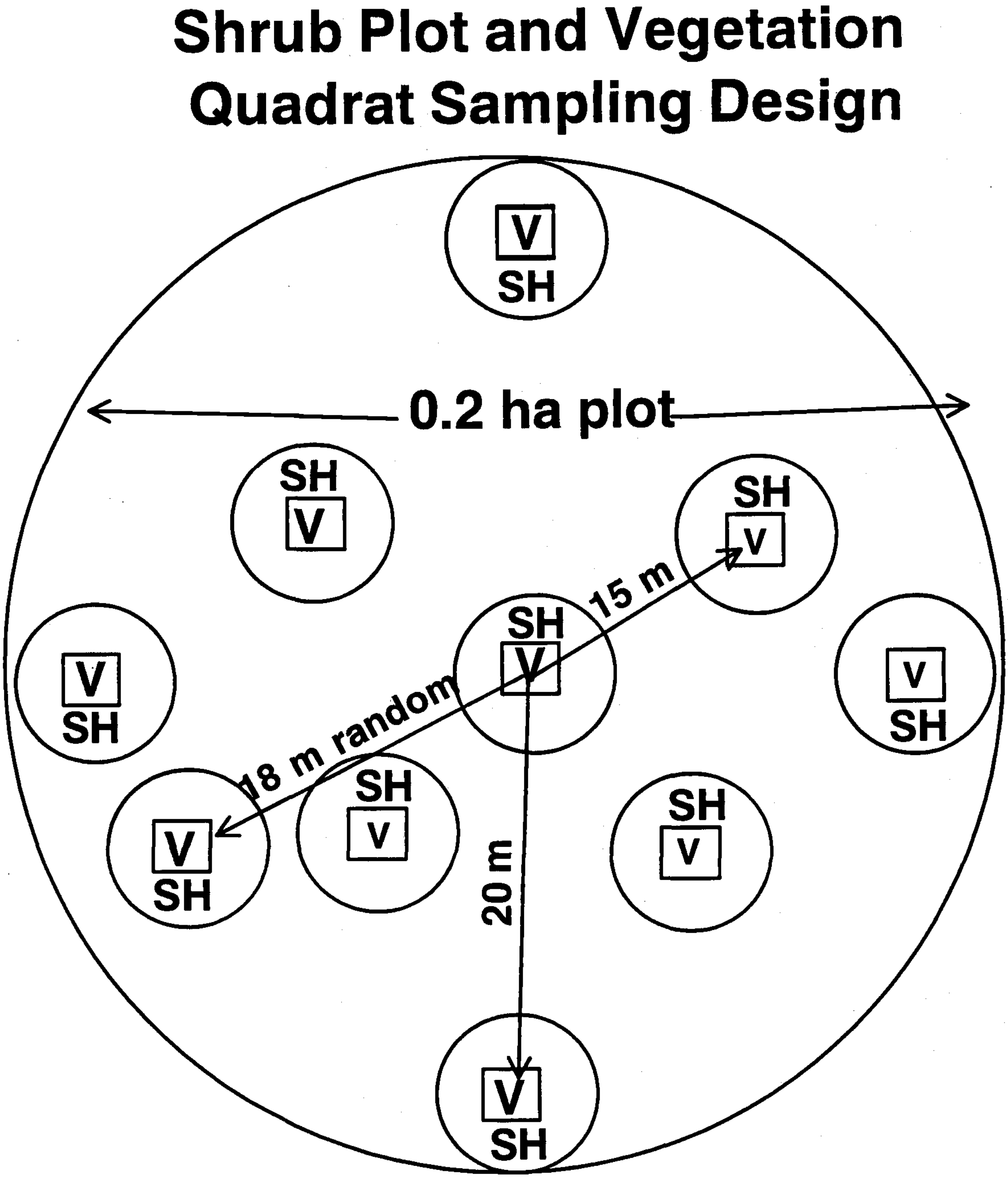

Figure 3.2 Layout of ten shrub plots and vegetation quadrats within larger 0.2 ha plot. Four shrub plots ("SH") and vegetation quads ("V") are located 20 m from plot center in north, south, east and west directions, four are located 15 m from plot center in NE, SE, NW, and SW directions, one is located 18 m from plot center at a random bearing, and one is at plot center. All shrub cover is measured within the 2 m radius (12.57 m^2) shrub plots. All herb, tree seedling, moss, liverwort and lichen covers are measured within the 1m x 1m (1 m^2) vegetation quadrats.

measured for height within the shrub plots. Canopy cover classes were as follows: 0-1, 1-5, 5-25, 25-50, 50-75, 75-95 and 95-100% (Daubenmire 1959).

Construction of data sets

The canopy cover data for the ten vegetation quadrats and shrub plots were combined and averaged within each overstory plot to estimate average abundance for each plant species found on the overstory plots. Percentage vegetation cover for each species was calculated using the midpoints of each canopy cover class. A plot by species main matrix was constructed where species abundance data were average cover. Three separate data sets were constructed and used to assess species diversity and plant community structures. The first data set used the full set of 73 plots and 146 species. Another data set contained only vascular plants and included 73 plots and 56 species; this data set was used to assess species diversity and species richness of vascular plants and analyze the structure of the vascular plant community. Finally, a reduced data set was developed where species occurring in fewer than three sample units (<3% of plots) were removed from the data set. No plots were removed, but 36 species occurring on only one plot and nine species occurring on only two plots were removed, creating a reduced data matrix of 73 plots and 101 species. The reduced data was developed to determine if the elimination of rare species reduced the variability of species abundance and strengthened the relationship between plots and species composition. This reduced data set was later used for all additional analyses of plant community structures.

An environmental matrix was constructed using the stand structural data and environmental data from the overstory plots. This environmental matrix was constructed paralleling the main matrix plots. The environmental matrix had both quantitative and categorical variables. A coded class for cutting intensity was created using the proportion of basal area cut, with uncut plots (0), plots with less than 30% of basal area cut (1), plots with 30-60% basal area cut (2), and plots with greater than 60% of the basal area cut (3). Coding was also used for the other categorical variables including geographic area, and forest type.

Data analysis

Species richness and diversity measures

I tested the hypothesis of no difference in species richness between uncut and partially cut plots using both the full data set of all plant species and the data set containing only vascular plants. I blocked plots by stand, and then tested for differences in species richness among cut and uncut plots using contrast analysis (SAS Institute, Inc.). I also tested the hypothesis that species richness is not a function of cutting intensity using the full and vascular plant data sets. Species richness and species diversity were calculated for the full, reduced, and vascular plant data sets. Diversity measures (alpha, gamma and beta) for species, and data distribution (skewness and coefficient of variation) for both plots and species were determined. The data were tested for outliers. Diversity measures calculated included Shannon's diversity index, H′, (Shannon and Weaver 1949), and Pielou's evenness index, E, (Pielou 1975) from:

$$H' = -\sum(p_i * \ln(p_i)) \text{ where } p_i = \text{importance probability in element i.} \quad (1)$$

$$E = H' / \ln(\text{Richness}) \quad (2)$$

Multivariate analyses of plant community structures

Following construction of the reduced data set, I used dendrograms from cluster analysis, Non-metric Multidimensional Scaling ordination (NMS), and Multi-response Permutation Procedures (MRPP) in PC-ORD (McCune and Mefford 1997) to analyze plant community structures. For the MRPP analysis, I pooled all of the partially cut plots together and tested the hypothesis of no difference in species abundance between uncut and partially cut. Then I compared four plot cutting intensity classes (uncut, < 30% BA cut, 30-60% BA cut, and > 60% BA cut), and used MRPP to test separate hypotheses of no difference in species composition between the uncut plots and the three levels of plot cutting intensity plots. For cluster analysis, I used relative Euclidian distance and Ward's method group linkage, a method which is space conserving with consistently low chaining. For ordination analysis, I initially used a Bray-Curtis Ordination with Sørenson distance measure and variance-regression endpoint selection. This generally provided a good spread of points in the ordination, and I saved the ordination scores as an input starting point for NMS. I then used NMS ordination with Sørenson distance measure for two and three axes with 100 iterations. I also ran Monte Carlo tests on a series from six axes to one axis and compared the stress obtained from the randomized data with my data set. All ordinations were rotated to align with axis 1. For my final ordination model, I selected the model that explained the greatest amount of variation in the original distance matrix on the fewest number of axes. I then analyzed overlays of variables from the environmental matrix and reported the relation of NMS axes to main matrix and key environmental variables associated with each axis.

Analysis of key plant species for deer forage

Average cover for eight key plant species for deer forage (Hanley and McKendrick 1985, Kirchhoff and Hanley 1992) were averaged for each of the four plot cutting intensity classes. To determine if the abundance of key plant species may be different in stands after partial cutting, I first tested the hypothesis of no difference in species abundance between cut and uncut plots. I blocked plots by stand, and then tested for differences in abundance (average cover) between cut and uncut plots for each of 8 key plant species using contrast analysis (SAS Institute, Inc.). I then blocked plots by stand, and tested separate hypotheses relating to species abundance not being a function of cutting intensity.

Results

Species diversity

The full data set had high species richness with 146 plant species found on the 73 partially cut and uncut plots (Table 3.3). However, species richness was highly variable among stands, ranging from a minimum of 18 species found in a cut plot at Sarkar to 48 species found in another cut plot at Thomas Bay. The vascular data set also was species rich, particularly for the forest plant communities of southeast Alaska, and contained 56 shrubs, ferns, tree seedlings and herbaceous plants (Appendix, Table 4). The removal of species occurring in less than 3 plots (< 3% of all plots) resulted in a reduced data set of 101 species, and lowered plot beta diversity from 4.67 in the full data set to 3.30 in the reduced data set and only slightly reduced species richness (Table 3.3). The reduced data set also had a much more even distribution of species (evenness index, E) and a higher Shannon diversity index (H') than either the full data set or the vascular plant data set.

Table 3.3. Species diversity measures and data distribution for full data set (146 plant species), reduced data set (101 plant species), and vascular plant data set (56 species).

Data Set	Species Diversity Measures					Data Distribution			
						Coefficient of Variation[3]		Skewness	
	Gamma	Alpha	Beta	Evenness[1] E	Diversity[2] H'	Total of Plots	Total of Species	Plot Average	Species Average
Full	146	31.3	4.67	0.66	2.27	33.10	314.51	6.67	5.60
Reduced	101	30.6	3.30	0.82	2.80	31.95	75.46	3.51	4.42
Vascular	56	14.7	3.81	0.66	1.77	50.83	221.75	4.56	5.40

[1] Evenness = H' / ln (Richness).

[2] Diversity $= -\Sigma\,(p_i * \ln(p_i))$ where p_i = importance probability in element i.

[3] Coefficients of variation are in percentages.

The data distribution for the full data set had highly variable species abundance with an average skewness of 6.67 and 5.60 for plots and species respectively (Table 3.3). The coefficient of variation for plots was relatively low (33%) but very high for species (314%) reflecting the high variability in species abundance. The distribution of vascular plants was also highly variable for both plots and species. The reduced data set had lower average skewness for both plots and species than the full or vascular data sets, and a significantly lower coefficient of variation for total species. Overall, the reduced data set significantly reduced variability in species abundance while only slightly reducing species.

The effect of partial cutting on species richness

Plant species richness was high for all cutting intensities. The number of species per plot averaged 31.8 (SE = 1.3) in the uncut plots, and averages ranged from 33.7 (SE = 1.8) in plots with less than 30% of the stand basal area cut, to 27.5 (SE = 1.9) in plots with more than 60% of the basal area cut (Figure 3.3a). Species richness was highly variable among stands, and after accounting for potential differences in species composition among stands by blocking by stand, I found no significant difference in species richness between uncut and partially cut plots ($p = 0.295$). The species richness of vascular plants was also highly variable among stands but similar among the uncut and partially cut plots (Figure 3.3b). I found no significant difference in the species richness of vascular plants between the uncut and partially cut plots ($p = 0.263$).

Species richness decreased with increasing cutting intensity (Figure 3.3c), but the relationship was weak (adjusted $R^2 = 0.095$). Overall, I found a non-significant difference in species richness with increasing cutting intensity ($p = 0.137$). Species richness of

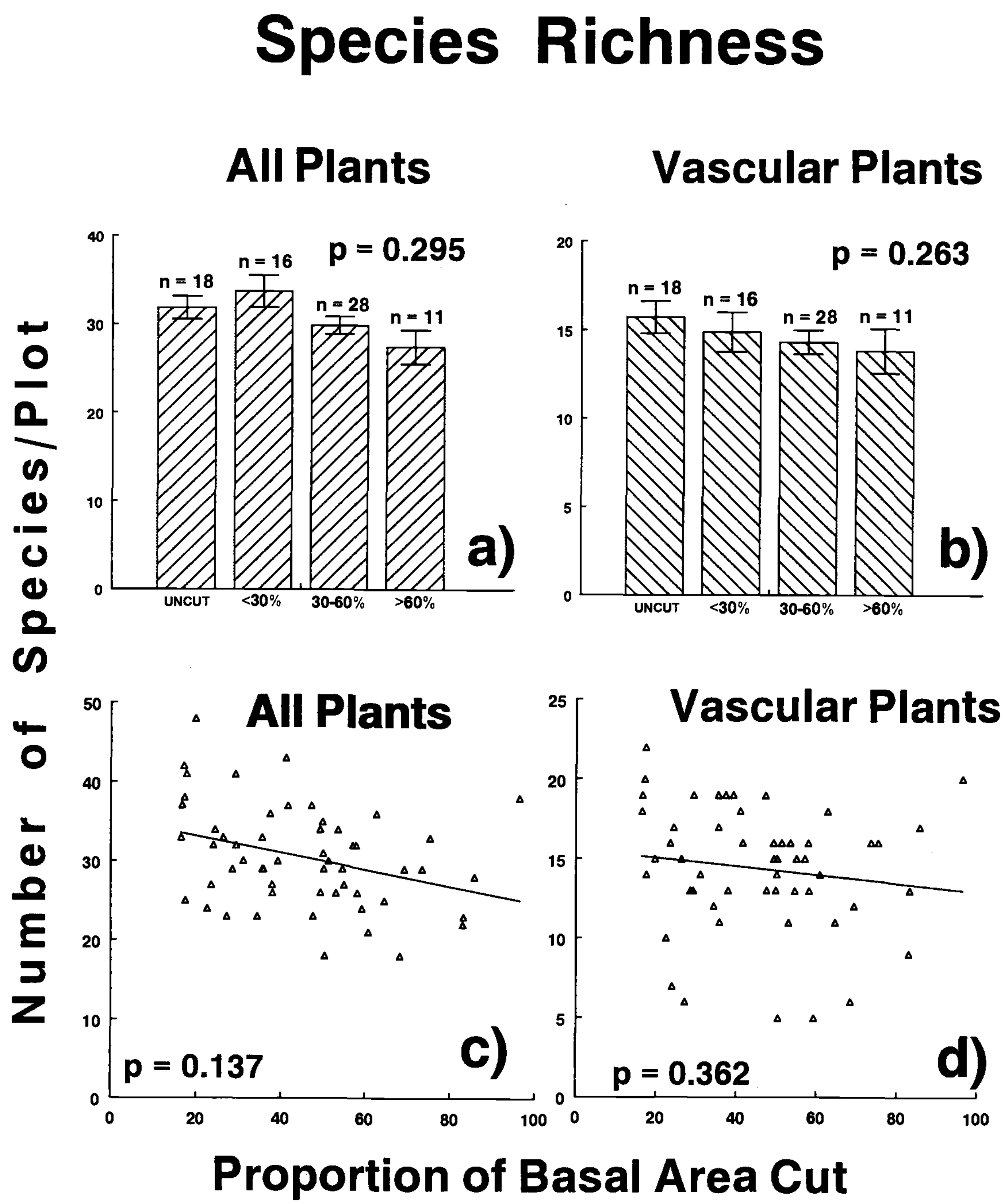

Figure 3.3 The species richness of all plants (a) and the vascular plants only (b), by plot cutting intensity classes. Vertical lines represent stand error and n is the number of plots for each cutting intensity class. The species richness of all plants (c) and the vascular plants only (d), as a function of cutting intensity for the 55 partially cut plots.

vascular plants varied among stands and within different cutting intensities (Figure 3.3d), but overall, I found no significant difference ($p = 0.362$) in vascular plant species richness with increasing cutting intensity.

In summary, there was insufficient evidence to reject the null hypothesis that species richness is the same in uncut and partially cut plots, or that it varies with cutting intensity. The species richness of all plants and vascular plants was similar among the uncut and partially cut plots and across cutting intensity. It appears that neither partial cutting nor the intensity of cutting led to significant changes in plant species richness.

Effects of partial cutting on plant community structures

Cluster analysis showed that most plots within a particular stand group together, and groups formed early in the cluster analysis for both partially cut and uncut plots within each stand. In 10 of the 18 sampled stands, uncut plots grouped with at least one cut plot very early in the cluster analysis, retaining at least 80% of the species abundance information (Figure 3.4). Some stands had very similar plant species composition and abundance for all plots within a stand (GR, SK, and TB), and distinctive cluster groups formed early for all plots (Figure 3.4). However, only a few stands had all plots included in early cluster groups; for example, only 5 of the 18 sampled stands retained at least 50% of the species abundance information after cluster groups included all plots. At least 5 stands formed cluster groups including all plots near the end of cluster analysis, indicating very different plant community structures among plots within these stands. Overall, cluster analysis showed that species composition varied widely among stands but plant community structures were similar for both the uncut and cut plots within each stand.

Cluster Analysis Dendrogram

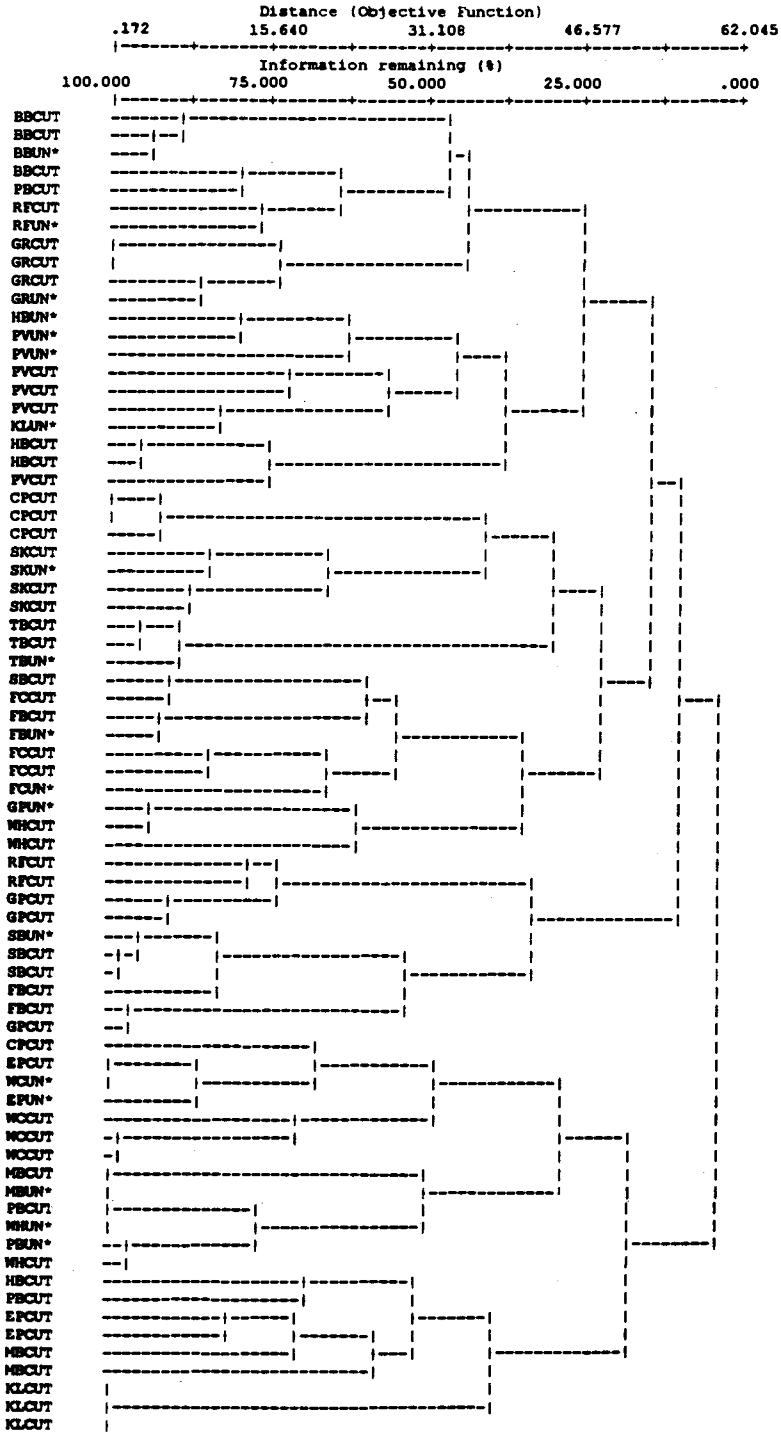

Figure 3.4 Cluster analysis dendrogram relating species composition and abundance with plots. Plots that form cluster groups on the left side of dendrogram indicate similar plant communities. The first two letters of each plot identify the site, CUT indicates partially cut plots, and *UN indicates uncut plots.

Plot ordination showed that species composition and abundance in the uncut plots was similar to the partially cut plots. The uncut plots were well distributed across species space both on axis 1 and on axis 2 (Figure 3.5a). Generally, the uncut plots formed close groupings with some of the partially cut plots indicating that plant community structures were similar. The uncut and partially cut plots frequently grouped together by stand, and in some stands all plots clustered close together (Figure 3.5b). However, in some stands the plots were widely scattered across species space, or formed two distinct groups, (Figure 3.5b), indicating wide within-stand variation in plant community composition.

