Effects of Selection Logging on Deer Habitat in Southeast Alaska: A Retrospective Study

Matthew D. Kirchhoff
Simon R.G. Thomson

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AUTHORS: Matthew D. Kirchhoff and Simon R.G. Thomson

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SUMMARY

We studied 43 sites in Southeast Alaska that were selectively logged between 1899 and 1946 (median cutting date = 1923). Logging removed, on average, 46% of the basal area (s = 26.8) and 5 trees from each plot. We measured the size and mapped the location of all trees, snags, and down logs in each plot, measured stem density and mapped ground cover of all shrub species, and used allometric regressions to compute shrub biomass. We clipped and weighed all herb-layer plants rooted in fixed plots to compute their biomass. Overstory canopy cover was measured from photographs.

Tree growth rates increased as the number of trees cut and the total basal area cut increased. Sitka spruce (*Picea sitchensis*) showed higher growth rates and a stronger response to selection logging than western hemlock (*Tsuga heterophylla*). Growth rates increased with increasing logging intensity, but basal area decreased with increasing logging intensity, indicating volume is still being replaced in intensively logged stands. Overall, stand basal area today averaged 95% of stand basal area at time of logging. Sitka spruce remained well represented in plots regardless of logging intensity.

One of the key characteristics of old-growth forest is its heterogeneous structure. As logging intensity increased, relative variation in tree diameters and crown cover decreased. The principal effect on the understory was a decrease in both ground cover and biomass of the dominant shrub species, blueberry (*V. ovalifolium* and *V. alaskaense*). Plant size decreased with increasing logging intensity, but stem densities remained the same. Blueberry appears well adapted to the disturbance regime typical of old growth, thriving where chronic disturbance maintains distinct gaps in the canopy. Other understory species showed no significant trends with logging intensity due to high variability and small sample sizes. When plants considered important sources of food for deer in winter were evaluated collectively, biomass declined with increased logging intensity— a finding that is due largely to the strong response by blueberry.

From these results, light selection logging offers good potential for maintaining high quality winter habitat for deer while improving stand growth and yield. Optimally, prescriptions should strive to emulate natural disturbance regimes with respect to intensity, frequency, and scale of

disturbance. We wish to emphasize the importance of spatial scale. We found that removing a high percentage of trees from land areas as small as 0.1-0.2 ha typically resulted in even-aged regeneration, regardless of stand conditions on adjacent land. On productive lowland sites where timber harvest is desired, and maintenance of deer winter range is an important objective, selection harvesting that removes small numbers of trees (<30 per ha) distributed evenly throughout the unit (1-6 trees per 0.2 ha) would probably be most effective and appropriate.

Key words: *Odocoileus hemionus sitkensis*, old growth, retrospective, selection logging, silviculture, Sitka black-tailed deer, Southeast Alaska.

CONTENTS

BACKGROUND

Selection logging refers to a harvest method in which only selected trees are cut and removed from a stand. Selective logging was used almost exclusively in southeast Alaska from the mid-1800s through the early 1920s when the tools available for falling trees and moving logs were relatively primitive (Kirchhoff 1997). By 1920, hand-logging in Southeast Alaska was in decline as loggers began using wire rope and steam or diesel "donkeys" to expand their operations inland, and more commonly, to cut swaths of high-quality timber instead of individual trees (Taylor 1926). The trend toward increased mechanization, expanded access, and less selective harvesting continued through the 1930s and 1940s. In 1938, the first truck logging and crude pole roads were introduced to the region (Robinson 1938). By the late 1950's an expanded and rapidly growing timber industry was harvesting large areas, principally by the clearcut method (Harris

1974). Today, clearcutting accounts for most, if not all, of the timber harvested in southeast Alaska.

While clearcutting is well suited to timber production, and in some cases, improves harvest economics (Ruth and Harris 1979, USFS 1997), the densely-stocked, even-aged stands that result are low in diversity and have generally poor understory development (Alaback 1982). These long-lasting habitat changes have negative implications for a number of important wildlife species, particularly Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) (Wallmo and Schoen 1980, Schoen et al. 1988, Person et al. 1996). Additional concerns with clearcutting center on aesthetics, habitat fragmentation, and associated risk of landslides and windthrow (USFS 1997). In response to these concerns, the Forest Service created a national ecosystem management initiative (Overbay 1992, Kauffmann et al. 1994) which, among other things, promotes management practices that mimic natural disturbance patterns and processes. In 1992, the Forest Service declared an agency-wide goal of reducing clear-cutting on National Forest lands by 70% (USFS 1992a). In Alaska, an ecosystem management strategy was drafted (1992b) which specified that alternatives to clearcutting could be considered as long as they were consistent with forest plan objectives and did not conflict with seven specific conditions identified in the Chief's policy (36 CFR 219.27(b)).

Recent research has improved our understanding of natural disturbance regimes in Southeast Alaska. Although complete stand replacement does occur from natural causes, including landslides and violent windstorms, this type of disturbance is uncommon in southeast Alaska. On Kuiu Island, 4.4% of the productive forestland shows the effects of high-intensity blowdown (Kramer 1997). On portions of Chichagof Island, 7-9% of the productive forestland shows evidence of complete or partial blowdown (Garvey 1996, Thomas et al. 1997). These proportions are the cumulative result of wind storms occurring over a 300-500 year time span. Affected stands are small; are located on wind-exposed topographic settings (Harris 1989, Kramer 1997), and usually retain a significant portion of the original stand structure (Garvey 1996, Thomas et al, 1997). The practice of clear-cut logging contrasts markedly with natural patterns and processes, even on areas subject to infrequent, intensive wind disturbances (Nowacki and Kramer 1998).

In contrast to large-scale disturbance events, wind more commonly affects individual trees, or small groups of trees in a stand, leading to a multi-aged, structurally diverse condition (Brady and Hanley 1984). Ott (1997) studied forest disturbance on sites that ranged from wind-protected to wind-exposed. Across that gradient, the median gap size was 46 m^2, with 85% of gaps less than 100 m^2. Canopy gaps resulted from the death of relatively few trees ($\bar{x} = 2.4$), most of which were snapped by wind and had internal decay (Ott 1997). Comparable findings are reported in unpublished studies by Hocker (1990) and Garvey (1996), and are consistent with data on gaps and forest age structure collected in similar forest in British Columbia (Lertzman et al 1996). Within the temperate rainforest ecosystem, the predominant disturbance regime is frequent, low intensity disturbances spread through time (Veblen and Alaback 1996, Kramer 1997, Nowacki and Kramer 1998).

Under the recently completed revision to the Tongass Land Management Plan, clearcutting remains the predominant harvest method; and selection harvest of single trees, or small numbers of trees (<10) is scheduled only for limited, special situations (USFS 1997). Lack of biological

information, however, is also a contributing factor. Despite the early history of selection logging, and its obvious parallels to natural disturbance patterns, there are no published studies that quantify its short- or long-term effects on regeneration, species composition, stand structure, growth, understory development, and wildlife habitat value. This study (Kirchhoff 1994) and others (USFS 1994) were designed to acquire that basic information. Measuring selective logging on sites cut 50-100 years ago, and comparing it with attributes reflected in the stand today, can provide powerful insights into the relationship between selection logging and these basic parameters. This knowledge can provide silviculturists and wildlife biologists with a scientific basis for prescribing selection logging in ways that achieve multiple management objectives.

OBJECTIVES

The objectives of this research project are to determine how selection logging affects forest composition, structure and growth in southeast Alaska. Particular attention is given to understory response by plant species important to deer. Results of this research should help silviculturists and wildlife biologists prescribe alternatives to clearcutting that allow extraction of timber while minimizing adverse effects on deer and other old-growth associated wildlife.

STUDY AREA

Southeast Alaska is an 800 km-long archipelago of islands and a narrow mainland strip extending from Dixon Entrance (54 °30 ' N) to Icy Bay (60 °30 ' N). The climate is strongly maritime, with cool summers, mild winters, and abundant precipitation distributed throughout the year. At lower elevations (< 600 m) lands are mostly forested with western hemlock (*Tsuga heterophylla*), Sitka spruce *(Picea sitchensis*), red cedar (*Thuja plicata*) and Alaska Cedar (*Chamaecyparis nootkatensis*). These forests are an extension of the perhumid (perpetually wet) temperate rainforest, which extends from Vancouver, British Columbia, north through southeast Alaska (Veblen and Alaback 1996).

The study area included 5 large islands in the archipelago (Prince of Wales, Heceta, Kosciusco, Kuiu and Admiralty islands) spanning a latitudinal range from 54 ° 51 ' N to 57 °44 ' N. Sample stands were located at low elevations near the shoreline, consistent with where selection logging historically occurred. All stands sampled were in the closed western hemlock - Sitka spruce forest type (Viereck et al. 1992). Common shrubs included blueberry (*Vaccinium spp.*), salmonberry (*Rubus spectablis*), Rusty Menzesia (*Menzesia ferruginea*) and devil's club (*Oplopanax horridus*). Common herb-layer plants included bunchberry (*Cornus canadensis*), deer heart *(Maianthemum dilitatum*), trailing bramble (*Rubus pedatus*), shield fern (*dryopteris dilitata*) and oak fern (*Gymnocarpium dryopteris*). Plant associations were typical of productive forest sites, and included western hemlock/blueberry/shield fern, western hemlock/blueberry-devil's club, Sitka spruce/blueberry, and Sitka spruce/blueberry-devil's club (Martin 1989).