Ordination analysis (reduced data set of 101 plant species) did not show any clear pattern reflecting cutting intensity. In general, plant community structures in the uncut plots appeared to be more similar to the lightly cut plots (<30% of the basal area cut) than to the heavily cut plots (Figure 3.6a). However, ordination showed that plots with different cutting intensities were well distributed across both axes (Figure 3.6a), and distinct patterns of cutting intensity were not apparent. The proportion of basal area cut (PROPCUT) and total basal area cut (BACUT) both showed a weak but increasing trend on axis 1 ($r = 0.174$ for PROPCUT, and $r = 0.127$ for BACUT) and a poor correlation on axis 2 (Figure 3.6b). MRPP analysis also showed no significant differences in plant community composition between partially cut and uncut plots ($p = 0.110$, Table 3.4). The uncut plots were very similar to the lightly cut plots (<30% BA cut) and did not differ in community composition ($p = 0.982$, Table 3.4). However, the uncut and the medium cut plots (30-60% BA cut) did differ significantly ($p = 0.032$) in community composition, and the communities in the uncut and heavily cut plots differed even more strongly ($p = 0.003$, Table 3.4). In summary, it appears that there is no significant difference in plant community composition between the uncut and partially cut plots. However, the intensity of cutting does cause

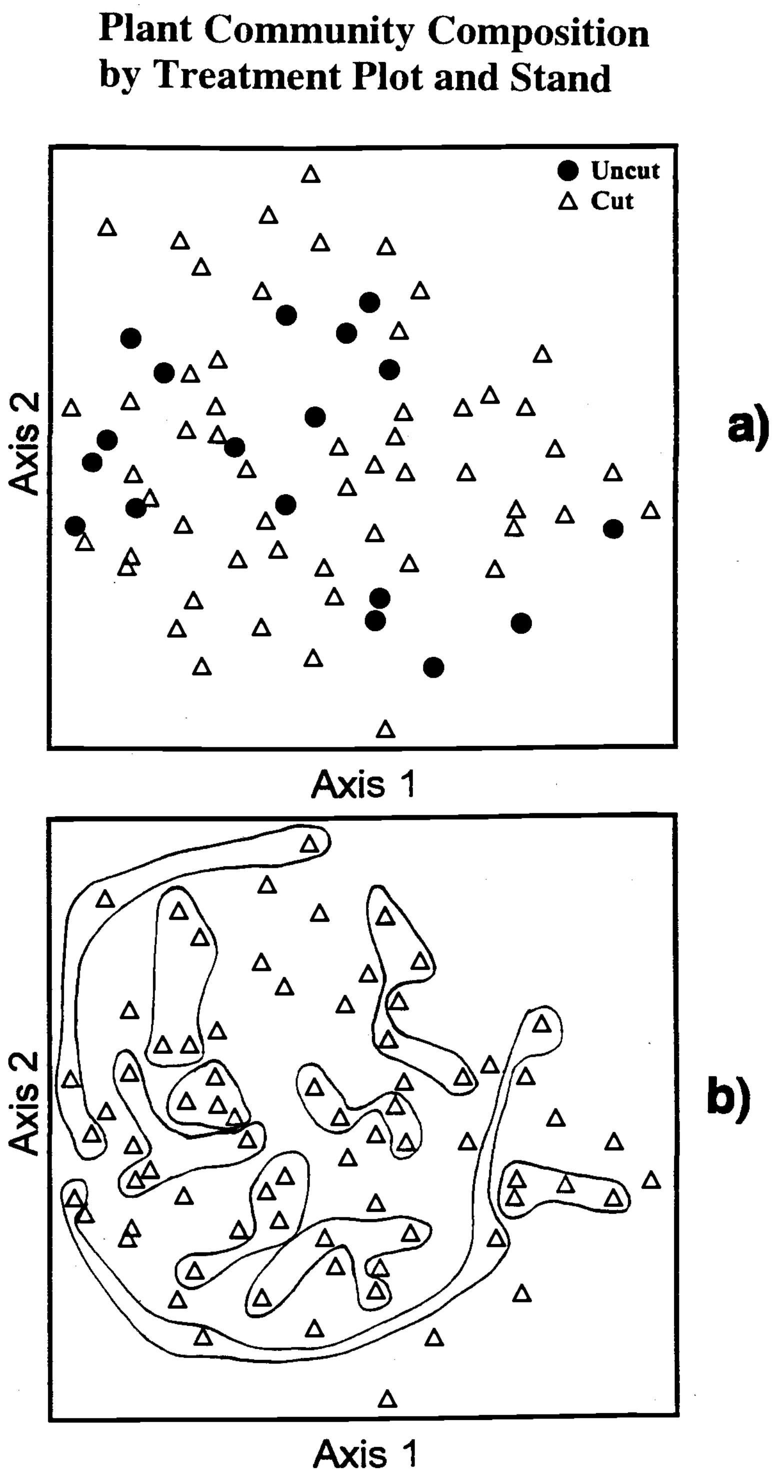

Figure 3.5 The plant community composition in species space for the 73 uncut and partially cut plots (a), and ordination groups for several circled stands showing within-stand plot clustering (b).

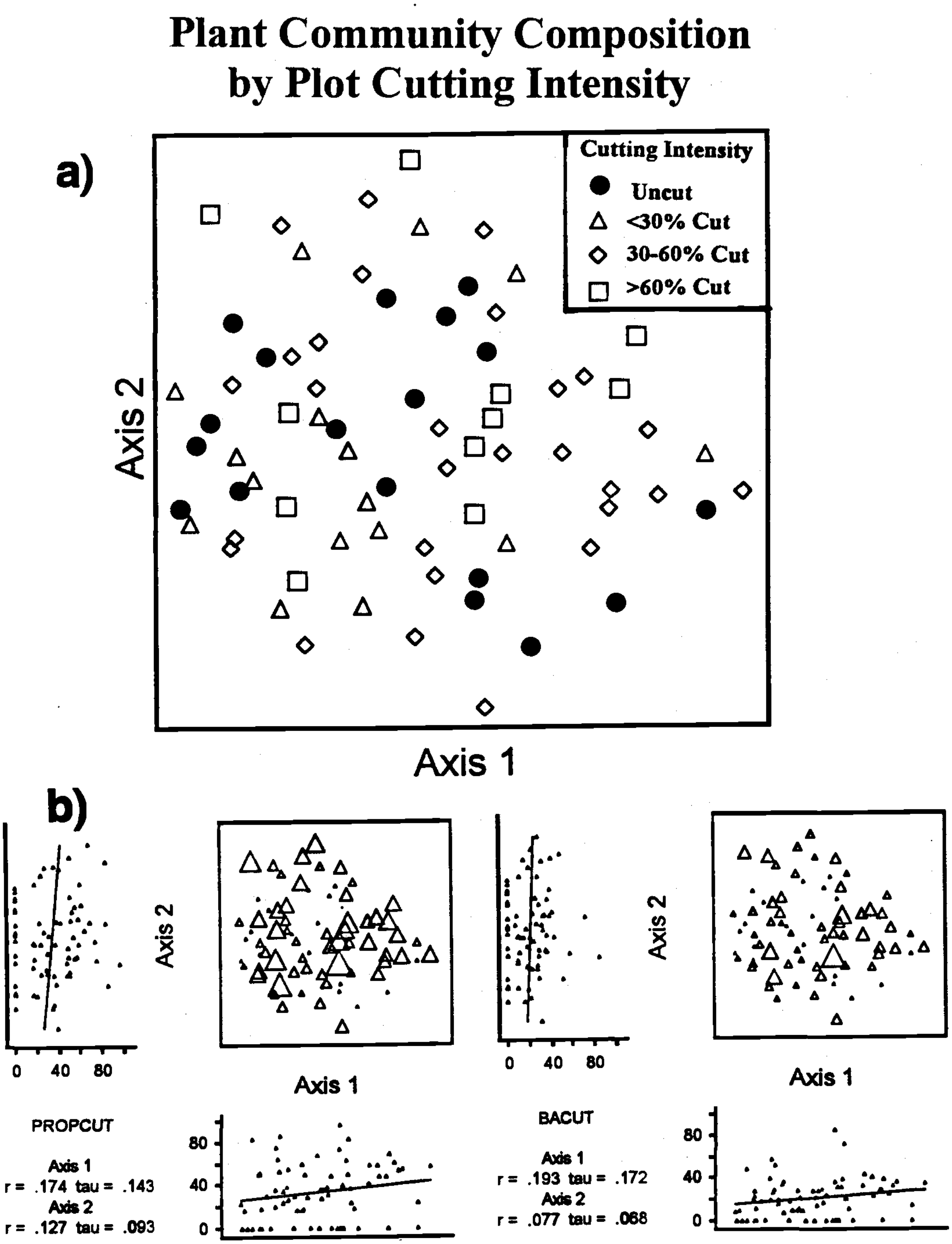

Figure 3.6 The plant community composition in species space for the 73 uncut and partially cut plots by cutting intensity class (a), and the relationship of ordination axes (b) to the proportion of basal area cut (PROPCUT) and total basal area cut (BACUT).

Table 3.4 The effect of cutting intensity on plant community composition. The multi-response permutation procedure (MRPP) probabilities are the probability of no difference in community composition between uncut plots and partially cut plots, and uncut plots and different levels of plot cutting intensity.

Cutting Treatment Comparisons (n)	MRPP Probabilities
Uncut plots (18) vs. Partially cut plots (55)	0.110
Uncut plots (18) vs. Light cut[1] plots (16)	0.982
Uncut plots (18) vs. Medium cut[2] plots (28)	0.032
Uncut plots (18) vs. Heavy cut[3] plots (11)	0.003

[1] Less than 30% of original stand basal area cut.
[2] Between 30% and 60% of original stand basal area cut.
[3] Greater than 60% of original stand basal area cut.

some significant changes in community composition. The moderate and heavily cut plots had significantly different community composition than the uncut plots and it appears that increasing cutting intensity causes some changes in plant community structures. The different community composition in moderate to heavy cutting intensities may parallel the common stand response to heavy cutting that promotes the development of overstory conifers and suppresses understory plants. However, most stand and environmental variables including stand density measures such as basal area and CCF were poorly correlated with ordination analysis (Table 3.5), and the underlying reasons for differences in species diversity and abundance appear complex.

Plant communities were apparently related to both geographic location and site productivity. Communities differed from north to south in the Tongass National Forest. The northern Chatham area (area-1, Figure 3.7a, Table 3.1) plots were ordinated on the right side on axis 1 and well distributed on axis 2, the southern Ketchikan area (area-3, Figure 3.7a) plots were ordinated on the left on axis 1 and on the upper end of axis 2, and the central Stikine area (area-2, Figure 3.7a) plots were located in the middle between the two north-to-south regions. Plant communities showed rather distinctive changes in structures according to their geographic location and plant communities appeared to change with latitude. Community patterns relative to forest site index (Figure 3.7b) were less distinctive than those relative to geographic location, but ordination showed that most lower productivity plots were on the left side on axis 1.

Plant communities differed by overstory tree composition, particularly the relative abundance of western hemlock and Sitka spruce (Figure 3.8a). Hemlock stands were generally towards the left side and spruce stands generally towards the right side of axis 1

Table 3.5 The correlation (r) and cumulative coefficient of determination (R^2) of stand and environmental variables (secondary matrix), and species variables (main matrix) with NMS ordination axes. The ordination was rotated to align the variable "Forest Type" with the first axis. Species selected were either key species for deer forage or were species highly correlated with ordination axes.

Stand and Environmental Variables	r Axis 1	r Axis 2	R^2 Both Axes
Time since cutting	0.043	0.361	0.132
Elevation	-0.432	0.022	0.187
Current stand BA	0.131	0.158	0.042
CCF[1]	-0.285	0.292	0.166
Total stems	-0.567	0.125	0.337
Proportion spruce	0.551	-0.145	0.325
Proportion hemlock	-0.517	0.212	0.312
Proportion other species	0.038	-0.177	0.033
Stand BA cut	0.193	0.076	0.043
Stand BA left	-0.130	-0.037	0.018
Proportion of stand cut	0.174	0.127	0.046
Species Variables			
Athyrium felix-femina (fern)	0.649	-0.135	0.439
Blechnum spicant (fern)	-0.434	-0.211	0.233
Circaea alpina (herb)	0.487	-0.102	0.248
Coptis asplenifolia (herb)	-0.058	-0.357	0.131
Cornus canadensis (herb)	-0.208	-0.484	0.278
Dryopteris expansa (fern)	0.250	-0.161	0.089
Gymnocarpium dryopteris (fern)	0.645	-0.191	0.453
Hypnum circinale (moss)	0.495	-0.036	0.246
Lysichiton americanum (herb)	-0.035	-0.339	0.116
Maianthemum dilatatum (herb)	0.444	0.067	0.202
Menziesia ferruginea (shrub)	-0.497	-0.051	0.250
Oplopanax horridus (shrub)	0.638	-0.324	0.512
Plagiomnium insigne (moss)	0.459	-0.104	0.222
Rhitidiadelphus loreus (moss)	-0.603	0.019	0.364
Rubus pedatus (herb)	-0.100	-0.324	0.115
Sphagnum girgensohnii (moss)	-0.496	0.025	0.247
Streptopus amplexifolius (herb)	0.403	-0.298	0.251
Tiarella trifoliata (herb)	0.519	-0.210	0.314
Vaccinium alaskaense/ovalifolium (shrub)	-0.525	-0.306	0.369
Vaccinium parvifolium (shrub)	-0.336	-0.051	0.116

[1] $CCF = \pi(MCW^2)*100/(4*10{,}000)$ (Krajicek et al. 1961) where $MCW = 1.07 + 0.334(D^{0.8263})$ for southeast Alaska (Farr et al. 1989) and (D) is tree diameter.

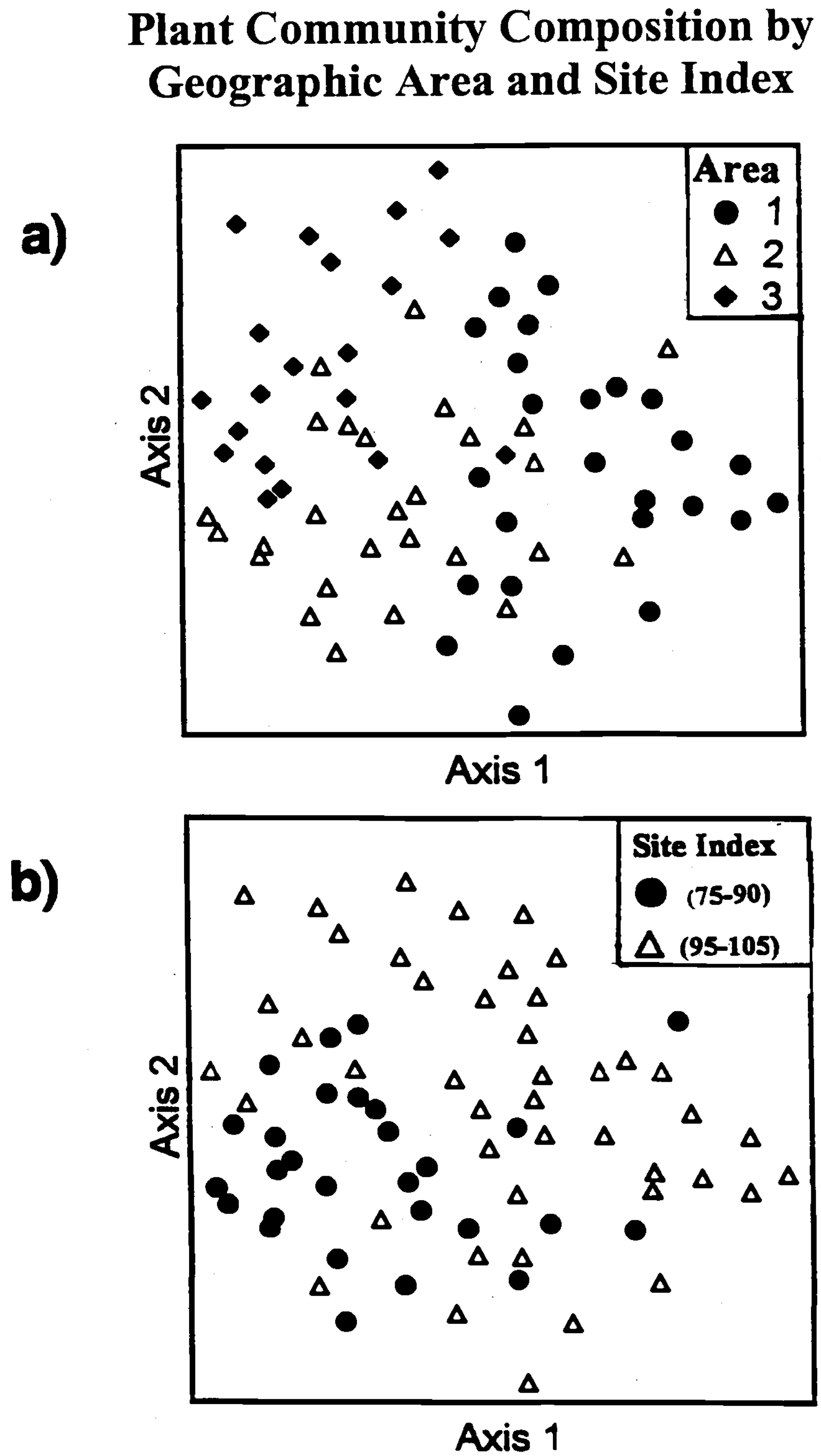

Figure 3.7 The plant community composition in species space for the 73 uncut and partially cut plots by geographic area of the Tongass National Forest (a), and site productivity index (b). Geographic area 1 is the northern Chatham Area, area 2 is the central Stikine area, and area 3 is the southern Ketchikan Area.

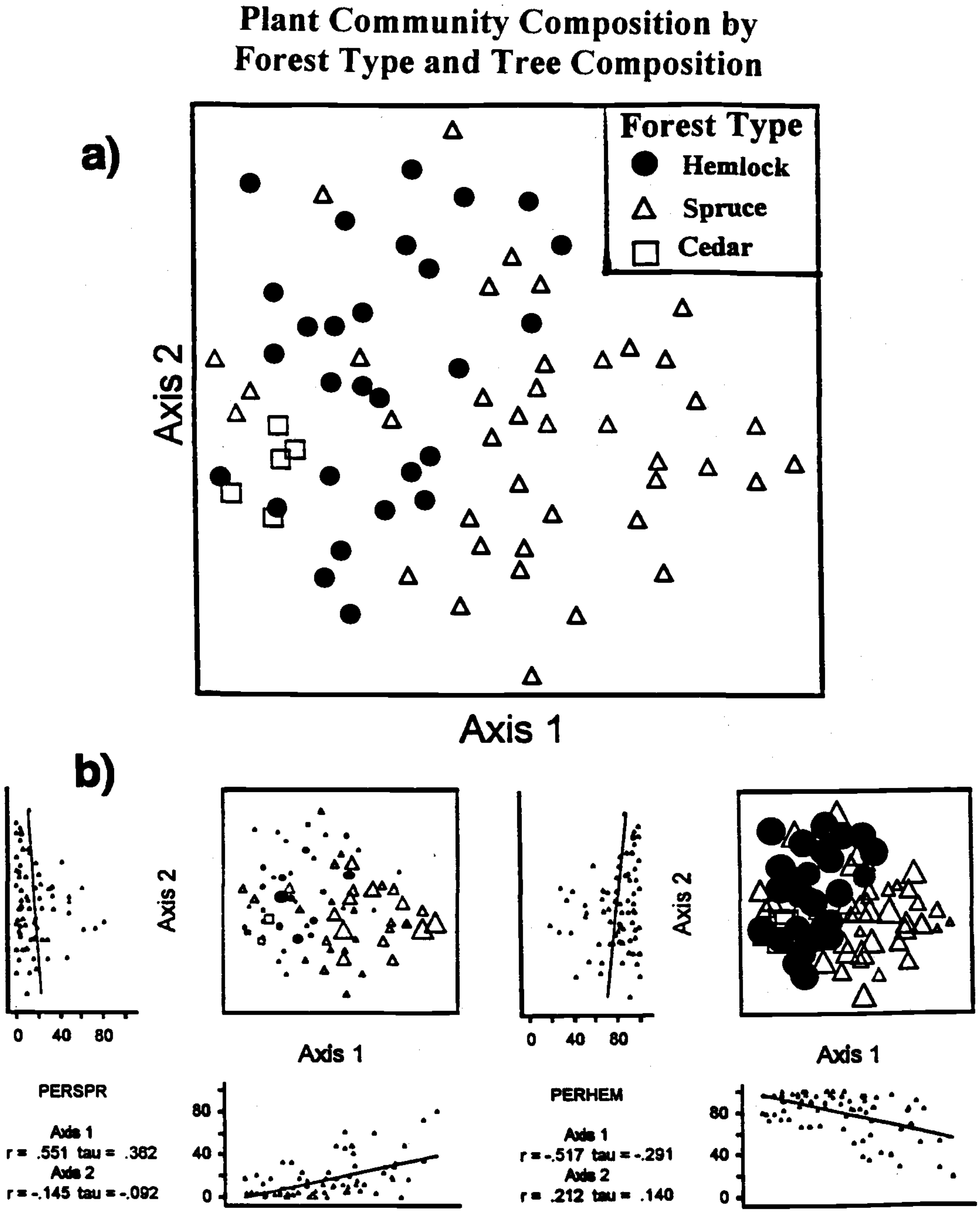

Figure 3.8 The plant community composition in species space by the major overstory tree species on each plot (a), and the relationship of ordination axes to the proportion of trees by stem number (b) for spruce (PERSPR) and hemlock (PERHEM). The size of symbol in (b) indicates the strength of relationship.

(Figure 3.8a). The few cedar-dominated stands were often closely associated with hemlock stands. The proportion of spruce stems (PERSPR) was strongly correlated (r = 0.551) with axis 1, and the proportion of hemlock stems (PERHEM) was negatively correlated

(r = -0.517) with axis 1 (Table 3.5, Figure 3.8b). Plant abundance (canopy cover) for a few key plant species was closely associated with overstory tree composition (forest type). In particular, three shrubs (*Oplopanax horridus*-OPHO, *Menziesia ferruginea*-MEFE, and the *Vaccinium alaskaense/ovalifolium* complex-VACC) showed strong correlations with the first axis (Figure 3.9, Table 3.5). OPHO was a frequent associate with Sitka spruce, and VACC and MEFE were common associates with western hemlock. Two ferns also showed strong associations with Sitka spruce (*Athyrium felix-femina*-ATFI, and *Gymnocarpium dryopteris*-GYDR, Figure 3.9, Table 3.5). Another important stand structural characteristic was the total number of stems, and stem number appeared to closely parallel the proportion of hemlock in the stand (Table 3.5). Overall, species composition and abundance appears to differ among densely-stocked hemlock-dominated stands and lighter-stocked spruce-dominated stands.