Additional information on the physiography, climate, soils, and vegetation of this area is available in Harris et al. (1974) and Alaback (1982).

METHODS

STUDY DESIGN

The study is retrospective in nature, meaning the treatment (selective logging) occurred in the past and was not controlled in an experimental sense. In retrospective studies, the timing and extent of prior logging is typically determined from historic documentation (e.g., maps and sale records), or from persistent physical evidence (e.g., stumps and down logs) (Thomas et al. 1993). Either of these means involves a degree of uncertainty, and therefore, some potential error. We minimized that error by avoiding stands where the logging history was difficult to reconstruct, or evidenced > 1 entry or major disturbance event. We also limited our study to older sites—those where selection logging occurred 50 or more years ago. This avoids the highly dynamic early successional stages (<30 years post-logging)(Alaback 1982). Properly designed and narrowly focused, retrospective studies provide a powerful means for gaining knowledge that would otherwise take decades to discover.

The treatment variable of primary interest in this study was logging intensity, which can be variously expressed as number of trees cut, absolute basal area of trees cut, or percentage of original basal area cut. The study design called for sampling independent stands evenly across the full spectrum of disturbance intensity, while minimizing the influence of confounding site variation. Once a suitable stand was identified, and disturbance history determined, we measured current stand attributes with respect to species composition, stand structure, growth, and understory biomass. The specific variables measured, and the methods used, are described in detail below. We measured or calculated > 100 stand metrics, and used graphical techniques (Tukey 1977) to preliminarily explore data structure and develop hypotheses. Hypotheses about stand response to disturbance intensity were tested with standard regression methods (Draper and Smith 1981). We report all significant bivariate regression models ($P < 0.05$), as well as selected non-significant results of management interest. We used SPSS (1998) software for all statistical analyses.

PLOT SELECTION AND LAYOUT

Evidence of historic selection logging in Southeast Alaska is widespread and readily identifiable. Large, decaying stumps, many with ax-cut springboard notches, can be found in virtually any bay or inlet where large trees grow within a few hundred meters of the shore. We used a combination of aerial photos and on-the-ground inspection to locate suitable study plots. We avoided site with evidence of recent logging, or sites influenced by nearby openings (clearcuts or windthrow). In two field seasons we measured 43 plots, including 14 on Kuiu and Admiralty Islands (August 1995), and 29 on Prince of Wales, Kosciusco, and Heceta Islands (July and August 1996). Transportation and field support both years was provided by the research vessel *Arcturus* (Alaska Research Voyages, Juneau).

We located each stand with reference (bearing and distance) to a witness tree on the beach that was marked with flagging and a numbered aluminum disk. We took photographs, bearings to prominent landforms, and an uncorrected GPS reading to guide future relocation of the witness tree and study plot (Appendix A). Plots were 0.1 ha in size (31.7m x 31.7m), centered on the selective logging activity, with boundaries oriented in true E-W (x coordinate) and N-S (y

coordinate) directions. We marked a prominent tree near the corner of each plot with a numbered aluminum tag corresponding to the plot number, and recorded average slope, aspect, and elevation of each plot. We established a center-weighted grid of 10 measuring tapes running from west to east and south to north, intersecting at 9 interior sample points, and dividing the plot into 16 compartments. The location of every tree, stump, snag and down log was described in x and y terms (with reference to the ground tapes), and drawn to scale on a stem map. An example of a stem map showing the plot layout, as well as other vegetative features, is provided in Appendix B.

OVERSTORY COMPOSITION AND STRUCTURE

We measured all trees > 5 cm d.b.h. (diameter at breast height) rooted in the plot. For each live tree we recorded species, diameter (at breast height) total height, height to lowest green limb, and presence of defect indicators (e.g., broken tops, conks, frost cracks). For stumps and snags, we recorded dbh, height and decay class (1-5, ref. Alaback and Hastings 1995). All trees, stumps and snags were drawn to scale on stem maps, and their location noted with reference to the ground measurement tapes. In 1996, we additionally began documenting conifer saplings by mapping extent of their crown perimeters projected vertically on the ground. We took photographs oriented towards plot center from each corner to record the general appearance of the plot (on file, ADFG, Douglas).

Overstory composition and structure was analyzed using a geometric model (Stand Visualization System, McGaughey 1996). This software program graphically displays trees and down material to scale and in spatially correct terms, allowing the user to depict the stand from any distance or angle. Tree attributes measured in the field include spatial location, species, height, dbh, crown ratio, and damage indicators. We specified values for growth form and color (of bole branches, and needles) to yield realistic-looking trees of each species. The program computes tabular summaries for each plot, including mean, standard deviation, minimum and maximum statistics for dbh and height of all live trees, stumps, and snags. Bar charts showing the diameter class distribution, height distribution, and species distribution, of live trees, stumps, and snags are also generated. Illustrative examples are shown in Appendix C.

DEAD AND DOWN LOGS

We mapped the location of all dead and down logs intersecting any portion of the study plot. We measured mean diameter, decay class (Alaback and Hasting 1995), type (breakage or sawn), direction of fall, and location on the ground with reference to measurement tapes that ran throughout the plot Appendix B. The x,y coordinates at each log end were used to calculate the length of each log using the Stand Visualization System (McGaughey 1996). A uniform taper formula was used to reconstruct end diameters from length and mean diameter. Although down logs are separated by decay class in the database, for visual simplicity, we represent all decay classes with a single color (Appendix C).

CANOPY COVER

At each of the 9 sample points, we took vertically projected black and white photos of the overhead canopy using a mid-telephoto length lens (70 mm)(Kirchhoff and Schoen, 1987). We converted the photographs to digital images (> 275,000 pixels/photo) and used ArcView to

compute precise canopy cover (% of all pixels that were black) for each photograph. The 9 digitial images could be spatially oriented to allow measures of the clumpiness or gap variability in the canopy structure (Appendix D). Variability in canopy cover for each plot was expressed by the coefficient of variation among 9 photo-based cover measurements per plot. We used dbh to predict maximum crown width of each tree (Farr et al. 1989), and computed a crown completeness factor (CCF) for the plot by dividing the sum of the maximum crown widths by total plot area (Farr et al. 1989). Theoretically, a CCF value of 100 indicates full occupancy of an area by the canopy if all trees are open grown and evenly spaced; a value above 100 indicates the degree of crowding or layering.

LOGGING HISTORY AND GROWTH

We cored 5 trees per stand, selecting residual trees likely to show a "release" (rapid growth) the year following logging, or trees that, based on size and similarity to other trees, likely initiated growth right after logging. Cores were mounted in clear wood blanks, sanded, and oiled to highlight rings. Using a stereoscope, we counted the number of tree rings back to date of release, or stem initiation, to determine probable date of logging. We measured mean radial growth since date of logging, and used this as the dependent variable in a multiple regression model to compute stand-specific growth rates. A best-fit regression model showed radial growth (cm) was significantly related to time since logging (years), tree species (hemlock = 1 or spruce = 2), basal area cut (cm^2), and number of trees cut ($r^2=0.369$, $P < 0.001$, N=217). From this model we computed growth since date of logging for each tree in a particular stand. By subtracting this growth from current tree diameters, we reconstructed original stand structure (basal area and diameters) at time of logging. We used stump diameter as a surrogate for dbh, and assumed 100% of the sawn stumps and 20% of dead standing snags were alive at time of logging.

UNDERSTORY COMPOSITION AND BIOMASS

For shrub-layer plants, density of stems > 10 cm tall rooted in each plot was measured using the variable area transect (VAT) method (Parker 1979). This plotless density estimator is efficient to use in the field, simple to compute, and accurate over a range of spatial patterns and population densities (Engeman et al. 1994, ADF&G unpubl. data). We established 4 variable area transects radiating in cardinal directions (N,S,E,W) from each of the 9 sample points. We recorded the species and measured distance (d) to the 3rd shrub rooted in each transect. If a plot boundary was reached before encountering a 3rd shrub, r was the number of stems counted (0-2), and d was distance from the sample point to plot the boundary. Shrub stem density on the 36 variable area transects per plot was computed according to Parker (1979).

On each variable area transect we recorded the species and minimum basal diameter of each shrub stem encountered (up to 3 per transect). From these data we calculated the proportion of shrub stems, and shrub basal area, by species. On the 3rd shrub in each transect, we counted the number of browsed twigs, and clipped all leaves and green stems < 3mm diameter (Kirchhoff 1994). For tall shrubs, we recorded weights above and below 1.5 m to describe fraction of shrub forage available to deer. We weighed leaves and green stems from each sample to the nearest 0.1 g. We saved a subset of samples for later drying, and calculation of leaf:stem and wet:dry weight conversion ratios.

We developed allometric regression equations (Pitt and Schwab 1988) to predict available shrub biomass from stem basal diameters. We log-transformed mass to stabilize variance (Draper and Smith 1981) and pooled data across plots to develop general predictive models. For each shrub species, a quadratic model provided the best fit between log of green weight and basal diameter. The regression models for all species were highly significant (P = 0.0000) with the exception of salal (*Gaultheria shallon*) and thimbleberry (*Rubus parviflorus*) which were encountered only rarely (N = 6 and 7 out of 1,314 total plants sampled). Figures showing these regressions and associated statistics are provided in Appendix E.