Key plant species for deer forage

The abundance (average cover) of the four herbs, *Coptis asplenifolia* (COAS), *Cornus canadensis* (COCA), *Rubus pedatus* (RUPE), and *Tiarella trifoliata* (TITR) varied greatly among stands and within different plot cutting intensities (Table 3.6). The average cover of COAS (Figure 3.10a) was marginally different among uncut and partially cut plots (p = 0.085). Cover decreased slightly with increasing cutting intensity (Figure 3.10b), but there was no significant correlation between cutting intensity and cover

Plant Cover by Forest Type

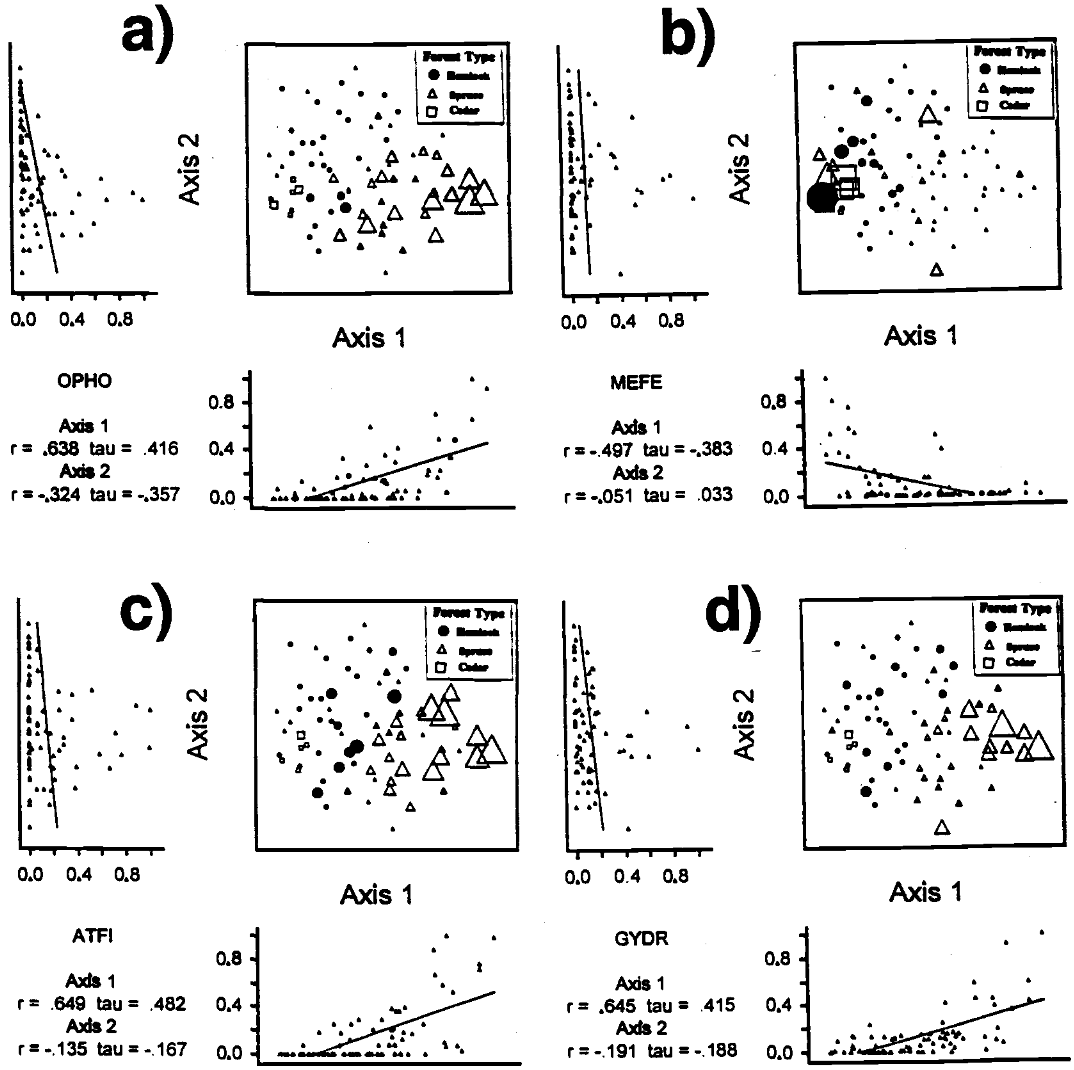

Figure 3.9 The average plant cover for devil's club (a) *Oplopanax horridus* (OPHO), rusty menziesia (b) *Menziesia ferruginea* (MEFE), lady fern (c) *Athyrium filix-femina* (ATFI), and oak fern (d) *Gymnocarpium dryopteris* (GYDR). The ordination was rotated to align the variable "Forest Type" with the first axis. The size of symbol indicates the strength of relationship.

Table 3.6 Plant abundance data of key plant species for deer forage by plot cutting intensity.

Species	Uncut			Light			Medium			Heavy		
	Plot Cutting Intensity[1]											
	Freq[2]	Ave[3]	Rng[4]	Freq	Ave	Rng	Freq	Ave	Rng	Freq	Ave	Rng
Coptis asplenifolia	56	1.3	0-10.0	63	1.0	0-6.1	43	0.6	0-3.6	45	0.6	0-3.3
Cornus canadensis	83	2.0	0-8.0	81	2.2	0-10.6	50	0.9	0-9.4	45	0.5	0-3.6
Dryopteris expansa	83	3.0	0-13.6	75	4.5	0-19.1	96	5.3	0-17.2	100	6.6	0.3-18.1
Lysichiton americanum	44	4.4	0-10.5	31	1.4	0-8.2	11	0.8	0-11.5	18	1.0	0-5.4
Rubus pedatus	94	3.2	0-15.8	88	3.1	0-15.6	71	2.2	0-17.6	55	1.6	0-7.4
Tiarella trifoliata	78	2.3	0-11.1	81	1.4	0-6.1	79	3.1	0-12.7	64	2.2	0-6.9
Vaccinum complex	94	20.6	0-47.8	94	21.7	0-61.8	96	8.8	0-30.9	100	10.8	0.1-57.5
Vaccinium parvifolium	50	0.7	0-4.6	50	0.4	0-3.4	39	0.6	0-6.9	73	0.4	0-1.6

[1] Uncut includes 18 plots with no cutting, light includes 16 plots with less than 30% of the stand basal area cut, medium includes 28 plots with 30-60% of the stand basal acre cut, and heavy includes 11 plots with greater than 60% of the stand basal area cut.

[2] Freq is the proportion of plots on which species occurred.

[3] Ave is the average plant cover for all plots within each plot cutting intensity class.

[4] Rng is the range of average plant cover within each plot cutting intensity class.

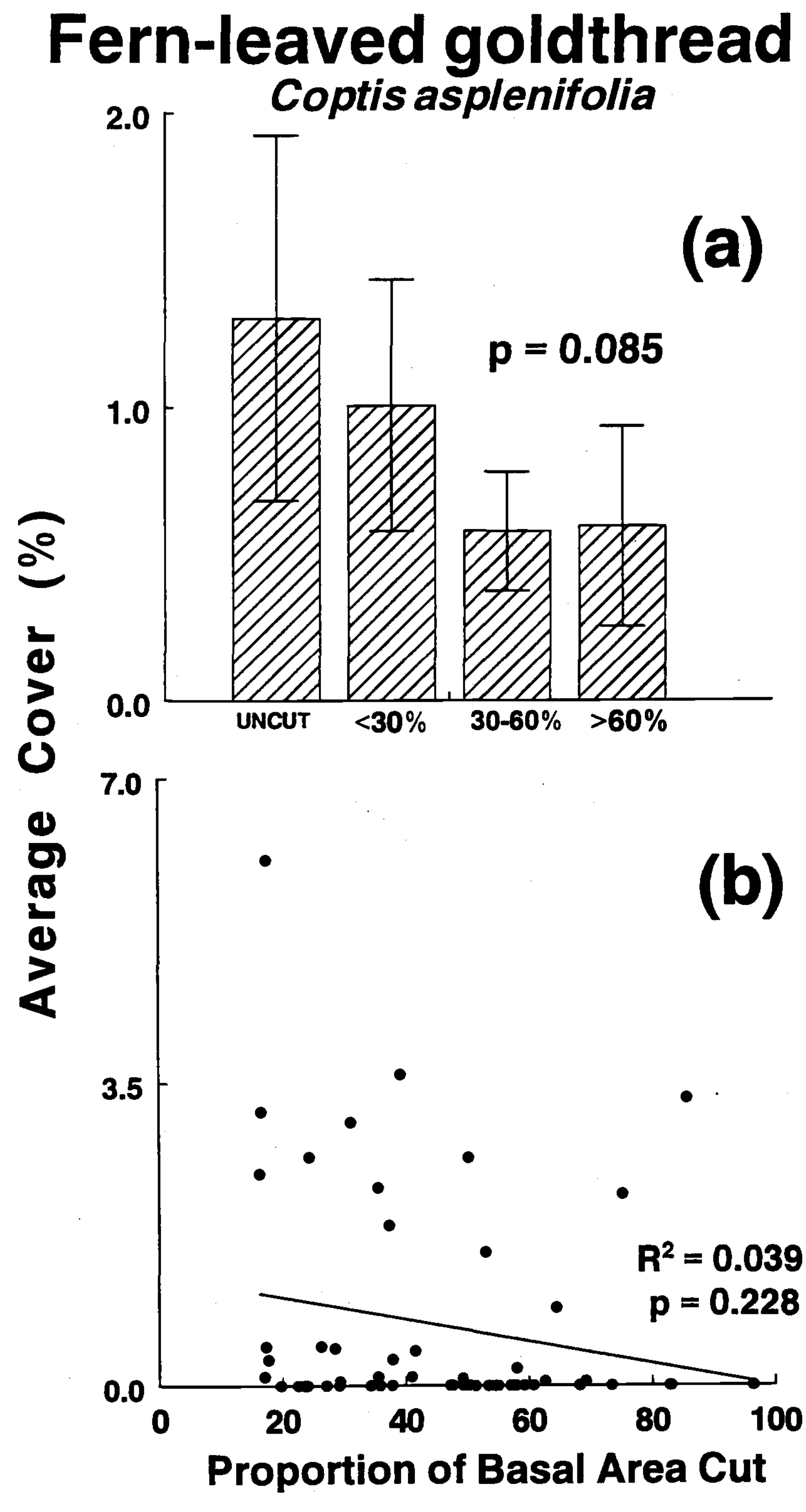

Figure 3.10 The average cover of fern-leaved goldthread, *Coptis asplenifolia*, by plot cutting intensity classes (a), and as a function of cutting intensity (b) for the 55 partially cut plots. Vertical lines in (a) represent standard error.

($R^2 = 0.039$, $p = 0.228$). There was no significant difference ($p = 0.187$) in average cover of COCA among uncut and partially cut plots (Figure 3.11a). Cover tended to decrease with increasing cutting intensity (Figure 3.11b), but the correlation was not statistically significant ($R^2 = 0.089$, $p = 0.446$). The average cover of RUPE (Figure 3.12a) was not significantly different among uncut and partially cut plots ($p = 0.345$). Abundance generally decreased with increasing cutting intensity (Figure 3.12b), but the correlation was not statistically significant ($R^2 = 0.069$, $p = 0.139$). The average cover of TITR (Figure 3.13a) was not significantly different among uncut and partially cut plots ($p = 0.780$). Cutting intensity was also poorly correlated ($R^2 < 0.001$, $p= 0.596$) with TITR abundance (Figure 3.13b).

The herb *Lysichiton americanum* (LYAM) and the fern *Dryopteris expansa* (DREX) had very different responses to partial cutting. The cover of LYAM was much lower in the partially cut than in the uncut plots (Figure 3.14a, $p = 0.0005$). However, cutting intensity was poorly correlated ($R^2 = 0.0074$, $p = 0.1481$) with average cover (Figure 3.14b), and LYAM was found on only 18 plots with highly variable cover. LYAM is a recognized indicator of wet soil conditions (Klinka et al. 1989), and the presence and abundance of LYAM is probably more related to wet microsites than either cutting treatment or cutting intensity. The only key plant species with higher cover in partially cut plots was DREX (Figure 3.15a, $p = 0.0098$). Abundance also tended to increase with increasing cutting intensity (Figure 3.15b); however, while statically significant ($p = 0.005$), the relationship did not explain much of the variation ($R^2 = 0.017$).

The blueberry shrub complex *Vaccinium alaskaense/ovalifolium* (VACC) was common, occurring in 70 plots (Table 3.6) and its cover varied widely among stands.

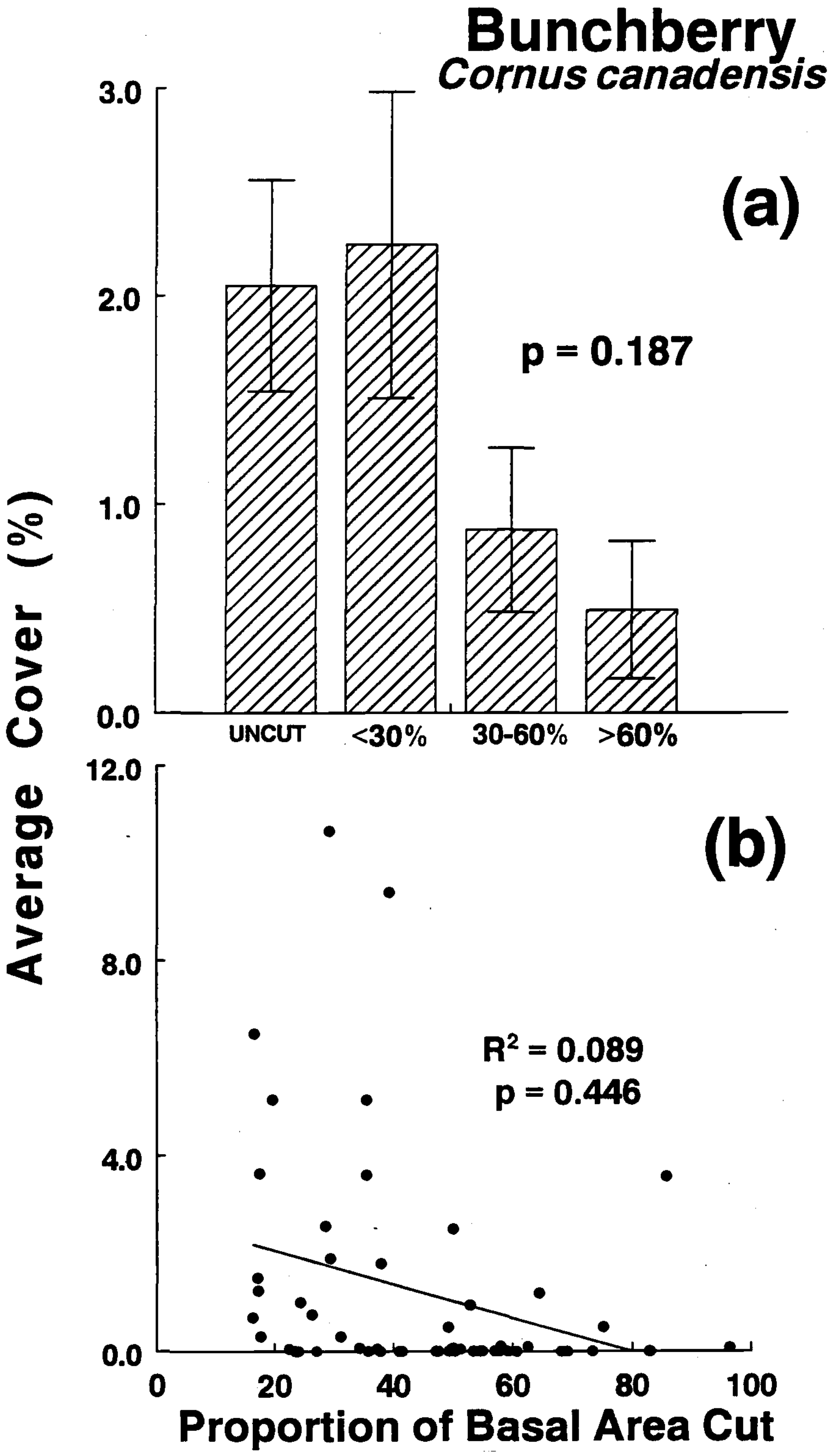

Figure 3.11 The average cover of bunchberry, *Cornus canadensis*, by plot cutting intensity classes (a), and as a function of cutting intensity (b) for the 55 partially cut plots. Vertical lines in (a) represent standard error.

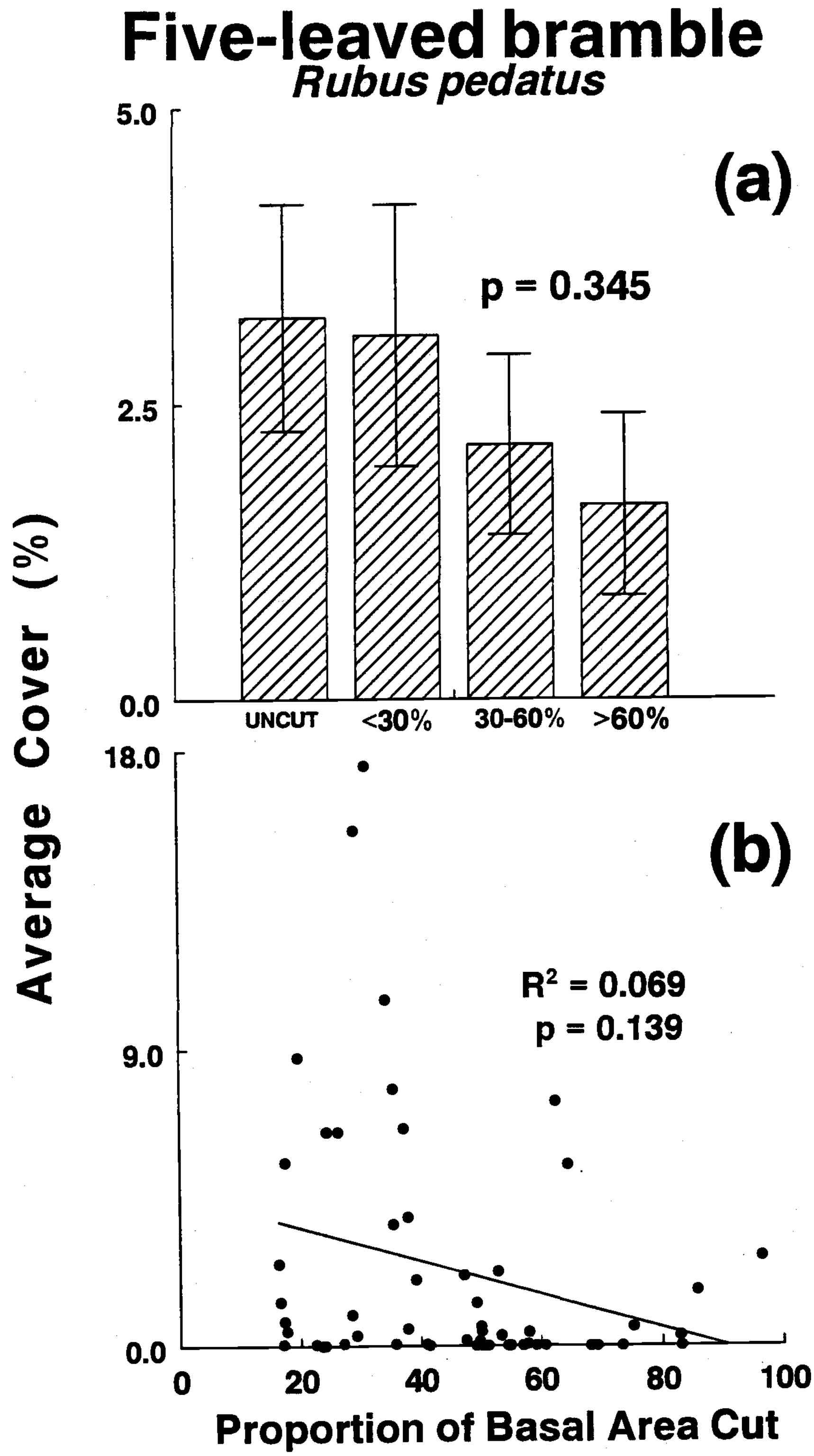

Figure 3.12 The average cover of five-leaved bramble, *Rubus pedatus*, by plot cutting intensity classes (a), and as a function of cutting intensity (b) for the 55 partially cut plots. Vertical lines in (a) represent standard error.

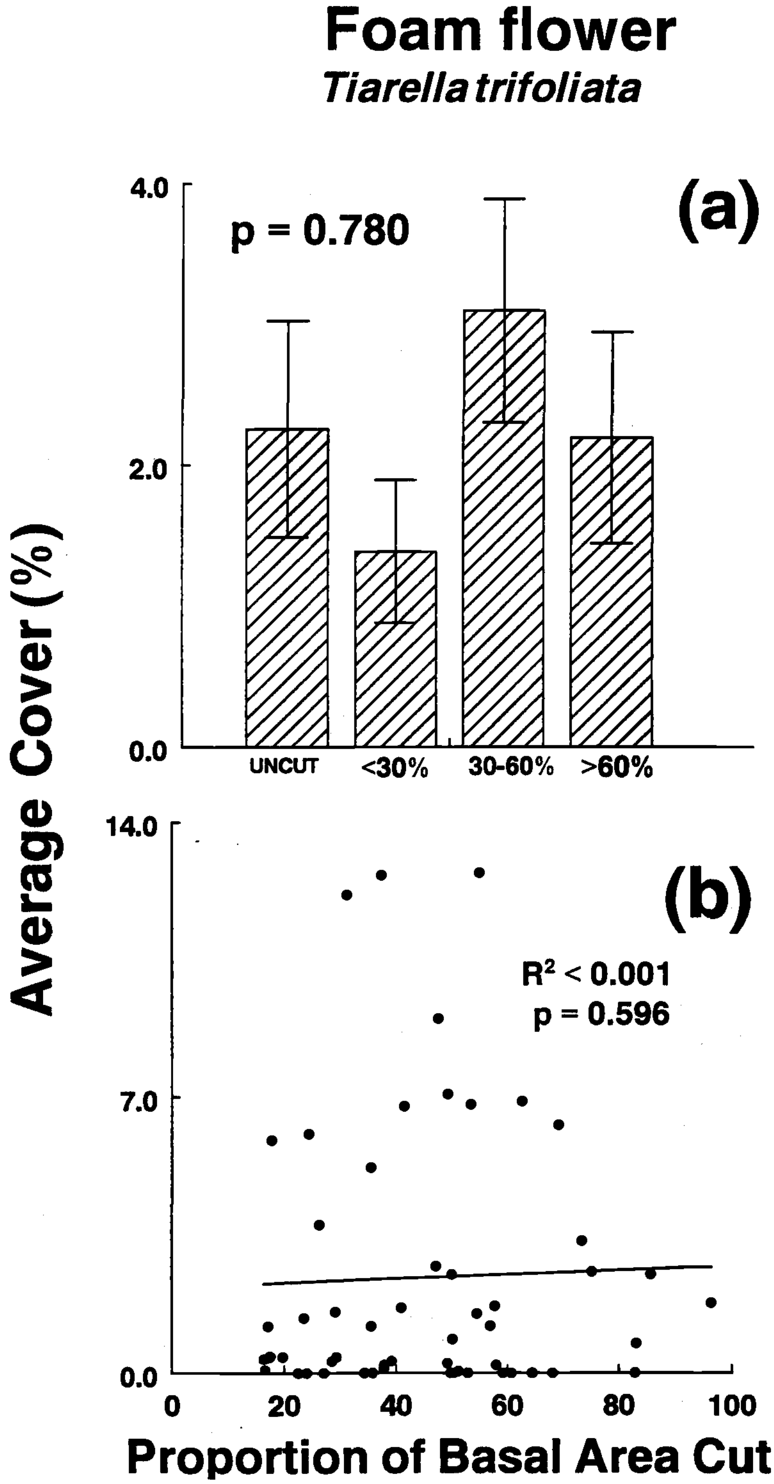

Figure 3.13 The average cover of foamflower, *Tiarella trifoliata*, by plot cutting intensity classes (a), and as a function of cutting intensity (b) for the 55 partially cut plots. Vertical lines in (a) represent standard error.