In addition, we mapped the ground cover of all shrubs and hemlock regeneration (trees with dbh< 5 cm) overlapping the plot area. Ground cover polygons were drawn with reference to ground measurement tapes and coded to species (e.g., Appendix B). Boundaries of individual polygons were digitized, their areas summed, and ground cover for each species expressed as a percent of total plot area. Measuring ground cover in this way (as opposed to estimating percent) reduces observer bias, and improves accuracy and precision. Ground cover maps also permit examination of overstory-understory relationships at a smaller within-plot scale.

Herb-layer plants included all forbs, ferns, and half-shrubs, as well as low-growing shrubs < 10 cm tall. We used the clip and weigh technique to measure herb-layer biomass on our plots. This technique is more labor intensive than regression-based methods or cover estimates, but is more accurate (Pitt and Schwab 1988, Hanley and Hoel 1996). Within each study plot we established 36 circular $0.1m^2$ plots. We located the circular plots 2.4 m (8 ft) in cardinal directions (N, E,W, and S) from each of the 9 sample points. All herb-layer plants rooted in each plot were clipped, sorted by species, and weighed to the nearest 0.1 g.. We retained a subsample of plants for later drying and calculation of wet:dry weight conversion ratios.

RESULTS

LOGGING CHRONOLOGY AND INTENSITY

We sampled 43 plots on 5 islands in Southeast Alaska (Table 1). Dates of selection logging ranged from 1899 to 1946, distributed uniformly across that range (Figure 1). Mean date of logging was 1922 (median = 1923). The extent, or intensity, of selective logging varied widely, from no logging (2 plots) to complete overstory removal (1 plot). The mean number of trees cut per plot was 5 (median = 3, range = 0-20); mean basal area logged was $3.6 m^2$, (median 3.2, range 0-11.4). For this report, the intensity of selection logging was described primarily in terms of the percentage of original basal area removed. Across the 43 plots sampled, an average of 46 % of original basal area was removed by selective logging (*s* = 26.8, median = 46 %). The great majority of plots sampled (84 %) fell in the range of 20-80% basal area removal (Figure 2).

STAND GROWTH

We expect the tree growth response to selective logging will vary depending on intensity of disturbance, years time disturbance, species mix, and site potential. A step-wise multiple regression model showed the principal factors influencing growth were: (1) basal area cut (2) number of trees cut (3) tree species, and (4) years since logging ($r^2 = 0.39$, P < 0.000, N=215). These results include 2 elements worth noting. First, site potential, as indicated by average height

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of dominant trees, was not significant. This likely reflects the relatively limited range of sites sampled, and the fact that historically, logging occurred only on more productive sites. Secondly, we found growth increased significantly as basal area cut increased, but decreased as more trees were cut. This suggests that if increased growth in the residual stand is a management objective, it is preferable to cut fewer large trees, rather than more small trees when harvesting a fixed basal area.

As expected, variability in growth rates from one tree to the next was high within these plots. Because the stands were uneven-aged, young, thrifty trees located in gaps tended to grow rapidly, whereas older dominants, or suppressed or crowded trees in the same plot grew slowly. In general, as more basal area was removed from a stand, the rate of growth increased. Predicted growth rates for Sitka spruce were significantly higher than western hemlock at all logging intensities, with spruce showing a stronger growth response to selection logging than hemlock (Figure 3). Western hemlock's relatively weak and variable response reflects their generally more decadent or suppressed status. When a hemlock was young and growing in a gap, it exhibited good growth (and we usually cored it); but more typically, a spruce tree occupied that position.

Gross stand growth from date of logging ranged from 22.9-79.7 m^2/ha ($\bar{x} = 41.6$, $s = 13.9$, N = 41), and increased significantly ($r^2 = 0.20$, P = 0.003) as logging intensity increased (Figure 4). While the growth *rates* were higher in heavily logged stands, the *absolute* basal area was highest in lightly logged stands (Figure 5), suggesting that replacement of logged volume (or basal area) in these stands is still taking place. On average, basal area today was slightly lower than original levels ($\bar{x} = 95.6\%$, t =23.7, P = 0.000, N = 41). Plots that had been lightly logged (i.e., < 33% basal area removal) showed a net improvement in stand basal area, whereas plots that had been heavily logged (> 33% basal area removal), showed a net deficit (Figure 6). These results may well shift if, over the next 10-30 years, heavily logged stands continue to accumulate volume at current rates. However, at least for the time period studied (50-100 years), light logging intensities resulted in significantly increased stand basal area and volume compared to heavy logging intensities.