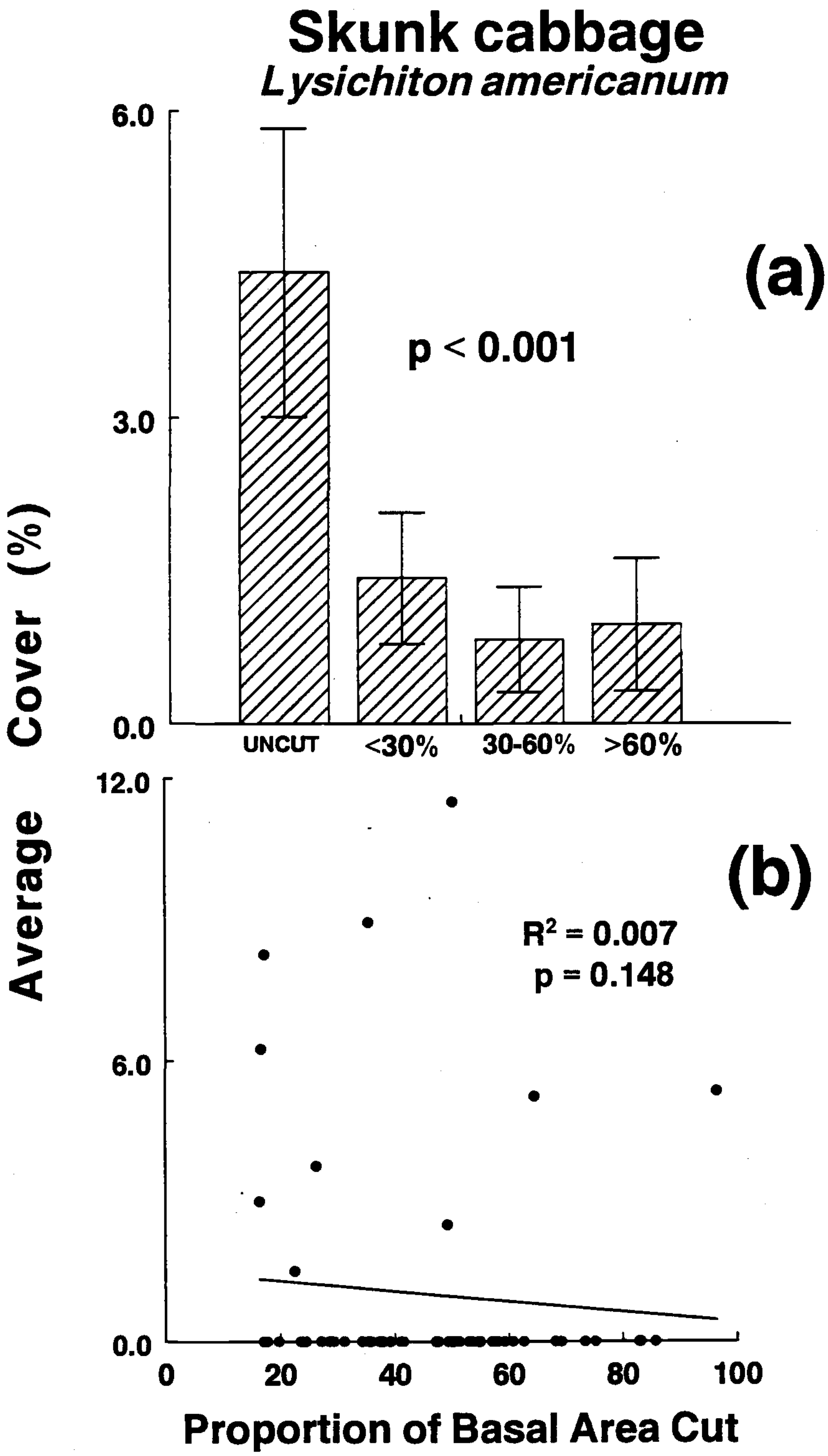

Figure 3.14 The average cover of skunk cabbage, *Lysichiton americanum*, by plot cutting intensity classes (a), and as a function of cutting intensity (b) for the 55 partially cut plots. Vertical lines in (a) represent standard error.

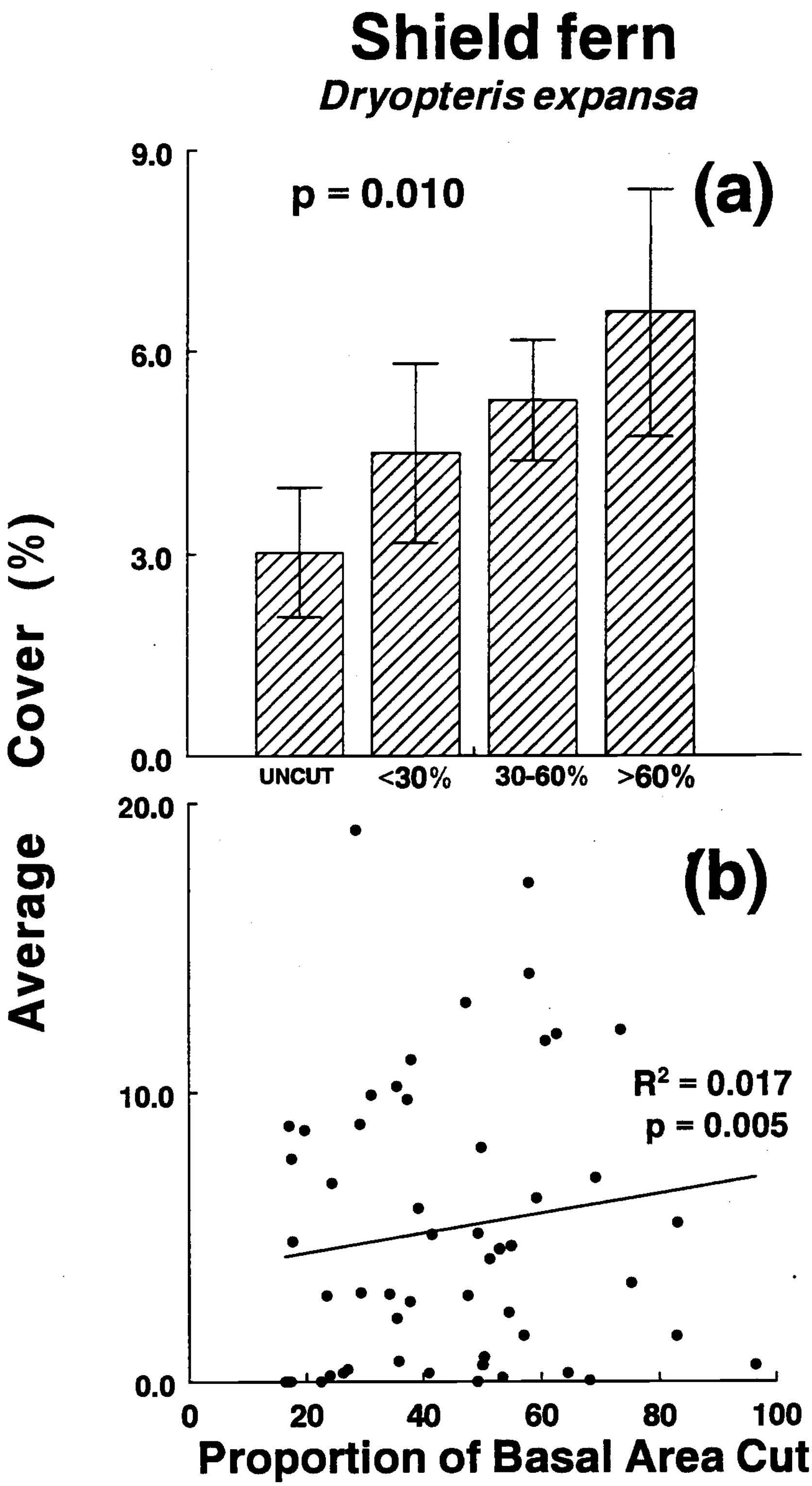

Figure 3.15 The average cover of shield fern, *Dryopteris expansa*, by plot cutting intensity classes (a), and as a function of cutting intensity (b) for the 55 partially cut plots. Vertical lines in (a) represent standard error.

There was a significant difference (p = 0.008) in average cover of VACC among uncut and partially cut plots (Figure 3.16a). Cover also significantly decreased with increasing cutting intensity (Figure 3.16b, p = 0.020, $R^2 = 0.060$). There was no significant difference (p = 0.4255) in average cover of the shrub *Vaccinium parvifolium* (VAPA) among uncut and partially cut plots (Figure 3.17a). Cover of VAPA decreased slightly with increasing cutting intensity (Figure 3.17b), but the relationship was weak ($R^2 = 0.013$, p = 0.2707).

The blueberry complex (VACC) is a common shrub and an important food source for Sitka black-tailed deer in southeast Alaska, and the significant decrease in blueberry abundance with intensity of partial cutting may reduce available deer forage. However, the decrease in blueberry abundance after partial cutting is relatively small compared with the near elimination of understory shrubs and herbs that commonly occurs after clearcutting. The average cover of blueberry in the partially cut plots was relatively constant over time since cutting (Figure 3.18a). This response is in sharp contrast to the pronounced decrease in blueberry during the stem exclusion stage after clearcutting. Comparison of partially cut and clearcut stands shows the rapid peak and dramatic drop of blueberry abundance in stands after clearcutting (clearcutting data from Alaback 1982b, Figure 3.18b). The abundance of blueberry in partially cut stands was much more uniform during the comparable 20-90 years since cutting, and did not show the drastic decrease in abundance common during this stage of stand development after clearcutting.

In summary, five of the eight key plant species for Sitka black-tailed deer forage showed no significant differences in abundance among uncut and partially cut plots. Four of the five herbaceous plants (COAS, COCA, RUPE and TITR) showed no significant differences in cover among uncut and partially cut plots. However, skunk cabbage

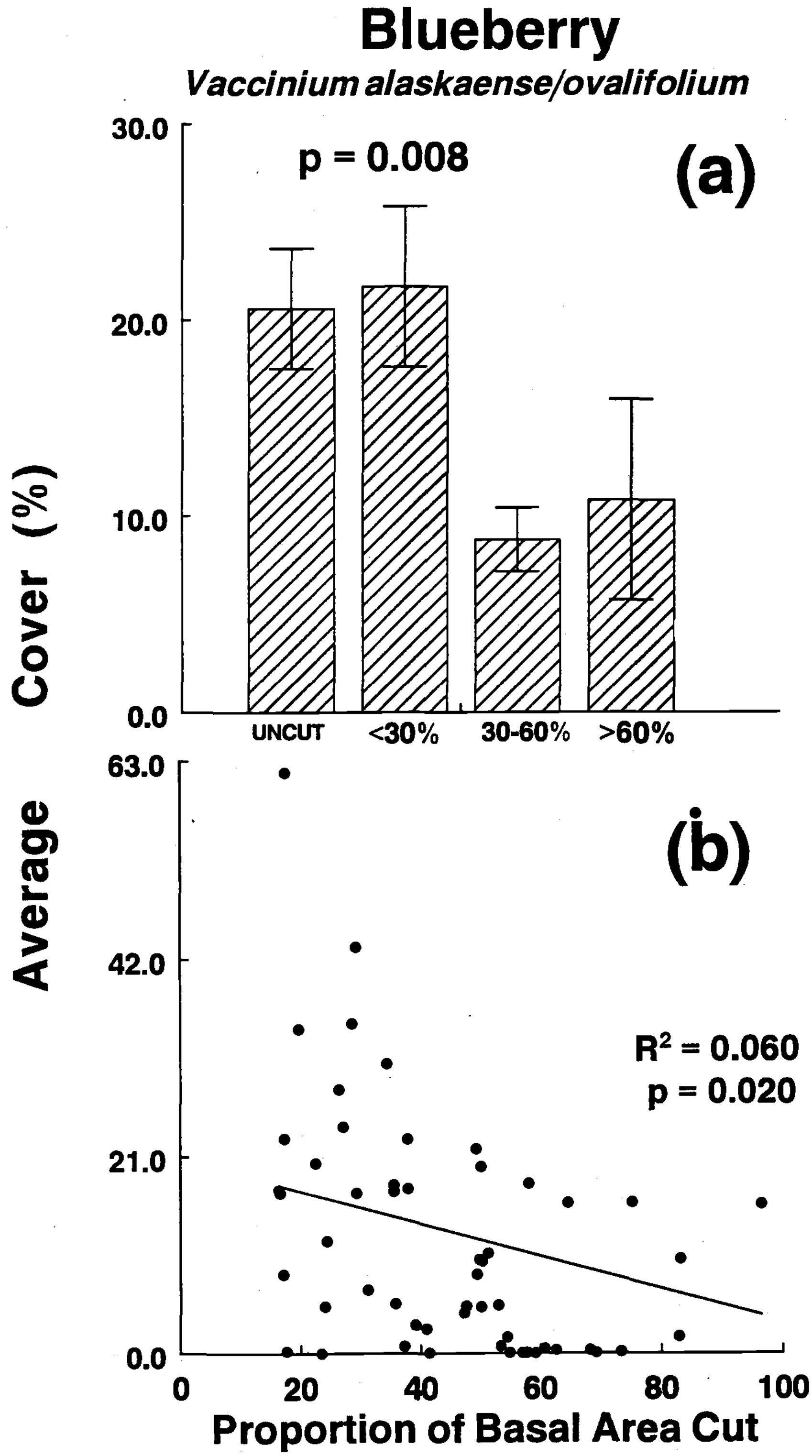

Figure 3.16 The average cover of the blueberry complex, *Vacciniumalaskaense/ovalifolium*, by plot cutting intensity classes (a), and as a function of cutting intensity (b) for the 55 partially cut plots. Vertical lines in (a) represent standard error.

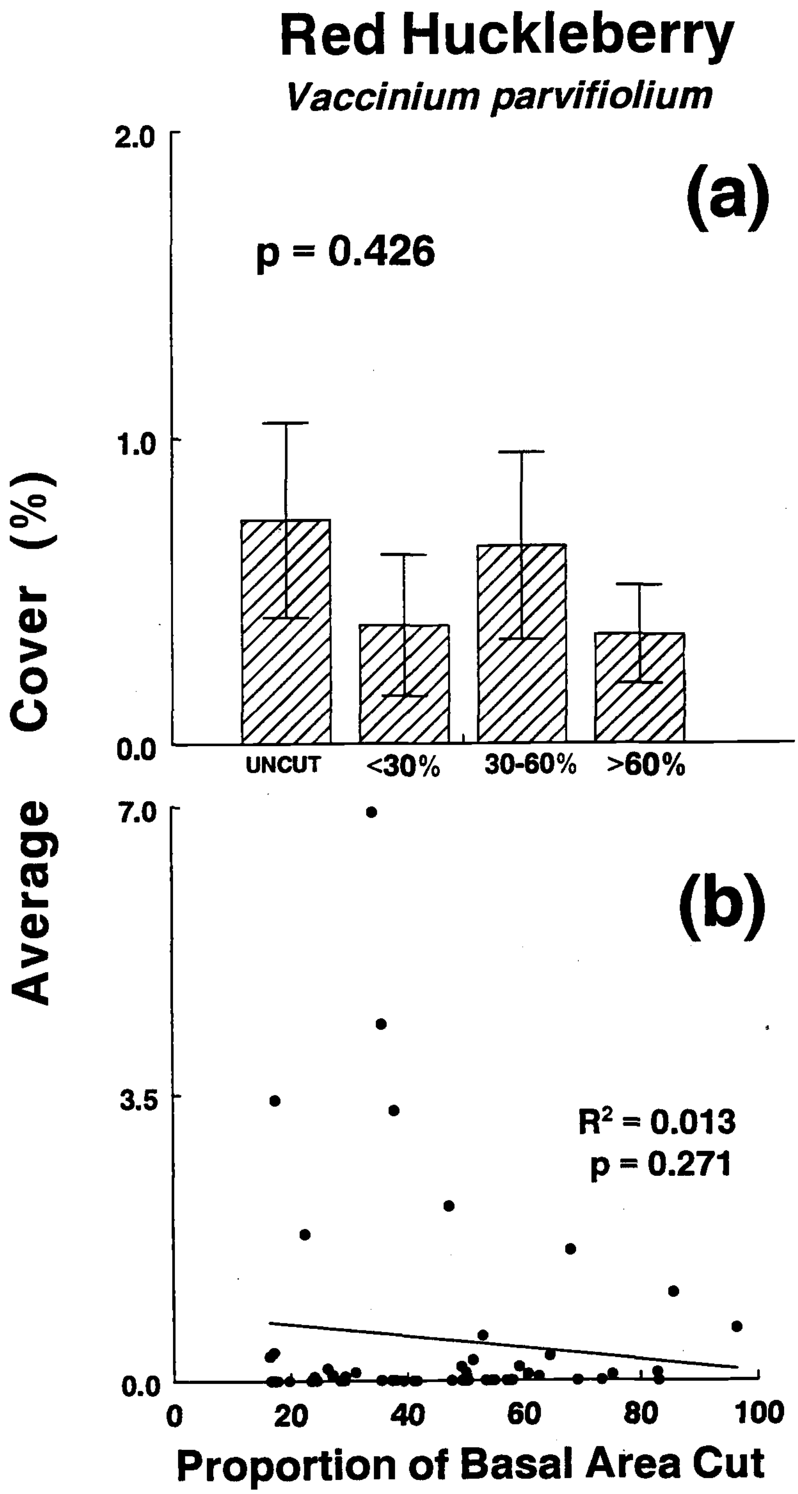

Figure 3.17 The average cover of red huckleberry, *Vaccinium parvifolium*, by plot cutting intensity classes (a), and as a function of cutting intensity (b) for the 55 partially cut plots. Vertical lines in (a) represent standard error.

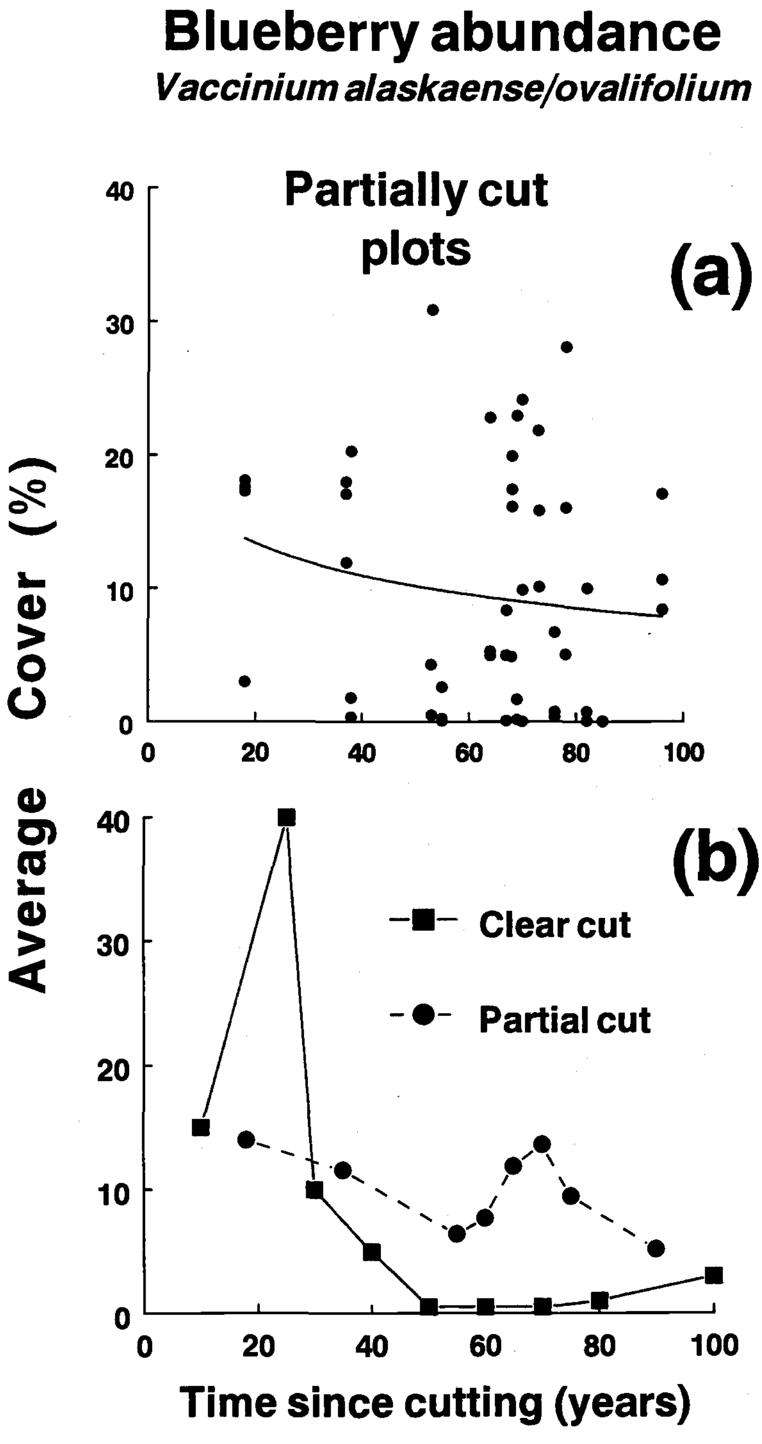

Figure 3.18 The average cover of the blueberry complex, *Vaccinium alaskaense/ovalifolium*, by time since cutting for the 55 partially cut plots (a), and comparison of abundance (b) in partially cut stands and in stands developing after clearcutting (clearcutting data from Alaback 1982b).