UNDERSTORY COMPOSITION AND BIOMASS

Herb layer

The most common herb-layer plants included 5 evergreen forbs (or half-shrubs), 6 deciduous forbs, 2 evergreen ferns, and 3 deciduous ferns (Table 2). Five species occurred with > 50% frequency, including shield fern (*Dryopteris dilitata*) (72%), oakfern (*Gymnocarpium dryopteris*) (65%), dear heart (*Maianthemum dilitatum*) (58%), Five-leaf bramble (*Rubus pedatus*) and bunchberry (*Cornus canadensis*) (51%). The biomass of all herb-layer vegetation (including shrub species < 10.0 cm tall) ranged from 0-4089.3 kg/ha, with a median of 127.8 and mean of 344.9 (s = 695.1) (Figure 7). The high range was due largely to skunk cabbage (*Lysichiton americanum*) which occurred in 4 plots, and was quite abundant in 2 of those plots (> 1000 kg/ha). When a plant fell within a clip plot, the entire plant was sampled and weighed. In some cases the biomass of a single skunk cabbage plant exceeded the biomass of all other herb-layer plants combined. Reference to median values in this case eliminates the distortion caused by including large, relatively uncommon plants.

Herb-layer species contributing the greatest amount of biomass (after skunk cabbage) were shield fern, oak fern and deer heart (Table 2). Other species occurring with moderate frequency (> 30%), and in moderate amounts (> 9 kg/ha) were five-leaf bramble and bunchberry. The mean biomass for evergreen plants was 81.3 kg/ha, and for deciduous plants was 258.3 kg/ha. Wet weight:dry weight conversion ratios for these two categories are 3.277:1 and 6.986:1 respectively (ADF&G, unpubl. data). Using these conversion factors, the combined biomass of herb-layer forbs and ferns on our study plots ranged from 0-699.4 kg/ha (dry wt), which brackets published biomass values for second-growth and old growth forest (Alaback 1982, Alaback and Sidle 1986, Hanley and Hoel 1996, ADF&G unpubl.). Species-specific conversion ratios can be developed from existing frozen samples, if desired, however, wet weights are sufficient for purposes of making relative comparisons between stands.

Shrub Layer

Because it is not possible to separate *Vaccinium alaskaense* and *V. ovalifolium* in the absence of flowers or fruits, these 2 species were combined and reported as "blueberry". Blueberry comprised 64.3 % of the shrub stems, and contributed about 3 times as much ground cover and 3 times as much biomass as the next most abundant shrub, salmonberry (*Rubus spectablis*). (Table 3). Blueberry occurred on all but 3 of our study plots (93%); salmonberry occurred in 29 of 43 plots (67%). Rusty menzesia *(Menzesia ferruginea)*, Red huckleberry (*V. parvifolium*) and devilsclub (*Oplopanax horridus*) occurred in half to 2/3 of the study plots. Stem density of all shrubs > 10 cm tall averaged 1.30 stems per m^2 (s = 1.03, N = 43), and ranged from 0-6.4 stems/m^2. Allometric equations used to calculate biomass as a function of basal stem diameter are given in Appendix E.

To describe the abundance and composition of the understories sampled, we classified the shrubs into 2 categories. Devils club and salmonberry predominated in riparian and spruce-dominated sites, and were termed "floodplain" species. Blueberry, huckleberry and menzesia tended to be associated with dryer upland plots (or drier microsites within a plot). We termed these "upland species". The plots with the greatest overall shrub biomass generally had an abundance of forage in both of these categories (figure 8). Ten sites, mostly at the lower end of the biomass spectrum lacked floodplain species. Only 1 site lacked upland species. Total shrub biomass on the plots ranged from 0-575.5 kg/ha (median 124.3 kg/ha).

OVERSTORY COMPOSITION AND STRUCTURE

The plots sampled in this study were relatively productive. Each plot had at least 1 tree over 33m tall, and the average maximum tree height was 46.7 m (153 ft) (Table 4). Mean tree diameter was 38.4 cm, with a range of 25.0-68.1. Percentage spruce (based on basal area) averaged 27.0 percent, and ranged from 0 to 75.2% on individual study plots. Overstory attributes measured on these plots (Table 4) encompassed the range of values reported for riparian and upland old-growth sites in southeast Alaska (Alaback and Sidle 1986, Hanley and Hoel 1996).

RESPONSE TO SELECTIVE LOGGING INTENSITY

Silviculturists have many tools available to them for creating desirable stand conditions including timing and frequency of entries, differential harvest by species or diameter class, and varying the

intensity of harvest. Clearcut logging represents one extreme on the intensity scale, where all of the suitable crop trees are harvested. At the other end of this broad spectrum is the harvesting of a single tree from that stand. Understanding how forest composition, structure, and growth vary across this spectrum of disturbance intensities is of primary interest. We expressed logging intensity in terms of percent of original basal area harvested. We were not able to reliably identify the species of tree logged from the stumps, although historical accounts suggest early logging was strongly selective for Sitka spruce (Kirchhoff 1997).

Overstory

One of the key characteristics of old-growth forest is it heterogenous structure. Gap-phase disturbance patterns typical of this ecosystem result in all-aged stands, with mature dominants, suppressed intermediates, pole timber, saplings, and seedlings interspersed. Even-aged second-growth stands, in comparison, are composed of trees that are all approximately the same age, with relatively uniform heights and diameters. We hypothesized that as an increasing proportion of the original stand was harvested, the variability of the future stand would decline. Based on measured diameters of all trees (> 5 cm) on the plot, we computed a coefficient of variation (relative variability)(Zar 1974) and regressed it against % basal area logged. Structural heterogeneity, as reflected in tree diameters, decreased significantly as an increasing percentage of stand basal area was logged (P = 0.000, r^2=0.29)(Figure 9).

Understory production is closely related to the quantity and quality of light that penetrates the overhead canopy. The range of canopy cover reflected in these plots was relatively low (68-87%). There were quite pronounced differences, however, in the gap sizes or variability of the canopy both within and between plots. We hypothesized that as the intensity of logging increased, the canopy cover in the future stand would be increasingly homogeneous. From mean canopy cover measured digitally in each of 9 photographs per plot, we computed a coefficient of variation and regressed it against % basal area logged. Canopy variability decreased significantly as an increasing percentage of stand basal area was logged (P=0.009, r^2=0.15, N=43) (Figure 10). In essence, stands that are more extensively logged have canopy characteristics suggestive of even-aged second-growth stands, with few large gaps and a homogeneous texture.

Clearcutting generally assures a higher percentage of Sitka spruce regeneration, a desirable species that is less shade-tolerant than hemlock (Harris and Farr 1974). One of the disadvantages of selection logging is that it would likely promote hemlock regeneration instead of spruce (USFS 1997). We hypothesized that as the intensity of logging increased, spruce regeneration would be favored, resulting in a higher proportion of Sitka spruce basal area in the future stand. Although there is this tendency in the data (Figure 11), the relationship was not significant (P = 0.29, N = 43). These stands retained a significant spruce component at all levels of selective logging. At the heaviest logging levels (> 75% basal area removed), the percentage of spruce may actually increase, similar to what is observed with clearcut logging. There is no evidence that selective logging will result generally in the elimination of spruce from the future stand. Even at light and moderate levels of selective logging, spruce appear capable of exploiting small openings, just as they do in a natural old-growth forest subject to frequent, low-intensity wind disturbance.

Understory

The dominant understory plant in southeast Alaska, both in terms of biomass and ground cover, is blueberry. On our plots it occurred 4 times more frequently, covered 3 times as much ground area, and contributed 2.5 times more biomass than salmonberry, the next most abundant shrub. We hypothesized that as stand structure (including crown cover) became more homogenous at higher disturbance intensities, shrub cover and shrub biomass would decline. In the case of ground cover for blueberry, as logging intensity increased, ground cover decreased in a nonlinear fashion ($P = 0.001$, $R^2 = 0.23$, $N = 43$) (Figure 13). A similar declining trend (although linear) was documented with respect to blueberry biomass ($P = 0.035$, $r^2 = 0.10$, $N = 43$). The similar nature of these responses, measured by two independent methodologies, suggests a robust relationship despite low r^2 terms. In exploring the underlying basis for this relationship, we found that the number of plants (stem density) does not change significantly across this disturbance gradient ($P = 0.25$), but the size of individual plants does increase significantly ($P = 0.008$, $r^2 = 0.16$, $N = 43$) (Figure 14). Shrub seedlings and small plants appear to be widely established on suitable microsites in many stands. When a canopy gap is created through the death of an individual tree, the shrubs respond by rapidly increasing growth (analogous to a tree "release") rather than seeding in new individuals. The frequency with which small gaps are created on the forest, combined with the shrub's relatively long life span (> 30 years), makes this an effective strategy for exploiting ephemeral canopy gaps.