(LYAM), which is an infrequent but important plant for deer forage in the early spring season, may have lower abundance following partial cutting. The fern (DREX), which is important for deer forage in the late fall, showed a significant difference in abundance among uncut and partially cut plots, and cover generally increased with increasing cutting intensity. The two shrubs (VACC and VAPA) showed a significant difference and no change in abundance respectively after partial cutting, and cover of VACC generally decreased with increasing cutting intensity. Overall, following partial cutting, there was no significant difference in cover for most of the key species for deer forage, and I could not reject the null hypothesis that abundance of key plant species for deer forage was the same among uncut and partially cut plots.

Discussion

The species richness and plant diversity of these partially cut stands was very high and comparable to species richness reported in old-growth stands in the region Alaback 1982a, 1982b, Alaback and Juday 1989, Hanley and Hoel 1996, Hanley and Brady 1997). We found no significant differences in species richness between our uncut and partially cut plots, both for total plants and for vascular plants. The intensity of partial cutting appeared to change plant community composition but had little effect on species richness. The maintenance of species diversity and plant abundance after partial cutting was very different than what occurs after clearcutting. The loss of biodiversity is well documented following clearcutting (Wallmo and Schoen 1980, Schoen et al. 1988, Yeo and Peek 1992, Hanley 1993) and the development of conifers after clearcutting virtually excludes understory plants (Alaback 1982b, 1984, Deal and Farr 1994) for several decades. Alaback (1982a) found stands between 40-90 years after clearcutting to have very species-poor plant understories with most shrubs and herbaceous plants nearly absent. Some of the important plant species for wildlife forage showed slight reductions in cover following partial cutting, but overall plant abundance was much greater for these key plants than in stands that had been clearcut.

Plant communities appeared to be resilient within a wide range of cutting intensity. Ordination and cluster analysis showed that similar plant communities develop for different cutting intensity plots within individual stands. The differences in plant communities among stands appear to be much greater than the differences attributable to cutting intensity. Species composition may be related to site differences in soil drainage (Hanley & Brady 1997, Bormann et al. 1995, Ver Hoef et al. 1988), overstory tree composition (Hanley & Hoel 1996, Deal 1997), or other site-specific factors (Alaback 1994). The species composition and richness of uncut and partially cut plots was similar; however, there were significant differences in plant community composition between the uncut and the more heavily cut plots. These differences in community composition were generally non-significant for individual species, but when all species were evaluated together (MRPP analysis) significant differences in plant community structures between the uncut and heavily cut plots were apparent. However, these differences in community composition following moderate cutting intensity were relatively small compared with the virtual elimination of shrubs and herbaceous plants that occurs after clearcutting. There is a brief but very noticeable increase in understory plant biomass that peaks 15-to-25 years after clearcutting (Alaback 1982a). Tree canopy closure occurs soon afterward and causes a sharp and dramatic decline in plant diversity and abundance. This decline in plant abundance during the stem exclusion phase of stand development (Oliver & Larson 1990) is extremely intense in southeast Alaska and can last for over 100 years (Alaback 1984).

Following canopy closure there is a near total elimination of the shrub and herb strata (Alaback 1982b). In these partially cut stands, the dramatic increase and decrease in plant abundance was not apparent as stands developed after cutting. Overall, it appears that partial cutting leads to relatively stable plant communities and contain diverse and abundant plant understories comparable to what is found in old-growth stands.

The high species diversity reported in this study does not necessarily indicate that these partially cut stands are more stable, or demonstrate benefits in ecosystem function arising from high levels of bidiversity. Recent work by several authors (Wardle et al. 1997, Tilman et al. 1997, Hooper and Vitousek 1997) indicate that variations in ecosystem properties are related to differences in dominant plants, and there is no convincing evidence that ecosystem properties such as productivity and nutrient cycling are crucially dependent on high levels of biodiversity. The presence of key dominant plants appears to be critical for ecosystem stability; however, knowing which are the key plants for a particular ecosystem is largely unknown. In this study I found very high levels of species richness for both non-vascular and vascular plants. Although I have no clear idea which plants are the key species for ecosystem stability, species diversity of plants in these partially cut stands was very similar to old-growth stands and is likely to include the key plant species necessary for healthy ecosystem functioning.

The reasons that some stands have poor understory species diversity and abundance appear related more to stand dynamics and overstory tree composition than to cutting intensity. The nine plots with the poorest plant species diversity and abundance were located in only four stands. Cutting intensity varied widely from 22.5 to 82.9 percent of the original basal area cut. The current stand basal area was about average for plots in this study and only four of nine plots had greater than 60 m^2/ha. Stand density measures such as SDI and CCF were also only slightly higher than overall plot averages. The most important structural components for these poor-understory plots appear to be the number of trees and the proportion of hemlock in the stand. These nine poor-understory plots averaged over 1300 trees/ha which (cut plot average = 814 trees/ha) and 7 of 9 plots had greater than 1000 trees/ha. The proportion of hemlock stems in the plots also appears to be closely related to reduced species diversity and abundance. In these poor-understory plots almost 90% of the trees were hemlock and all nine plots were well above the cut plot average (79% hemlock). Furthermore, the six plots with the fewest vascular plants averaged almost 95% hemlock. It appears that hemlock-dominated stands with large numbers of trees severely suppressed understory development. In addition, most of the trees in these poor-understory plots were small-diameter trees established soon after cutting, and these trees formed a dense new cohort in the stand that suppressed shrubs and herbs. In a coastal spruce-hemlock stand in Oregon, Alaback and Herman (1988) also found that the establishment of a second cohort of trees below the spruce stand severely suppressed the understory vegetation. Deal and Farr (1994) also found that thinning young stands promoted dense germination of understory conifers and prevented the establishment of other understory plants. It appears that stand dynamics and tree species composition are important components of overstory-understory interactions and influences understory plant community composition.

Tappeiner and Alaback (1989) found that the germination and overall survival for 3 to 4 years of VACC, COCA, RUPE, COAS and TITR was significantly lower in young stands than in old stands and they found a highly positive correlation between incident solar radiation and survival for most species. Understory establishment was retarded by slow seedling growth and clonal development, especially in the young stands. They found maintenance of most understory plants in old-growth stands was due to new seedling establishment and clonal development. These species also showed vigorous response to disturbances such as windthrow or clearcutting and all but TITR responded quickly to severe disturbances. Clearcut stands had three to seven times the rhizome growth than in undisturbed old-growth stands. However, these benefits are generally short lived and once canopy closure occurs most of these plants are shaded out and virtually eliminated. Partial cutting may provide conditions that are very conducive to establishment and growth of understory plants, and is probably more comparable to natural disturbances than clearcutting.

Partial cutting may closely mimic the natural disturbance regime of southeast Alaska. This region is dominated by small-to-medium scale wind disturbances and tree blowdown is common. Large-scale catastrophic events such as fires are rare. The intensity and frequency of wind disturbances appears to be related to aspect and topography (Ott 1997, Kramer 1997, Nowacki & Kramer 1998). Frequently, some of the original stand remains after blowdown creating complex stand structures and small-scale, low intensity disturbances are common (Lertzman et al. 1996). Partial cutting does a much better job of mimicking this natural disturbance regime than clearcutting. The complex structures left after partial cutting appears to create conditions similar to natural low intensity disturbances common in the region.

Partially cut and old-growth stands had similar species diversity and plant community structures and these similarities may be related to forest stand structures. Following partial cutting there are often a wide range of large and small trees left in the residual stands, and the newly developing stands are structurally complex with multi-layered forest canopies. These stand structures created from partial cutting are very different than the uniform, single-generation stands that develop after clearcutting or other catastrophic events. The heterogeneous stand structures created from partial cutting are much more similar to old-growth stands than to the uniform young-growth stands that develop after clearcutting. Alaback (1984) found that several structural differences between old-growth stands and young-growth stands were related to differences in canopy density and canopy structure. These stand structures may influence light levels that are critical components for understory plant development (Alaback 1984, Tappeiner and Alaback 1989). The presence of large and small residual trees left after partial cutting creates structural heterogeneity and complex overstory-understory interactions, and these structures may be important for maintaining abundant and diverse understory plant communities.

Conclusion

Partially cut stands had high species diversity and maintained understory plant abundance over a wide range of cutting intensity. The species richness of all plants and vascular plants was similar among uncut and partially cut plots and the intensity of partial cutting did not led to significant changes in plant species richness. Overall, there were no significant differences in plant community structures between the uncut and partially cut plots. However, the intensity of cutting did cause some significant changes in plant community composition. The moderate and heavy cutting intensities had significantly different community composition than the uncut plots and it appears that increasing cutting intensity caused some changes in plant community structures. Distinct patterns of plant communities were apparent for both geographic location and forest type. Plant communities changed with latitude and species composition and abundance appeared to be distinctly different among hemlock-dominated and spruce-dominated stands.

Partial cutting did not significantly change abundance for most of the key species for deer forage. Five of the eight key plant species (COAS, COCA, RUPE, TITR, and VAPA) showed no significant changes in abundance, two species decreased in abundance (LYAM and VACC) and one species increased in abundance (DREX) following partial cutting. Also, the modest decreases in abundance for some key species after partial cutting were relatively small compared with the near elimination of understory shrubs and herbs that commonly occurs after clearcutting.

Partially cut and uncut old-growth stands had similar species diversity and plant community structures, and these similarities may be related to forest stand structures. The heterogeneous stand structures created from partial cutting are much more similar to old-growth stands than to the uniform young-growth stands that develop after clearcutting. These partially cut stands also appear to be able to maintain plant diversity over a wide range of cutting. Overall, partial cutting appears to be a viable uneven-aged management prescription to maintain biodiversity in western hemlock-Sitka spruce stands in southeast Alaska.

Chapter 4.

THE FEASIBILITY OF USING NEW SILVICULTURAL SYSTEMS IN WESTERN HEMLOCK-SITKA SPRUCE STANDS IN SOUTHEAST ALASKA

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Introduction

The purpose of this chapter is to assess the possibility of using new silvicultural systems in southeast Alaska. The results from different sections of the retrospective study on partial cutting will be synthesized, with a focus on concerns with conventional and new silvicultural systems. In this study, the term "partial cutting" refers to any harvesting practice where part of the original stand was cut and the rest of the residual stand was left intact after logging. These partially cut stands were not part of a planned silvicultural system, and generally little thought was given to the future management of the stand. Several examples of partially cut hemlock-dominated and spruce/hemlock stands will be presented using photographs, tree diameter distributions and other stand structural information. These stands were chosen to show a range of current stand conditions following partial cutting, and the cutting history and stand development since time of cutting in these stands is discussed. Finally, the management implications and feasibility of using new silvicultural systems will be discussed using some of these representative stands as potential candidates.

In the western United States, there is increasing interest in developing new stand management strategies to maintain or enhance biodiversity and assure long-term sustainability of forest resources. Therefore, new silvicultural systems are being considered in attempts to develop late-succession and old-growth stand characteristics. Many of these new systems include forms of uneven-aged and selection silviculture used in other regions. However, these systems are being applied in new regions with different forest types. It is important to objectively evaluate the likelihood of success of a new system before implementing this system region-wide. A particularly controversial area of forest management has been the use of clearcutting, and recent region-wide forest-management plans (Record of Decision 1994, Record of Decision 1997) have prescribed specific silvicultural guidelines for management activities where alternatives to clearcutting will be implemented. However, very little is known about the effects of new systems that use small openings or individual tree selection, particularly in southeast Alaska where clearcutting has been the dominant regeneration method. The effects of any new silvicultural system on stand dynamics, plant diversity, stand regeneration and mortality should be evaluated before broad scale implementation.

In southeast Alaska partial cutting of western hemlock and Sitka spruce was common until the establishment of pulp mills in the region in the early 1950s. Hemlock was used for dock pilings and lumber, and Sitka spruce for salmon cases, barrels and buildings. Logging was limited to easily accessible areas near the shoreline and along river valleys. The total harvested areas were also generally small (less than 50 hectares), and timber was harvested by cutting individual trees or small openings in the stand and leaving the remaining overstory stand intact. The opening of pulp mills in the region lead to significant changes in the way forests were managed. Road building opened up areas of previously inaccessible forests, and large blocks of forest were clearcut. Clearcutting with natural regeneration has been the predominant practice in the region since the 1950s.

Several biological and economic reasons have been reported for the continued use of clearcutting in the western hemlock-Sitka spruce forest type of southeast Alaska, and some major concerns with the use of partial cutting have been presented by Harris and Farr (1974). However, most of the adverse effects of partial cutting are speculative or based on research done in other regions. Prior to this study, information on the effects of partial cutting on stand structure and growth, tree composition, regeneration, and patterns of disease and mortality in hemlock-spruce stands in southeast Alaska was largely unknown. In addition, there are also some serious concerns with the use of clearcutting on biological conservation, long-term maintenance of understory plants, wildlife habitat, and with the public acceptance of clearcutting. The results from this study will be used to evaluate some of the reported problems with partial cutting and to assess some of the known concerns with clearcutting. Some of the commonly stated biological concerns with partial cutting include:

1) partial cutting reduces the proportion of Sitka spruce, a more desirable timber species;
2) residual trees left after partial cutting are often of poor quality and low vigor, and the future yields will be reduced in stands developing after partial cutting;
3) dwarf mistletoe is common in older stands with heavily infected western hemlock trees, and partial cutting increases the proportion of stand infected;
4) both western hemlock and Sitka spruce are thin-barked species and easily wounded during logging, and partial cutting increases the wounding of trees left after logging;
5) windthrow is common after partial cutting.

Some of the major concerns with clearcutting in southeast Alaska include the following:

1) following clearcutting relatively uniform stands develop with greatly reduced structural diversity, and these stands provide inadequate winter deer habitat;
2) plant diversity and abundance, particularly for importance species for deer forage, dramatically declines for several decades following stand canopy closure that naturally occurs 20-30 years after clearcutting;
3) clearcutting is socially unacceptable with poor aesthetic and visual quality.

Synthesis of results from the retrospective study

In this study, we used a retrospective approach to evaluate the effects of partial cutting on stand structure and growth, patterns of conifer regeneration, stand mortality and disease, and understory plant diversity and abundance. We established seventy-three 1/5 ha plots in 18 different stands that were partially cut 12 to 96 years ago. Stands were selected throughout southeast Alaska and harvest intensity ranged from 16 to 96 percent of the original stand basal area cut.

Changes in tree species composition

Partial cutting did not lead to significant changes in the composition of either Sitka spruce or western hemlock, nor did the intensity of partial cutting cause significant changes in tree species composition. Overall, species composition in stands generally did not change after partial cutting, and hemlock-dominated stands remained hemlock stands, and spruce/hemlock stands remained spruce/hemlock stands. The proportion of new tree regeneration increased with increasing intensity of cutting but the species proportions remained relatively similar over a wide range of cutting intensity. In all of the spruce/hemlock stands, and in most of the hemlock-dominated stands, there are generally sufficient numbers of spruce to maintain spruce in the future stand. Analysis of the 55 partially cut plots in this retrospective study showed that new spruce regeneration was established in 23 plots, and residual spruce were present and responded to release in 47 plots. Furthermore, new spruce regeneration was established in only 2 of the 18 uncut plots in this study. It appears that partial cutting can maintain Sitka spruce in mixed hemlock/spruce stands within a wide range of cutting intensity.

Establishment of seedling banks

Both western hemlock and Sitka spruce had established seedling banks in most stands. The density of hemlock and spruce seedlings (current seedling bank) was generally high throughout our study sites with hemlock density ranging from 47,000 to 723,000 seedlings per ha and spruce density ranging from zero to 114,000 per ha (Yount 1997). Spruce seedling density averaged at least 3000 seedlings per ha at all but one site. The only stand that did not have a spruce seedling bank was in a very densely stocked (plot mean of 1823 trees/ha), hemlock-dominated stand at Margarita Bay where full canopy closure was suppressing understory trees and plants. Hemlock seedlings were always more numerous than spruce seedlings, however, most sites had more than adequate numbers of spruce seedlings to restock the site for timber management purposes. Significantly more seedlings of both species were found on logs than on the undisturbed forest floor when data from all sites were combined (Yount 1997). The amount of substrate (logs and undisturbed forest floor), treatment (logged and unlogged), and shrub cover varied from site to site. Overall, there was 3 ½ times more ground surface area covered by forest floor (7,700 m^2/ha) than logs (2200 m^2/ha). Seedling height growth rates for hemlock and spruce were uniformly low in closed canopy stands ranging between 1.2 and 2.3 cm/year.

Stand and tree growth

The stand net basal area growth increased with increasing cutting intensity and cut plots had significantly greater growth than uncut plots. However, the growth response was irregular among and within stands, and a few of the lightest cutting intensity plots had negative net growth. Overall, stand net basal area growth since cutting averaged 36.9 m^2/ha for all cut plots compared with 27.3 m^2/ha for the uncut plots. The medium and heavy cutting intensities (plots that had at least 30 percent of the original stand basal area cut) had significantly greater growth (average of 40.6 m^2/ha) than the lighter cutting intensities (average of 28.0 m^2/ha for plots with less than 30% of stand basal area cut). The current stand basal area, tree species composition, and stand growth for all cutting intensities was strongly related to trees left after harvest. More than 90 percent of stand basal area growth for the fifty-five partially cut plots occurred on residual trees, and there was a highly significant difference in growth among new and residual trees. The least growth occurred on the new tree regeneration with an average diameter growth for trees in the cut plots of only 12.9 cm for the 60-year-growth period analyzed. The most diameter growth occurred on residual trees that were 10- to-70 cm dbh at time of cutting. These trees grew an average of 23 to 27 cm during the 60-year-growth period. Basal area growth of hemlock and spruce was proportional to species composition left after cutting, and there were no significant differences in growth among species in either size classes or cutting intensities. About 60-75% of stand basal area growth was on hemlock trees, the remainder of growth from spruce and other species.

Hemlock dwarf mistletoe

The amount and severity of hemlock dwarf mistletoe infection were highly variable among stands, and appear to be more related to tree species composition and stand history than cutting treatments. The amount and severity of dwarf mistletoe infected trees were similar among uncut and partially cut plots. The average hemlock Dwarf Mistletoe Rating (DMR scale of 0 to 6, 1-2 = low, 3-4 = moderate, 5-6 = severe) was 1.4 for uncut plots and 1.0 for cut plots (Palkovic unpublished data). Dwarf mistletoe infection also showed a slight but non-significant decrease with increasing cutting intensity. Overall, hemlock dwarf mistletoe did not appear to be a major concern in these partially cut stands.

Tree mortality and wounding

There were no significant changes in the amount of tree mortality following partial cutting. The proportion of tree mortality was similar for the uncut and partially cut plots with 17.4 percent tree mortality since date of cutting in the uncut plots and 14.1 percent in the cut plots. However, it appears that the mode of death was different between the cut and the uncut plots. There was a 10% increase in the proportion of trees uprooted in the cut plots and a corresponding 10% increase in the proportion of broken and dead standing trees in the uncut plots. The proportion of trees wounded from partial cutting (visible scars on the bole) was also not significantly different than naturally wounded trees in uncut plots. The cut plots had an average of 13.0 percent of trees wounded compared with 13.4 percent of trees wounded in the uncut plots (Palkovic unpublished data). Overall, tree mortality and wounding injuries from logging did not appear to be a major management concern in these partially cut stands.

Forest plant communities

Overall, the partially cut stands had high species richness, and the understory plant species composition was not different than uncut plots. The species richness of all plants and vascular plants was similar among uncut and partially cut plots, and the intensity of cutting did not lead to significant changes in plant species richness. The number of species per plot averaged 31.8 in the uncut plots, and averages ranged from 27.5 to 33.7 in the cut plots. Overall, there were no significant differences in plant community structures between the uncut and partially cut plots. Species composition varied widely among stands but plant community structures were similar for both the uncut and cut plots within each stand. However, the intensity of cutting did cause some significant changes in community composition. The moderate and heavy cutting intensities had significantly different community composition than the uncut plots, and it appeared that increasing cutting intensity caused some changes in plant community structures. Also, plant communities changed with latitude, and species composition and abundance appeared to be distinctly different among hemlock-dominated and spruce/hemlock stands. The plots with the fewest species and least abundance of understory plants were those with dense hemlock overstories. The six plots with the fewest vascular plants were in stands with hemlock accounting for 95% of the tree density. In addition, most of these plots with poor understory plants contained numerous small-diameter trees that were established soon after cutting, and these trees formed a dense new cohort in the stand that suppressed shrubs and herbs. It appears that hemlock-dominated stands with large numbers of trees severely suppressed understory plant development.

Five of the eight key plant species (fern-leaved goldthread, bunchberry, five-leaved bramble, foamflower, and red huckleberry) showed no significant changes in abundance, two species decreased in abundance (skunk cabbage and blueberry), and one species increased in abundance (shieldfern) following partial cutting. Overall, the modest decreases in abundance for some key species after partial cutting were relatively small compared with the near elimination of most understory herbs and shrubs that commonly occurs after clearcutting. Partially cut and uncut old-growth stands have similar species richness and plant community structures, and these similarities may be related to forest stand structures. The heterogeneous stand structures created from partial cutting are generally more similar to old-growth stands than to the uniform young-growth stands that develop after clearcutting. These partially cut stands also appear to be able to maintain plant diversity over a wide range of cutting intensity. Partial cutting also did not significantly change abundance for most of the key plant species for deer forage.

Examples of partially cut stands

Several examples of partially cut stands were used to show current stand overstory and understory conditions. These representative stands were chosen to show a range of current stand structures following partial cutting, and the cutting history and stand development since time of cutting of these stands is discussed. Photographs of current overstory and understory conditions are presented, and the current tree diameter distribution and seedling bank of these stands are shown. The cutting intensity, residual basal area and other structural information are also described for each example. Hemlock-dominated and spruce/hemlock stands frequently had different responses to partial cutting and these stands are discussed separately. Hemlock-dominated stands had much higher proportions of hemlock and higher tree densities and regeneration than spruce/hemlock stands. Stands with hemlock trees comprising at least 85% of the established trees were designated as hemlock-dominated stands. Conversely, the total tree density and density of hemlock trees was substantially less in stands with spruce comprising at least 12% of the trees. These stands were designated as spruce/hemlock stands. Hemlock-dominated and spruce/hemlock stands are also described separately in the management implications and feasibility of using new silvicultural systems sections of this chapter.

Examples of hemlock-dominated stands

a) The stand at Thomas Bay is an example of a hemlock-dominated stand 12 years after cutting (Figures 4.1 and 4.2). The Thomas Bay stand was similar to some of the younger hemlock-dominated stands in this study including the Granite and Pavlof River sites. This stand is a moderately productive site with a site index of 30 (Farr 1984, base age 50, height in meters). Cutting intensity at Thomas Bay ranged from 19.7 to 29.2 percent of the original stand basal area cut. The stand has vigorously responded to cutting with prolific new conifer regeneration and abundant understory herbs and shrubs. Most of the overstory trees are hemlock including 83% of the tree density and 99% of the stand basal area. However, there are many spruce saplings and seedlings in the stand (Figure 4.1) and in the medium cutting intensity plot a new cohort of spruce is apparent (Figure 4.2). The current seedling bank is also prolific (Figure 4.2) and averaged 747,000 seedlings/ha (97% hemlock). This stand is relatively open and has high plant species richness and abundance (stand average of 41 to 48 species/plot), but the excessive conifer regeneration may eventually shade out and suppress the understory. If one of the major objectives in this stand is to maintain understory plant diversity and abundance, then thinning the new conifer regeneration will probably be required to reduce the tree density in this stand.

b) The stand at Margarita Bay is an example of hemlock-dominated stand 38 years after cutting (Figures 4.3 and 4.4). The Margarita Bay stand is an atypical site, and different than other stands in this study. This stand appears to have responded more like young-growth stands 30 years after clearcutting, than to stands that were partially cut. The cutting intensity was generally high in this stand ranging from 22.5 to 82.9 percent of the stand basal area cut and two of the plots were very heavily cut (68.2 and 82.9 percent).

Thomas Bay stand 12 years after cutting

Figure 4.1 The hemlock-dominated stand at Thomas Bay was recently cut (12 years ago) and the cutting has resulted in a vigorous understory plant response and the establishment of excessive numbers of new conifer regeneration. The plot pictured is the medium cutting intensity plot that had 29.2 percent of the stand basal area cut with 43.8 m^2/ha left after cutting. This plot is still relatively open with a basal area of 49.4 m^2/ha and CCF of only 162. There are 766 trees/ha that are at least 2.5 cm d.b.h., and most of the overstory trees are hemlock with hemlock comprising 83% of the trees and 99% of the stand basal area. Most of the new regeneration is 1-2 meters tall and not large enough to be included in tree density estimates. However, many sapling-sized spruce trees are evident in this photo, and it appears that adequate numbers of spruce have become established to maintain spruce in the stand. Understory plant species richness and abundance is high. This plot contained 41 species of plants including 13 vascular plants. Several key plant species for deer forage are also present including five-leaved bramble, foamflower, shield fern and large amounts of bunchberry and blueberry.

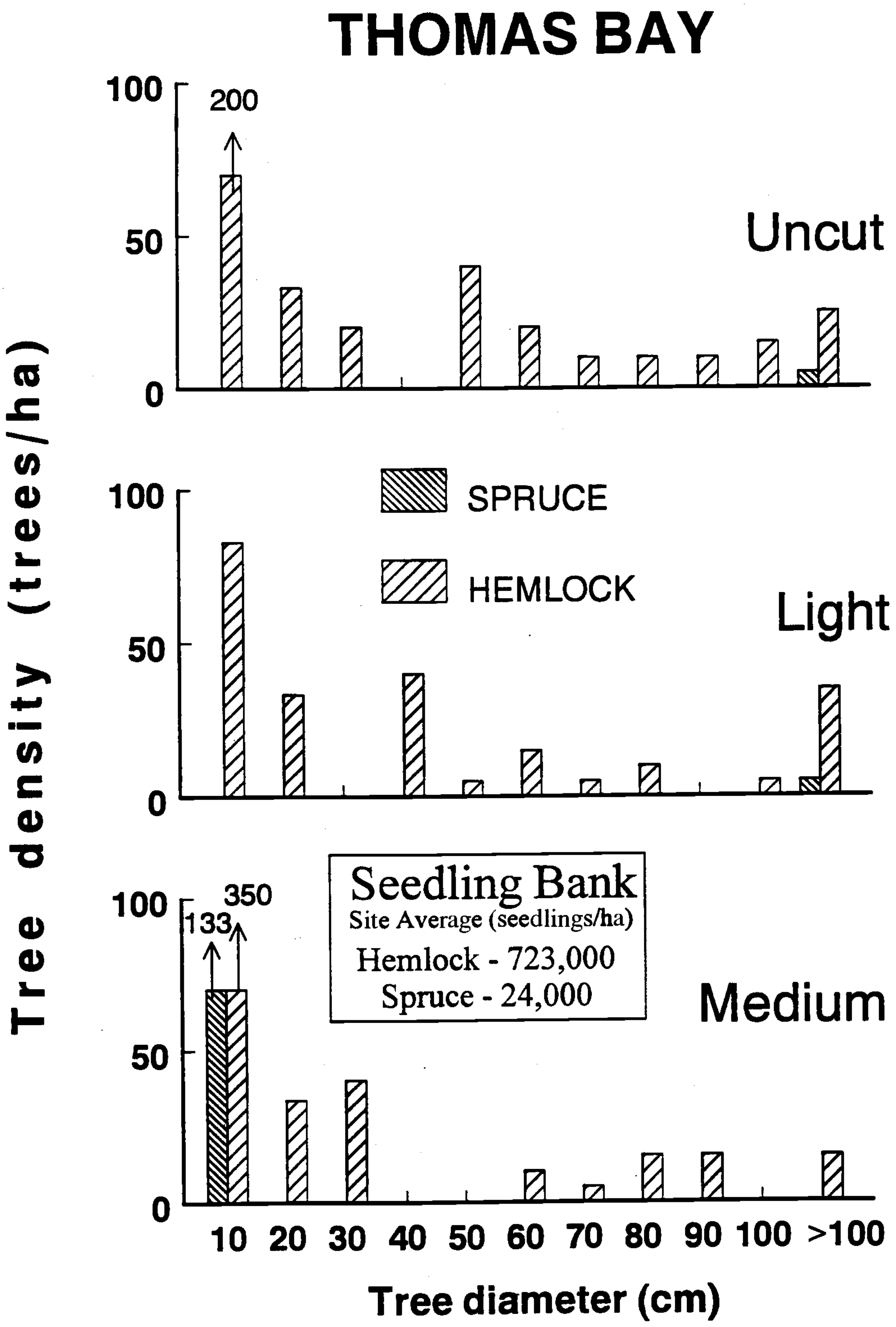

Figure 4.2 The current tree diameter distribution 12 years after cutting in a hemlock-dominated stand at Thomas Bay. The diameter distribution includes all trees greater than 2.5 cm d.b.h. for the uncut, light, and medium cutting intensity plots. The seedling bank includes all seedlings less than 3 m tall in the current stand (data from Yount 1997).

Margarita Bay stand 38 years after cutting

Figure 4.3 The hemlock-dominated stand at Margarita Bay is an example of a stand that had excessive new regeneration established after cutting, and this new regeneration has developed and suppressed the understory plants. The plot pictured is the medium cutting intensity plot and it had 68.2 percent of the stand basal area cut with 13.0 m^2/ha left after cutting. Full canopy closure is apparent and the suppression of understory plants is similar to the stem exclusion stage of stand development that normally occurs after clearcutting. This plot has a stand basal area of 44.3 m^2/ha and a CCF of 298 indicating high stand density. The plot is very heavily stocked with an average of 2695 trees/ha that are at least 2.5 cm d.b.h. Most trees on the plot are new regeneration established after cutting, with 2117 new hemlock and 233 new spruce per hectare. Overall, 88% of the tree density and 85% of the stand basal area is hemlock. Understory plant species richness and abundance is very low. This plot contained 18 plant species (mainly bryophytes) including only 6 vascular plants. The only key plant species for deer forage were some very small amounts of shield fern, blueberry and red huckleberry.

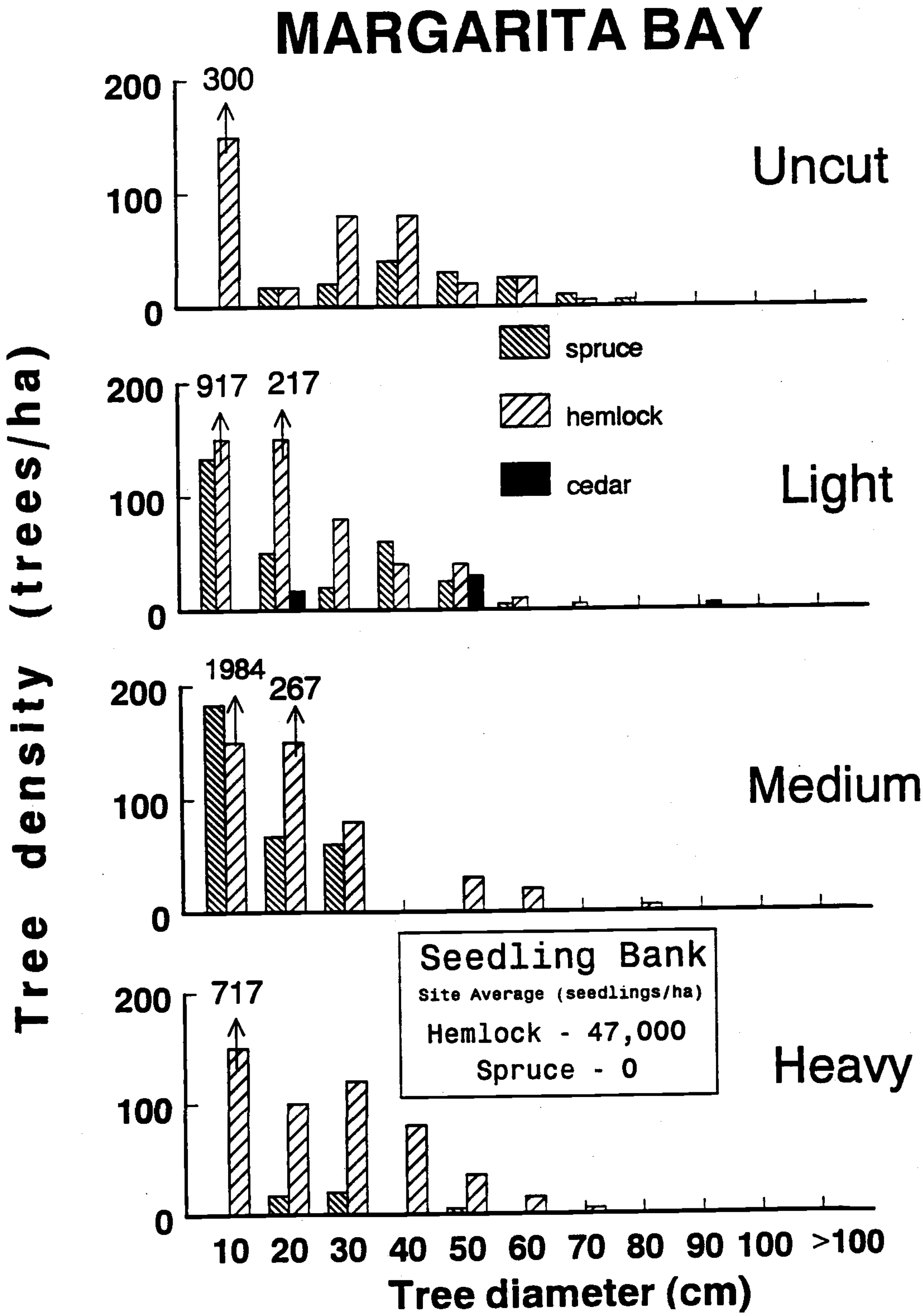

Figure 4.4 The current tree diameter distribution 38 years after cutting in a hemlock-dominated stand at Margarita Bay. The diameter distribution includes all trees greater than 2.5 cm d.b.h. for the uncut, light, medium and heavy cutting intensity plots. The seedling bank includes all seedlings less than 3 m tall in the current stand (data from Yount 1997).

Most of the stand had excessive new regeneration, very high tree density, and few large residual trees left in the current stand. Tree density ranges from 1658 to 2695 trees per hectare with hundreds of small-diameter and relatively uniform-sized hemlock trees. However, new spruce regeneration occurred in all of the cut plots, and although hemlock trees were much more numerous, it appears that many larger-sized spruce trees have become established (Figure 4.4). This stand looks similar to the stem exclusion stage of stand development that is common 30 to 40 years after clearcutting. Full canopy closure has occurred in the heavy and medium cutting intensity plots (Figure 4.4), and has resulted in the suppression of understory plants (Figure 4.3) and reduced conifer regeneration. Overall, the Margarita Bay stand averaged 47,000 conifer seedlings/ha (the fewest from any of the stands in this study) and all seedlings were hemlock (Figure 4.4). Understory plant species richness and abundance was very low with an average of only 6 to 10 vascular plants per plot. This stand is an example of heavy cutting in hemlock-dominated stands leading to overstocking, early canopy closure, and near elimination of the understory plant community.

c) The stand at Sarkar is an example of a hemlock-dominated stand 70 years after cutting (Figures 4.5 and 4.6). The cutting intensity at Sarkar ranged from 27.1 to 59.2 percent of the stand basal area cut. The Sarkar stand before cutting had only a few overstory spruce trees and these trees were all selectively cut. The light and medium cutting intensity plots have been converted into pure hemlock stands with no new spruce regeneration. The heavy cutting intensity plot had some spruce established in the current stand but these trees were predominantly from smaller advance regeneration spruce trees left after cutting (Figures 4.5 and 4.6). The current seedling bank averaged 434,000 seedlings/ha and 97% of the seedlings were hemlock (Figure 4.6). This stand was the only

Sarkar stand 70 years after cutting

Figure 4.5 The hemlock-dominated stand at Sarkar is an example of a stand that has been converted into a nearly pure hemlock stand after cutting. The medium and light cutting plots have no spruce trees in the stand. This stand also has relatively poor understory plant diversity and abundance for all of the cut plots. The plot pictured is the heaviest cutting intensity plot and 59.2 percent of the stand basal area was cut with 19.1 m^2/ha left after cutting. This plot has 583 trees/ha, a stand basal area of 57.7 m^2/ha and a CCF of 230. In this plot 89% of the trees and 79% of the stand basal area were hemlock. Fifty six percent of the tree stocking was new regeneration with 293 new hemlock and only 35 new spruce trees per hectare. This plot has 24 plant species (mostly bryophytes) and only 5 vascular plants. The only key plant species for deer forage present on this plat was shield fern and a small amount of red huckleberry.

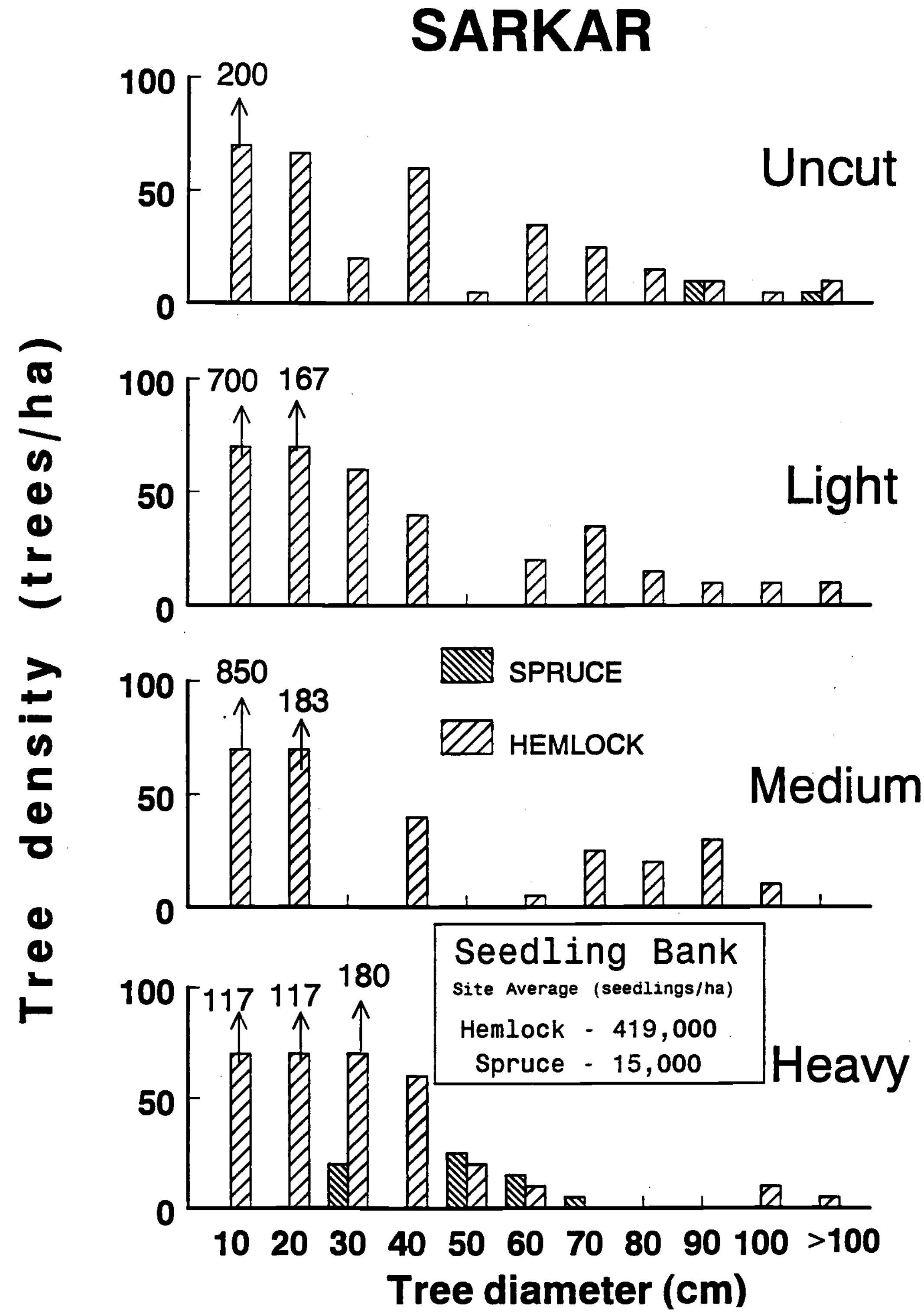

Figure 4.6 The current tree diameter distribution 70 years after cutting in a hemlock-dominated stand at Sarkar. The diameter distribution includes all trees greater than 2.5 cm d.b.h. for the uncut, light, medium and heavy cutting intensity plots. The seedling bank includes all seedlings less than 3 m tall in the current stand (data from Yount 1997).

example I found where a stand was converted from a predominantly hemlock stand into a nearly pure hemlock stand. In order to maintain spruce in hemlock-dominated stands, it will be important to leave some large overstory spruce and smaller-diameter understory spruce in the stand after cutting, both as a potential seed source for new regeneration, and to allow the smaller spruce trees to grow up into the overstory. This stand also had relatively poor plant species richness and abundance. Species richness ranged from 18 to 24 species per plot (mostly bryophtes and lichens) and the cut plots had only 5 to 6 vascular plants on each plot.

Examples of spruce/hemlock stands

a) The stand at Kutlaku Lake is an example of a spruce/hemlock stand 76 years after cutting (Figures 4.7 and 4.8). This stand was similar to several of the more productive spruce/hemlock stands in this study including Hanus Bay, Winter Harbor and Salt Lake Bay. The cutting intensity at Kutlaku Lake varied widely ranging from 31.1 to 62.6 percent of the stand basal area cut. Overall, the current seedling bank averaged 71,000 conifer seedlings/ha (94% western hemlock, Figure 4.8). The most striking feature of this stand was the high stand structural diversity (Figure 4.7), with several different tree canopy layers, and a wide range of tree diameters (Figure 4.8). This stand was very dense with current stand basal areas on the cut plots ranging from 57.8 m^2/ha to 108.4 m^2/ha. In spite of high stand density this site had one of the most species-rich plant understories of any of the stands in this study. The high stand structural diversity and the presence of very tall trees along with moderate numbers of smaller and medium sized trees, may be one of the reasons why this stand has been able to maintain such abundant and diverse understories. This stand is typical of many of the partially cut spruce/hemlock stands

Kutlaku Lake stand 76 years after cutting

Figure 4.7 The spruce/hemlock stand at Kutlaku Lake is an example of a structurally diverse stand with several tree canopy layers, some high quality trees for timber, and high understory plant diversity and abundance. The plot pictured is the light cutting intensity plot and 31.1 percent of the stand basal area was cut with 37.5 m^2/ha left after cutting. This plot is a dense stand with a stand basal area of 91.6 m^2/ha and a CCF of 282. The plot has 372 trees/ha, and 84% of the tree density and 69% of the basal area is hemlock. Most trees at least 2.5 cm d.b.h. are residual trees with only 29% of the tree stocking from new regeneration established after cutting. All new regeneration is hemlock. In spite of high stand density, the understory plant diversity and abundance is high. This plot contains 30 plant species and 14 vascular plants. Seven of the eight key plant species for deer forage are found on this plot including fern-leaved goldthread, bunchberry, shield fern, blueberry, red huckleberry and very abundant five-leaved bramble and foamflower.