Deer selectively utilize low-elevation productive forestland during winter because snow levels are reduced and forage is relatively available (Kirchhoff and Schoen 1987, Schoen and Kirchhoff 1990). To evaluate the potential effect of selective logging on deer in winter, we considered those evergreen understory species that represented > 2% of a deer's winter diet during relatively snow-free conditions (Kirchhoff and Larsen 1998). Those included Salal (*Gaultheria shallon*), blueberry, red huckleberry (*V. parvifolium*), bunchberry (*Cornus canadensis*), five-leaf bramble (*Rubus pedatus*), and deer fern (*Blechnum spicant*). We hypothesized that as logging intensity increased, the biomass of winter deer forage plants would decrease. Except for blueberry, no species changed significantly with changes in logging intensity ($P > 0.05$). This does not necessarily mean they are unrelated, for the likelihood of type II error here is substantial (see anonymous 1995). Herb-layer plants in particular are quite variable in their occurrence, and many species did not occur at all on many plots. We need to increase the sample size, or reduce variability, before biological inferences based on acceptance of the null hypothesis (no significant trend or difference) can be made.

When biomass of all winter deer forage species was combined in a single variable (winter deer forage), and regressed against the proportion of basal area logged. There was a significant decline in winter deer forage with increasing logging intensity ($P=0.049$, $r^2 = 0.09$, $N = 43$). The relatively low r^2 term indicates, however, that the addition of other herb-layer forage species important to deer does not strengthen the relationship. Because of it's relatively high contribution to deer forage biomass, blueberry response is largely determining the overall deer forage relationship.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Given the relatively small sample size (43 plots), and the inherent limitations of a retrospective approach, we were nonetheless able to identify a number of significant relationships with immediate relevance to current forest management issues in the region. Although this is a final research report for this project, we anticipate continuing to analyze these data, with publication of our findings to follow. The conclusions and management implications offered in this section should be considered preliminary.

Overstory growth and structure responded most strongly to different logging intensities. Not surprisingly, growth rates of residual trees increase as an increasing proportion of the competitors are removed by logging. This growth response is manifest primarily in spruce, which is apparently able to exploit these newly created openings quite efficiently, especially if suppressed trees (1-10 m tall) are left uncut. Spruce was adequately maintained in the stand at virtually all levels of selective logging. Unless a stand proposed for selective logging has no spruce to begin with, representative proportions of spruce can be maintained by leaving a small number of non-crop trees (saplings or suppressed spruce) in place.

Variability in stand structure is an important descriptor of stands that functionally resemble old growth. Interestingly, understory production was not as strongly correlated with canopy cover as it was with canopy variability. Shrubs, in particular, seem to respond to distinct gaps in the canopy (versus a lacey, more uniform coverage), and they respond primarily by increasing plant size, not stem density. In this respect, they are similar to hemlock seedlings which can germinate and live for very long time periods in shaded conditions, but respond with rapid growth when a canopy gap forms.

Stands that have had a low percentage of their basal areas removed by selective logging have higher understory biomass than stands that have had a high proportion of their basal area logged. For maintaining important deer winter habitat, very light selective logging appears to have relatively little impact on long-term production of browse biomass, while maintaining adequate overstory canopy for snow interception. Selection logging that removes no more than 3 adjacent trees would most closely emulate natural disturbance patterns (Ott 1997) and lead to a high degree of interspersion of gaps and cover. The fine-grained nature of this mosaic contributes significantly to the functional value of the stand as winter deer habitat.

In interpreting and applying the results of this study, it is important to keep in mind the spatial scale at which these relationships were measured. The specific relationships identified in this study function at a spatial scale of approximately 0.1 hectares, or 32 x 32 m. When all, or nearly all of the mature trees in that small area are removed by logging, the stand response is indistinguishable from that of a clearcut. It has been theorized that leaving scattered mature trees in a clearcut (e.g., old growth "legacies"), or small "islands" of old-growth in clearcuts will change the entire stand for the better (Swanson and Franklin 1992, USFS 1994). While such legacies no doubt provide marginal benefits as future snag habitat for cavity nesters, or a source of large-diameter woody debris on the forest floor, we find no evidence such limited retention materially affects secondary succession in the surrounding area. Functionally, these treatments are still clearcuts. On this basis,
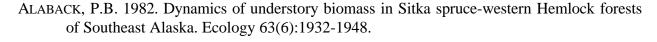
any prescriptions for logging a percentage of a stand's basal area should be applied on a fine grained spatial scale (every 0.1-0.2 ha).

Although a number of significant relationships revealed themselves through this study, the r^2 terms for most were relatively low, suggesting that much unexplained variability remains in the data. This is not surprising given the retrospective nature of this study. Some of the variability is no doubt due to error. Recreating history from fragmentary evidence is difficult and involves a degree of subjectivity and approximation. Moreover, because the study is retrospective, among-plot differences in topography, soils, and chronic disturbance history can be identified, but not well controlled. We accept these limitations, recognizing they are balanced by the potential to glimpse the distant future based on observations made today. This study successfully provides those insights and, hopefully, provides managers with information useful in making informed and appropriate decisions.

ACKNOWLEDGMENTS

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