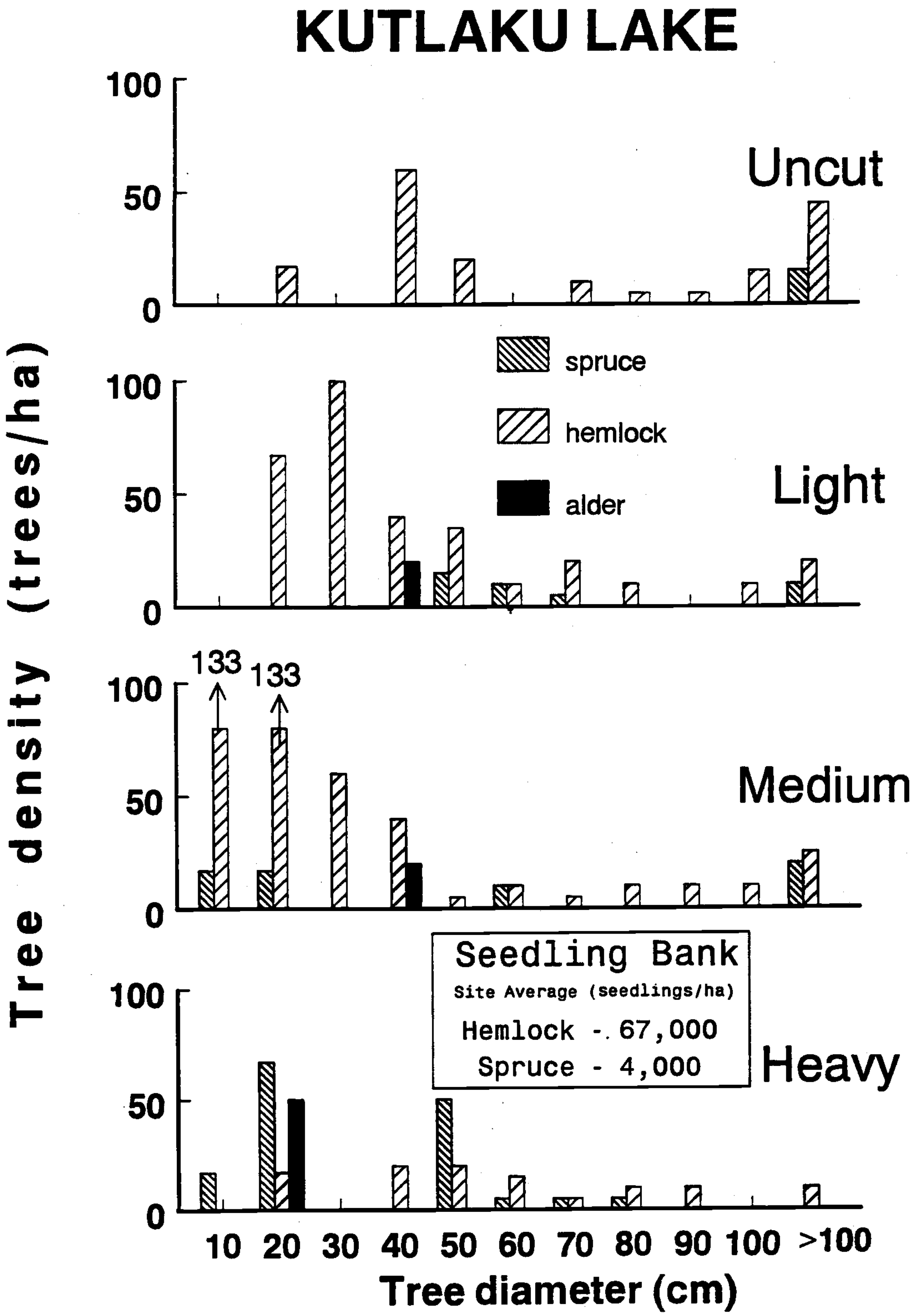

Figure 4.8 The current tree diameter distribution 76 years after cutting in a spruce/hemlock stand at Kutlaku Lake. The diameter distribution includes all trees greater than 2.5 cm d.b.h. for the uncut, light, medium and heavy cutting intensity plots. The seedling bank includes all seedlings less than 3 m tall in the current stand (data from Yount 1997).

found in this study, with some high quality trees for timber, moderate tree stocking, and abundant and diverse understory plants.

b) The stand at Florence Bay is an example of a spruce/hemlock stand 82 years after cutting (Figures 4.9, 4.10 and 4.11). The cutting intensities within the stand were relatively similar ranging from 49.9 to 57.0 percent of the stand basal area cut, and an absolute basal area cut of 43.5 m^2/ha to 37.8 m^2/ha. However, the response to thinning was very different among plots in this stand. The medium and heavy cutting intensity plots have fewer small-diameter trees (Figure 4.11) and much more abundant plant understories (Figure 4.9) than the light cutting intensity plot (Figure 4.10). One of the significant treatment differences among plots was the number of cut trees on each plot. The lightest cutting intensity plot had an average of 120 trees cut per hectare compared with only 40 trees cut per hectare on the heaviest cutting intensity. The current stocking of these plots may be related to the initial stand stocking conditions; the lightest cutting intensity plot has many more smaller diameter trees than the medium or heavy cutting intensity plots. All plots contain both hemlock and spruce trees but the number and proportion of hemlock is much greater in the light cutting plot. The Florence Bay stand has a current seedling bank of 92,000 hemlock seedlings/ha and 7000 spruce seedlings/ha (Figure 4.11). The understory plant response is also quite different and the light cutting intensity plot has much less abundant plant understories than the other plots (Figure 4.9). The medium and heavy cutting intensity plots have much more abundant understories (Figure 4.10) with a strong shrub response. This stand is another example of the need to control stocking to enhance understory plant development.

Florence Bay stand 82 years after cutting

Figure 4.9 The spruce/hemlock stand at Florence Bay had relatively similar cutting intensities for all the plots but these plots had very different responses to cutting. The plot pictured is the lightest cutting intensity plot and 49.8 percent of the basal area was cut with 37.9 m^2/ha left after cutting. This plot is relatively dense and heavily stocked (see other plot at Florence Bay, Figure 4.10) with a stand basal area of 82.9 m^2/ha, a CCF of 270, and 360 trees/ha. Forty three percent of the tree density and 42% of the stand basal area is Sitka spruce. All trees that are at least 2.5 cm d.b.h. on this plot are residual trees with no new regeneration established after cutting. The high stand density and tree stocking has resulted in a reduced abundance of understory plants. This plot contains 35 plant species and 13 vascular plants. Four key plant species for deer forage were present including bunchberry, five-leaved bramble, shield fern and blueberry, but only blueberry was abundant.

Florence Bay stand 82 years after cutting

Figure 4.10 The plot pictured here at Florence Bay has a different stand structure, is a more open stand, and has a much more abundant understory plant community than the other plot at Florence Bay (Figure 4.9). This plot is the heaviest cutting intensity plot with 57.0 percent of the stand basal area cut and 26.2 m^2/ha left after cutting. This plot has a stand basal area of 55.6 m^2/ha, a CCF of 152, and only 120 trees/ha indicating a relatively open stand. Most of these overstory trees are spruce, and spruce comprises 75% of the tree density and 62% of the stand basal area. Over fifty percent of the trees in this plot are new regeneration established after cutting, and all of the new regeneration is spruce. Understory plants species richness was high with 32 plant species and 15 vascular plants found on the plot. Three key plant species for deer forage were abundant and these plants included foamflower, shield fern and blueberry.

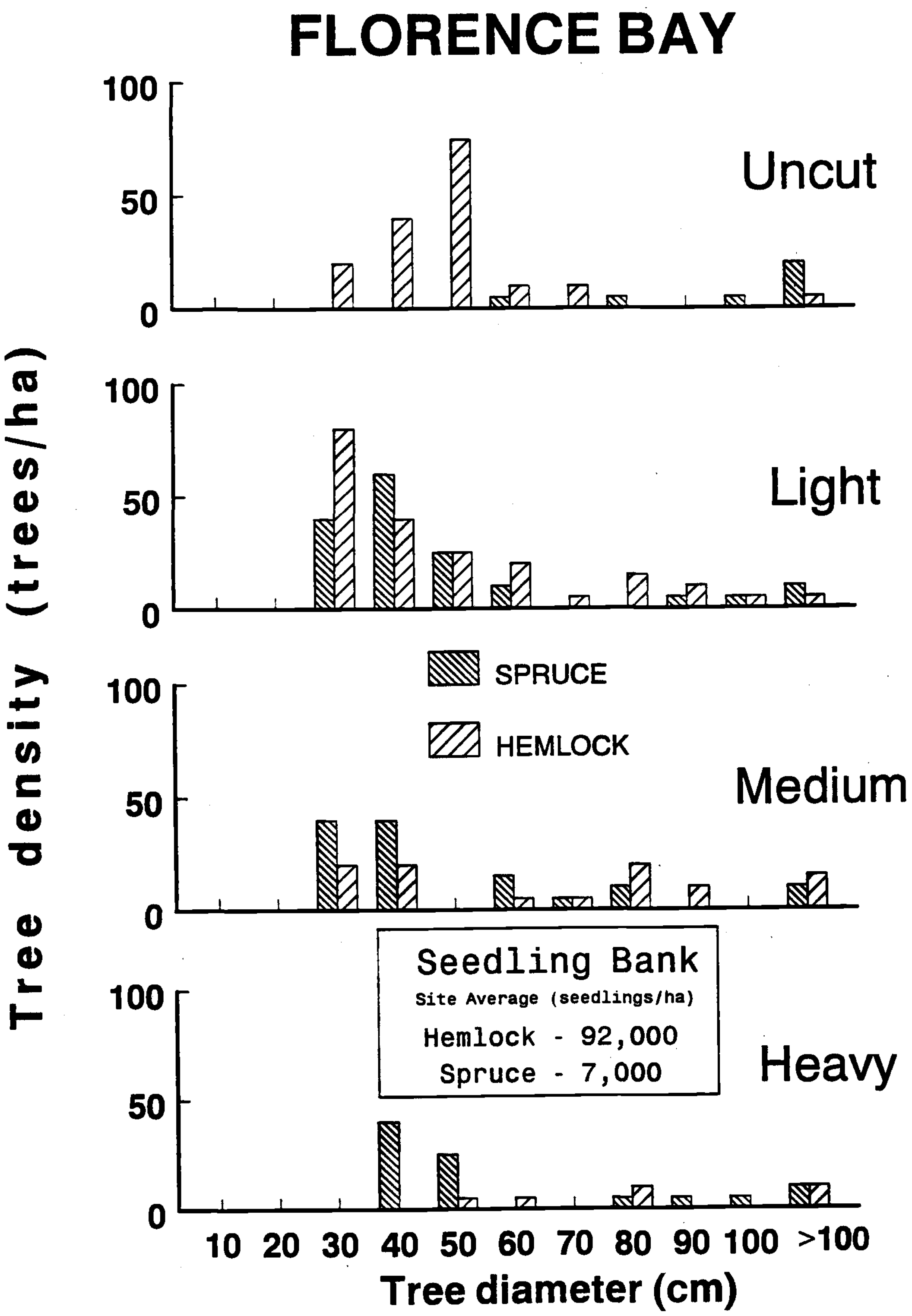

Figure 4.11 The current tree diameter distribution 82 years after cutting in a spruce/hemlock stand at Florence Bay. Diameter distribution includes all trees greater than 2.5 cm d.b.h. for the uncut, light, medium and heavy cutting intensity plots. The seedling bank includes all seedlings less than 3 m tall in the current stand (data from Yount 1997).

c) The stand at Glass Peninsula is an example of spruce/hemlock stand 85 years after cutting (Figures 4.12, 4.13 and 4.14). This stand is similar to some other partially cut stands (Weasel Cove, Portage Bay) that have maintained abundant and species rich plant understories for long periods of time. The cutting intensity varied widely within the stand ranging from 23.5 to 69.2 percent of the stand basal area cut. All of the plots have a wide range of tree diameters (Figure 4.14), and understory plants are abundant on all of the plots (Figures 4.12 and 4.13). The medium cutting intensity plot appears to have been more heavily disturbed with a significant number of red alder in this plot (Figure 4.14). This stand has several different tree canopy layers (Figure 4.12) and the high structural diversity may have helped to maintain species rich and abundant plant understories. The current seedling bank averages 67,000 hemlock seedlings and 46,000 spruce seedlings/ha (Figure 4.14). The heaviest cutting intensity plot also has a significant number of large, high quality new-cohort Sitka spruce trees (Figure 4.13), and this stand is an example of the possibility of producing high quality trees for timber value while also maintaining diverse and abundant plant understories.

The management implications of using new silvicultural systems in southeast Alaska

Silvicultural systems that use single tree selection or small openings can be used successfully to regenerate stands for timber management in southeast Alaska. Concerns about changing tree species composition, greatly reduced stand growth and vigor, increased dwarf mistletoe infection in hemlock trees, and higher incidence of tree wounding, decay, and mortality were largely unsubstantiated. Stand structural diversity, species richness and understory plant abundance were all greater in partially cut stands than in young-growth stands developing after clearcutting. It is also important to note that

Glass Peninsula stand 85 years after cutting

Figure 4.12 The spruce/hemlock stand at Glass Peninsula 85 years after cutting has maintained a diverse and abundant understory plant community. The plot pictured is the lightest cutting intensity plot with 23.5 percent of the stand basal area cut and 46.4 m^2/ha left after cutting. This plot has only a few trees (147 trees/ha) but the stand is relatively dense with a stand basal area of 84.4 m^2/ha and a CCF of 212. This plot has a few, large spruce trees with comprising 34% of the tree density and 60% of the stand basal area. All trees greater than 2.5 cm d.b.h. were residual trees with no new conifer regeneration. Shrubs dominate in the understory and devil's club is particularly abundant. This plot contains 27 plant species and 16 vascular plants. Seven of the eight key plant species for deer forage were found on this plot including fern-leaved goldthread, bunchberry, shield fern, five-leaved bramble, foamflower, blueberry and red huckleberry.

Glass Peninsula stand 85 years after cutting

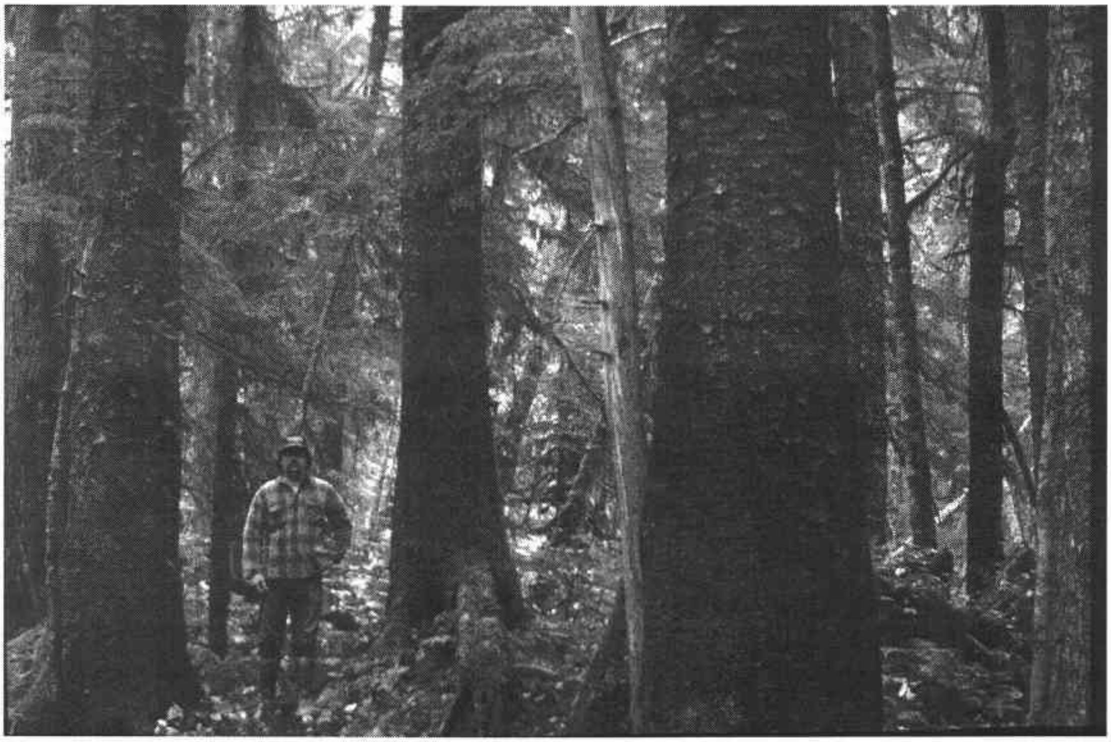

Figure 4.13 This plot at Glass Peninsula is an example of the establishment and growth of large, high quality Sitka spruce trees. The plot pictured at Glass Peninsula is the heaviest cutting intensity plot with 69.2 percent of the stand basal area cut and 16.9 m^2/ha left after cutting. This plot has 331 trees/ha, a stand basal area of 60.1 m^2/ha and a CCF of 185. Most of the trees in the picture are new regeneration established after cutting, and 68% of the trees greater than 2.5 cm d.b.h. are new regeneration including an average of 153 hemlock and 73 spruce trees/ha. The spruce trees are fewer but larger than the hemlock trees accounting for 33% of the tree density and 44% of the stand basal area. Understory plant diversity and abundance is high with 29 plants species and 12 vascular plants found on the plot. Four key plant species for deer forage are present: fern-leaved goldthread, shield fern, foamflower and blueberry.

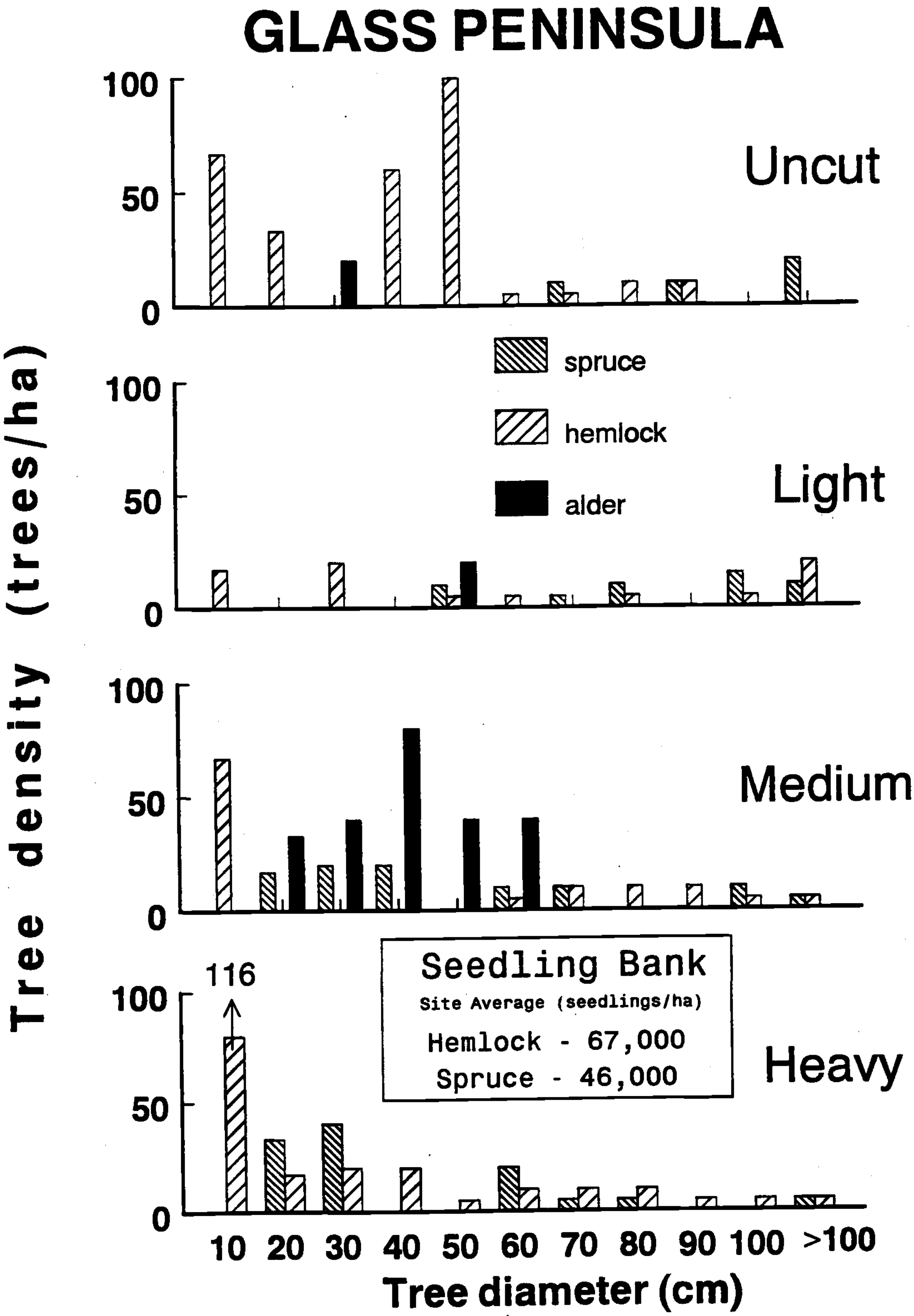

Figure 4.14 The current tree diameter distribution 85 years after cutting in a spruce/hemlock stand at Glass Peninsula. The tree diameter distribution includes all trees greater than 2.5 cm d.b.h. for the uncut, light, medium and heavy cutting intensity plots. The seedling bank includes all seedlings less than 3 m tall in the current stand (data from Yount 1997).

these partially cut stands were not part of a planned silvicultural system, and the careful evaluation and implementation of new silvicultural systems will probably further reduce problems and improve benefits. New silvicultural systems have excellent potential to maintain desirable tree species composition, create diverse stand structures that enhance biodiversity, and also provide high quality trees for future timber.

Tree species composition and stand growth

- Tree species composition is highly resilient to different cutting intensities and hemlock-dominated stands remain hemlock stands, and spruce/hemlock stands remain spruce/hemlock stands. Maintaining desirable tree species composition using new silvicultural systems does not appear to be a problem for most stands. However, if the goal is to maintain spruce in hemlock-dominated stands, it is important to leave some large overstory spruce and smaller-diameter understory spruce in the stand after cutting. These trees will serve as a potential seed source for new regeneration, and also allow the smaller spruce trees to grow up into the overstory.

- The establishment of new cohorts is important for the long-term sustainability of timber in these stands. In some cases it may be desirable to plant spruce trees if seed source is poor or other regeneration problems exist. The growth of new spruce may initially be slow, but the establishment of spruce trees will ensure that spruce will be a sustainable component of the future stand.

- The importance of both small advance regeneration and larger residual trees has probably been underestimated. These trees left after harvest were a major part of the current stand structure, species composition and stand growth. The largest tree diameter growth came from small-to-medium-sized trees (10 to 70 cm d.b.h. at time of cutting), and it will be important to carefully select vigorous, high quality residual trees for a future timber crop. Reducing the number of low vigor, large overstory trees may also increase stand growth.

- A major consideration for the successful implementation of any new silvicultural system is the maintenance of appropriate stocking levels of new regeneration. Excessive stocking is common following heavy stand cutting intensities, and it may be necessary to pre-commercially thin new regeneration in the stand to maintain desirable stocking levels. Also, in order to sustain high stand growth rates, it will be important to maintain appropriate stocking levels, select vigorous leave trees, and establish regeneration for future growth of these stands.

Plant diversity and abundance

- Leaving a wide range of large and small trees in the residual stand helps create stands that are structurally complex with multi-layered forest canopies. These stand structures may also encourage the development of forest plant communities. The heterogeneous stand structures created from cutting small openings in these stands and by individual tree selection are very different than the uniform, young-growth stands that develop after clearcutting. The large and small residual trees left after cutting creates complex vertical structures and multi-layered canopies, and these complex structures may be a critical component for maintaining understory plant communities.

- The tree density and the proportion of hemlock trees in these stands also appears to be closely related to species diversity and abundance. In the retrospective study, the plots with fewest species and least abundance of understory plants were in partially cut hemlock-dominated stands that had many small-diameter trees established soon after cutting. These trees formed a dense new cohort similar to clearcuts that suppressed shrubs and herbs. It appears that stand dynamics, tree species composition, and intensity of cutting are all important components of overstory-understory interactions, and together they form a major role in the maintenance of understory plants.

In summary, new silvicultural systems that use single tree selection or small openings can provide conditions that are very conducive to the establishment and growth of understory plants. These systems may also be more similar in intensity and frequency to natural disturbances than systems that use clearcutting as a regeneration method. The complex structures left after cutting appear to create conditions similar to natural low intensity disturbances common in the region. Overall, new silvicultural systems that use single tree selection or small openings appear to be a viable management prescription to maintain biodiversity in western hemlock-Sitka spruce stands in southeast Alaska.

The feasibility of using new silvicultural systems

Hemlock-dominated stands

Hemlock-dominated stands present challenges for any silvicultural system that has a major management goal to enhance stand structural diversity and provide long-term maintenance of understory plant diversity and abundance. The biggest challenge is to sustain appropriate stocking levels in these stands and to reduce the density of new regeneration following cutting. The hemlock seedling bank is prolific in these stands, and frequently, very dense regeneration grows above and suppresses understory vegetation. Hemlock regeneration is particularly abundant after moderate to heavy cutting, and recommended cutting intensities should probably range from light to moderate cutting levels for most treatment prescriptions.

If a management goal is to enhance stand structural diversity then heavy cutting should be avoided. One of the major objectives will be to provide both vertical and horizontal stand diversity with several vertical canopy layers and a wide range of tree sizes in the stand. An important consideration is the management of tree stocking, and heavy thinning of small-diameter or mid-canopy trees may be necessary. Following the initial cutting, new regeneration will be encouraged, but it will be critical to maintain moderate regeneration density, and a later entry to thin excessive regeneration may be required. Trees will develop and grow from one canopy layer into another, and the goal is to provide a range of tree sizes and vertical structures on a continuous basis. The stand at Thomas Bay is an example of a stand that initially was lightly cut and the current stand has some structural diversity (Figure 4.1). However, the dense new regeneration will need to be carefully monitored and it is likely that a pre-commercial thinning will be required in a few years to reduce density. The heavily cut plots at Margarita Bay (Figure 4.3) are examples of what may occur if stocking is not reduced, with hundreds of new trees leading to canopy closure and suppression of the understory. Preferential thinning of hemlock and the establishment of a greater proportion of spruce may help to reduce the high stand density that is common in hemlock-dominated stands. Also, leaving some overstory spruce trees will help to improve species diversity and enhance structural diversity.

If a major management goal is to create favorable overstory/understory conditions that promote understory plant development then heavy cutting should also be avoided (Figure 4.3). Light cutting of a few overstory trees will create small gaps and enhance development of shrubs and herbs. Natural shrub gaps could be enhanced but cutting large gaps will be discouraged as it allows too much light and tree regeneration. One common but important plant that is a key species for deer forage is blueberry, and the abundance of blueberry may serve as a good indicator of the success of the treatment. Light cutting levels may allow more frequent entries. The frequency of entries and the intensity of cutting will vary among stands and will depend on specific site conditions. Harvest may include valuable overstory trees for timber and reduction of stocking of understory trees. However, it is important to avoid highgrading the stand, and to maintain some residual spruce to prevent conversion of hemlock-dominated stands into pure hemlock stands such as occurred at the Sarkar site (Figure 4.5). Also, the release of healthy and vigorous residual trees, and the establishment of some regeneration will be necessary to provide a sustainable treatment prescription.

If a major management goal is to provide a sustainable and high quality timber resource then these stands can include moderate to heavy cutting levels. Stand cutting will encourage growth of residual trees and the establishment of new regeneration. Stand growth rates will be higher than either of the treatments designed to enhance stand structural diversity or encourage understory plant development. Some of the key components of this treatment include providing healthy vigorous residual trees for future timber, establishing and maintaining desirable tree species composition, managing stocking levels of different stand canopy layers, and the removal of poor quality residual trees. Vigorous trees with healthy crowns should be selected as future crop trees. Diseased and defective trees will generally be removed through a sanitation cut, but a few large overstory spruce and hemlock trees will be saved as seed trees and to provide stand structural diversity. These overstory trees have a greater likelihood of being wounded through logging and will probably not be a prime source for timber. The future timber resource will generally be from small-to-medium sized residual trees and the establishment of new regeneration. One of the most important components for this treatment is providing a dependable supply of high quality hemlock and spruce trees for timber production. Treatments should be designed to provide a sustainable crop of high quality trees. The establishment of new regeneration may not be a significant component of the next harvest cycle, but these smaller understory trees will eventually become a significant part of the future stand, and the successful establishment of regeneration will be critical for sustainable timber production. However, another key component of this prescription will be reducing the stocking of new regeneration and concentrating growth on a fewer number of higher quality trees for timber.

Spruce/hemlock stands

The use of new silvicultural systems in spruce/hemlock stands appears to be feasible, and will be easier to implement than in most hemlock-dominated stands. In general, spruce/hemlock stands are much more open than hemlock-dominated stands and can provide both high quality spruce trees for timber, and maintain understory plant diversity and abundance over a wide range of cutting intensity. Most of the spruce/hemlock stands evaluated in the retrospective study had high structural diversity (Figures 4.7 and 4.12), well developed plant understories (Figures 4.7, 4.10 and 4.12), and provided large, high quality spruce trees (Figures 4.10 and 4.13).

One of major management goals may be to encourage stand structural diversity to enhance late-successional or old-growth stand conditions while providing some timber value. These structures could provide winter habitat for Sitka black-tailed deer with large overstory trees capable of intercepting snow. These complex structures contain multiple stand canopy layers (Figures 4.7 and 4.12) that could enhance plant diversity and abundance and also provide a light but sustainable timber product. To develop structural diversity, cutting intensity can probably be more flexible then in hemlock-dominated stands and may range from light to moderately heavy cutting levels. An important consideration is the management of tree stocking, although this will be less of an issue than in hemlock-dominated stands. Regeneration will be encouraged but it will be important to maintain desirable stocking levels and pre-commercial thinning may be required. Trees will develop and grow from one canopy layer into another and the goal is to provide a sustainable range of tree sizes and vertical structures. Cutting entries may include a commercial entry into the stand every 50 to 80 years depending on the intensity of the cut and the growth potential of the site. The timing of entry will vary among stands, but a general rule may be that stands can be cut again once they reach their original stand basal area prior to initial cutting. However, the cutting entry and intensity of cutting may also depend on factors such as regeneration, stand growth and mortality.

If a management goal is the enhancement and long-term maintenance of plant diversity and abundance with some timber provided as a secondary product, then cutting intensity can probably range from light to moderate cutting levels. Light cutting of a few overstory trees and heavy cutting of understory trees may be used to enhance development of understory plants. One of the major objectives is to control stocking of understory trees.

Heavy stand cutting or removal of large numbers of trees such as occurred at Florence Bay (Figure 4.9) will be avoided to prevent establishment of excessive new regeneration that can suppress understory plants. Natural shrub gaps will be enhanced but cutting large gaps will be discouraged as it allows too much light and tree regeneration. The major objective for this prescription is to create favorable overstory/understory interactions that promote understory plant development. Light cutting of a few overstory trees will create small gaps and enhance development of shrubs and herbs and prevent excessive establishment of conifer regeneration (Figures 4.7 and 4.10). Light cutting levels may allow more frequent entries. The frequency of entries and the intensity of cutting will vary among stands and will depend on specific site conditions. Harvest may include valuable overstory trees for timber and the thinning of understory trees. However, it is important to avoid highgrading the stand, and the release of healthy and vigorous residual trees, and the establishment of some regeneration will be necessary to provide a sustainable treatment.

If a management goal is to provide a sustainable and high quality timber resource while maintaining other resources in the stand then these stands can include moderate to heavy cutting levels. Some of the key components of this treatment include providing healthy vigorous residual trees for future timber, establishing and maintaining spruce regeneration, and the removal of poor quality residual trees. Vigorous trees with healthy crowns will be selected as future crop trees. Diseased and defective trees will generally be removed through a sanitation cut, but a few large overstory trees will be saved as seed trees and to provide stand structural diversity. These overstory trees have a greater likelihood of being wounded through logging and will probably not be a prime source for timber. The future timber resource will generally be from small-to-medium sized residual trees and the establishment of new regeneration. One of the most important components for this treatment is providing a dependable supply of high quality Sitka spruce trees for timber production (Figure 4.13). Prescriptions should be designed to provide a sustainable crop of spruce through several cutting entries. In some stands it may be desirable to plant spruce trees after harvesting. Selection of vigorous advance regeneration spruce trees will be important as will the establishment of new spruce regeneration. The establishment of the new regeneration may not be a significant component of the next harvest cycle, but these smaller understory trees will eventually become a significant part of the future stand and will be critical for sustainable timber production.

Management prescriptions ultimately should be site specific and need to incorporate information on stand structure and growth, patterns of regeneration and mortality, species composition, soils, site productivity and disease. The feasibility of using new silvicultural systems is also largely dependent on the economics of the operation, costs for thinning, number of stand entries, equipment selection and the quantity and quality of timber products. Many of these questions are unresolved, however, research on many of these issues is currently being investigated in the region.

Forest management of federal lands in the United States is mandated to provide a wide range of different and often conflicting products and services including sustainable timber production, productive wildlife and fisheries habitat, biological conservation, and forests for public recreation. Recent region-wide forest-management plans in the Pacific Northwest and Alaska (Record of Decision 1994; Record of Decision 1997) have prescribed specific silvicultural guidelines for forest management using alternatives to clearcutting. However, prior to this study, information on the effects of partial cutting and the implications of using new silvicultural systems in southeast Alaska were largely unknown. Overall, the development and implementation of new silvicultural systems that use single tree selection or small openings has excellent potential to alleviate some of the problems associated with conventional clearcutting in southeast Alaska. New silvicultural systems appear particularly useful to maintain biodiversity in western hemlock-Sitka spruce stands. These systems could also provide a sustainable timber resource including more valuable spruce trees, while also maintaining stand structural diversity, and enhancing late-successional or old-growth stand conditions that are an important part of current region-wide forest management plans.

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APPENDIX

Table 1. Stem taper and bark thickness regression models to predict stump d.b.h. from stump diameter, and bark thickness from tree d.b.h., for western hemlock, Sitka spruce, western redcedar and yellow-cedar.

Dependent variable	n	B_0	B_1	X_1	R^2	MSE	P
Stump d.b.h. (mm)							
Western hemlock	334	21.7303	0.8722	STDIAM	0.9758	19.9395	0.0001
Sitka spruce	202	52.9811	0.8298	STDIAM	0.9707	29.3534	0.0001
Western redcedar	205	38.9438	0.8412	STDIAM	0.9804	39.1329	0.0001
Yellow-cedar	229	29.1807	0.8943	STDIAM	0.9805	23.4160	0.0001
All trees	970	32.6343	0.8442	STDIAM	0.9770	29.5107	0.0001
Bark thickness (mm)							
Western hemlock	334	2.4855	0.0519	DBH	0.5332	6.2155	0.0001
Sitka spruce	202	-46.6129	10.6945	ln(DBH)	0.2958	5.9813	0.0001
Western redcedar	205	-50.9360	12.3207	ln(DBH)	0.4796	7.3415	0.0001
Yellow-cedar	229	7.8180	0.0171	DBH	0.3085	4.2678	0.0001

Note: n is the number of observations; B_0 is the intercept and B_1 is the slope coefficient of the regression line; R^2 is the adjusted coefficient of determination; MSE is the mean square error; P is the probability value; STDIAM is the tree stump diameter at a height of 0.5 m; DBH is tree diameter breast height (1.3 m).

Table 2. Regression models with regression R^2, MSE, and P for tree d.b.h. at cutting date for eighteen research site stands.

Dependent variable	n	B_0	B_1	X_1	B_2	X_2	B_3	X_3	B_4	X_4	R^2	MSE	P
Tree d.b.h.(mm) at cutting date													
Thomas Bay	39	9.1389	0.8955	DBH	-15.9034	TRMT	0.000066	DBH^2			0.9964	26.5359	0.0001
Granite	31	-25.9198	0.9950	DBH	-14.3791	TRMT					0.9904	33.3668	0.0001
Pavlof River	65	-49.5589	0.9829	DBH							0.9932	30.9784	0.0001
Big Bear Creek	55	-1.1164	0.8715	DBH	-18.5378	TRMT	0.00005	DBH^2			0.9859	46.2153	0.0001
Margarita Bay	60	87.9575	0.3145	DBH	-55.4578	TRMT	0.00051	DBH^2			0.8442	78.2703	0.0001
Rainbow Falls	42	168.731	0.00044	DBH^2	-63.4244	TRMT	-96.1845	SPEC	0.3127	DBH	0.9031	100.775	0.0001
Finger Creek	62	64.5816	0.00034	DBH^2	0.4176	DBH	-73.4940	SPEC			0.9062	92.4447	0.0001
Winter Harbor	53	-62.9720	0.8104	DBH	0.000074	DBH^2					0.9667	80.1479	0.0001
Salt Lake Bay	62	109.198	0.00034	DBH^2	-34.7033	TRMT	-72.5692	SPEC	0.3798	DBH	0.9111	103.593	0.0001
Canoe Passage	64	14.2886	0.00094	DBH^2	-23.6187	TRMT					0.8958	98.6757	0.0001
Elf Point	64	-258.913	0.00045	DBH^2	-59.4632	TRMT	89.9580	ln(DBH)	-59.8918	SPEC	0.8360	137.745	0.0001
Sarkar	45	167.7315	0.8323	DBH	-114.774	TRMT	-114.499	SPEC			0.8757	133.490	0.0001
Hanus Bay	49	191.108	0.00056	DBH^2	-61.2362	TRMT	-94.5875	SPEC			0.8345	145.447	0.0001
Kutlaku Lake	54	1968.728	1.4432	DBH	-69.3543	SPEC	-74.1878	TRMT	-383.626	ln(DBH)	0.8616	181.251	0.0001
Portage Bay	64	-93.3010	0.7059	DBH	0.00015	DBH^2					0.9091	96.0436	0.0001
Florence Bay	60	353.259	0.00055	DBH^2	-90.3223	TRMT	-136.677	SPEC			0.8173	148.229	0.0001
Glass Peninsula	54	-85.8333	0.8576	DBH	-61.5255	TRMT	-43.6595	SPEC			0.8124	187.423	0.0001
Weasel Cove	63	111.536	0.00070	DBH^2	-47.8378	TRMT					0.7733	132.780	0.0001

Note: n is the number of observations; B_0 is the intercept and B_1-B_4 are slope coefficients of the regression line; R^2 is adjusted coefficient of determination; MSE is mean square error; P is the probability value; DBH is current tree diameter breast height (1.3 m); SPEC is tree species; TRMT is intensity of cutting.

Table 3. Snag and log decay classes for Sitka spruce *Picea Sitchensis*, western hemlock *Tsuga Hetrophylla*, western redcedar *Thuja plicata*, and yellow-cedar *Chamaecyparis nootkatensis*.

	Picea Sitchensis[1] and *Tsuga Hetrophylla*[1]	*Thuja plicata*[2] and *Chamaecyparis nootkatensis*[2]
Class 1	Some twigs retained; most bark intact; logs with little outer decay	Some twigs retained; most bark intact; logs with little outer decay
Age	10 years	14 years
Class 2	Twigs gone, long primary branches and some secondary branches retained; bark beginning to slough; top usually broken; sapwood decaying	Twigs gone, long primary branches and Some secondary branches retained; Bark beginning to slough; top usually Intact; sapwood decaying
Age	20 years	26 years
Class 3	Secondary branches gone, but short primaries or stubs present; height decreasing; most bark gone; logs decaying but can support themselves	Primary branches retained; top usually Intact; bark mainly gone; sapwood Decaying, heartwood sound but Beginning to check
Age	50 years	51 years
Class 4	Branch stubs mainly gone; height Decreasing; most bark gone; Considerable decay of heartwood at Base; logs slumping and colonized by moss or other vegetation	Primary branches mainly gone; bole Usually intact coming to point; surface Deeply checked, bark and sapwood Mainly gone
Age	80 years	81 years
Class 5	Broken stumplike appearance; top portion with branch stubs gone; bark almost completely gone; wood decaying and sloughing away; colonized by vegetation; log cannot support itself, Becoming oval as slumps into forest	Bole broken often with jagged top; Downed portion covered by vegetation Or unrecognizable
Age	100+ years	100+ years

[1] From Palkovic unpublished data collected in 1995-1996.
[2] From Hennon et al. (1990).

Table 4. Plant species list used for plot-species ordination from the reduced data set (includes all species having some cover at three or more plots).

Plant Group	Scientific Name	Common Name	Plant Freq[1]
Shrub	Menziesia ferruginea	Rusty menziesia	70
Shrub	Oplopanax horridus	Devil's club	70
Shrub	Ribes bracteosum	Stink currant	11
Shrub	Ribes lacustre	Black gooseberry	4
Shrub	Rubus spectabilis	Salmonberry	64
Shrub	Sambucus racemosa	Elderberry	10
Shrub	Vaccinium alaskaense/ovalifolium	Alaska/Early blueberry	96
Shrub	Vaccinium parvifolium	Red huckleberry	49
Tree seedling	Alnus rubra	Red alder	4
Tree seedling	Picea sitchensis	Sitka spruce	68
Tree seedling	Thuja plicata	Western redcedar	11
Tree seedling	Tsuga heterophylla	Western hemlock	9
Herbaceous	Actaea rubra	Baneberry	5
Herbaceous	Aruncus dioicus	Goats beard	5
Herbaceous	Circaea alpina	Enchanter's nightshade	27
Herbaceous	Clintonia uniflora	Queen's cup	10
Herbaceous	Coptis asplenifolia	Fernleaf goldthread	51
Herbaceous	Cornus canadensis	Bunchberry	64
Herbaceous	Grass sp.	Grass	7
Herbaceous	Listera caurina	Northwest twayblade	4
Herbaceous	Listera cordata	Heart-leaved twayblade	14
Herbaceous	Lysichiton americanum	Skunk cabbage	25
Herbaceous	Maianthemum dilatatum	False lily-of-the-valley	59
Herbaceous	Moneses uniflora	Shy maiden	36
Herbaceous	Prenanthes alata	Western rattlesnake-root	7
Herbaceous	Rubus pedatus	Five-leaf bramble	78
Herbaceous	Streptopus amplexifolius	Clasping twisted stalk	49
Herbaceous	Streptopus roseus	Rosy twisted stalk	32
Herbaceous	Streptopus sp.		19
Herbaceous	Streptopus streptopoides	Small twisted stalk	29
Herbaceous	Tiarella trifoliata	Foamflower	77
Herbaceous	Viola glabella	Stream violet	15
Fern	Athyrium filix-femina	Lafy fern	51
Fern	Blechnum spicant	Deer fern	23
Fern	Dryopteris expansa	Shield fern	89
Fern-ally	Equisetum arvense	Common horsetail	4
Fern	Gymnocarpium dryopteris	Oak fern	86
Fern-ally	Lycopodium annotinum	Stiff clubmoss	4
Fern	Polypodium glycyrrhiza	Licorice fern	12
Fern	Thelypteris phegopteris	Narrow beach fern	21
Moss	Antitrichia curtipendula	Hanging moss	8
Moss	Brachythecium frigidum	Golden short-capsuled moss	11
Moss	Dicranum sp.		55
Moss	Dicranum fuscescens	Dusky fork moss	38
Moss	Dicranum majus		14
Moss	Dicranum scoparium	Broom moss	32
Moss	Hookeria luscens	Clear moss	41
Moss	Hypnum circinale	Coiled leaf moss	38
Moss	Hylocomium splendens	Step moss	99
Moss	Hypnum subimponens	Curly hypnum	4
Moss	Isothecium myosuroides	Cat-tail moss	56
Moss	Kindbergia oregana	Oregon beaked moss	7
Moss	Leucolepis acanthoneuron	Menzie's tree moss	8

Table 4. Plant species list used for plot-species ordination from the reduced data set (includes all species having some cover at three or more plots).

Plant Group	Scientific Name	Common Name	Plant Freq[1]
Moss	Plagiothecium denticulatum		10
Moss	Plagiomnium insigne	Badge moss	38
Moss	Plagiothecium undulatum	Wavy-leaved cotton moss	9
Moss	Polytrichum commune	Common haircap moss	63
Moss	Pogonatum contortum		12
Moss	Rhizomnium glabrescens	Large leafy moss	99
Moss	Rhitidiadelphus loreus	Lanky moss	100
Moss	Rhizomnium magnifolium	Hairy lantern moss	34
Moss	Sphagnum girgensohnii	White-toothed peat moss	63
Moss	Sphagnum sp.		4
Moss	Sphagnum squarrosum	Spread-leafed peat moss	10
Liverwort	Bazzania tricrenata	Three-toothed whip liverwort	5
Liverwort	Bazzania sp.		8
Liverwort	Blepharastoma trichophyllum		19
Liverwort	Calypogeia arguta var. sullivantii		4
Liverwort	Calypogeia sp.		21
Liverwort	Calypogeia neesiana		11
Liverwort	Calypogeia trichomanis		10
Liverwort	Conocephalum conicum	Snake liverwort	40
Liverwort	Diplophyllum albicans	Common fold-leaf liverwort	19
Liverwort	Frullania nisquallensis	Hanging millipede liverwort	4
Liverwort	Lepidozia reptans	Little hands liverwort	25
Liverwort	Lepidozia sp.		48
Liverwort	Lophozia incisa		8
Liverwort	Lophozia sp.		44
Liverwort	Metzgeria sp.		11
Liverwort	Mylia taylorii	Hard scale liverwort	11
Liverwort	Pellia neesiana	Ring pellia	48
Liverwort	Plagiochila porelloides	Cedar-shake liverwort	40
Liverwort	Riccardia multifida	Comb liverwort	22
Liverwort	Scapania bolanderi	Yellow-ladle liverwort	75
Lichen	Alectoria sarmentosa	Common witch's hair	10
Lichen	Cladonia sp.		18
Lichen	Hypogymnia enteromorpha	Beaded bone	5
Lichen	Hypogymnia sp.		41
Lichen	Icmadophila ericetorum		8
Lichen	Lobaria sp.		4
Lichen	Lobaria oregana	Lettuce lung	30
Lichen	Lobaria pulmonaria	Lungwort	14
Lichen	Peltigera sp.		8
Lichen	Peltigera neopolydactyla		7
Lichen	Peltigera polydactyla		5
Lichen	Platismatia sp.		5
Lichen	Platismatia glauca	Rag bag	19
Lichen	Platismatia herrei	Tattered rag	5
Lichen	Platismatia norvegica	Laundered rag	5
Lichen	Sphaerophorus globosus	Common Christmas-tree	10
Lichen	Usnea longissima	Methuselah's beard	7

[1] The proportion of plots on which species occurred.