EFFECTS OF YOUNG-GROWTH MANAGEMENT ON SITKA BLACK-TAILED DEER IN SOUTHEAST ALASKA

By

Cade W Kellam, B.S.

A Thesis Submitted in Partial Fulfillment of the Requirements

for the degree of

Master of Science

In

Wildlife Biology and Conservation

University of Alaska Fairbanks

May 2023

APPROVED:

Todd Brinkman, Committee Chair
Teresa Hollingsworth, Committee Member
Knut Kielland, Committee Member
Todd Brinkman, Chair
Department of Biology and Wildlife
Karsten Hueffer, Interim Dean
College of Natural Science and Mathematics
Richard Collins, Director
Graduate School

Abstract

Commercial logging was the dominant industry in southeast Alaska during the second half of the twentieth century. Logging practices have left a landscape legacy of regenerative forest types such as clearcuts and second growth. Second-growth forest occurs about 20-30 years after a clearcut and is relatively unproductive compared to other forest types. To enhance productivity, second-growth is often thinned to a lower density of standing timber, this process is referred to as pre-commercial thinning (hereafter, thinning). Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) are an important cultural and subsistence resource across southeast Alaska. How thinned forests affect deer is not well known. To better understand how forest management is affecting local populations of deer in southeast Alaska we examined how thinning treatments impact deer browse intensity and snow accumulation on the forest floor. In this thesis, we presented two studies that examine the effects of thinning on deer habitat quality and deer access to forage. In the first study of this thesis, we quantified browse intensity in recently thinned (≤4 years post thinning) and adjacent old-growth forests. We also explored the immediate effects of thinning and slash (felled trees left on the forest floor) on forage availability. We performed a pairwise comparison of browse intensity between thinned and adjacent old-growth forests and modeled the effects of thinned forest characteristics on browse intensity. In the second study of this thesis, we quantified maximum snow depth in thinned, unthinned second-growth, old-growth and unforested (control) habitat types. Forest structure and composition affected how snow accumulates on the ground. Snow can impede the movement of ungulates species, such as deer, and reduce available forage. We evaluated how different forest types accumulated snow in southeast Alaska to better understand the implications on winter habitat quality for Sitka black-tailed deer.

To quantify browse intensity in thinned and adjacent old-growth forests, we conducted browse surveys in recently thinned stands (2017 to 2021) and adjacent middle to high volume old-growth forests. We

established 50m transects and surveyed plots every five meters to quantify browse of *Vaccinium sp*. (blueberry and huckleberry), a preferred deer forage species. In the second study, we measured snow depths throughout thinned, unthinned, old-growth and unforested sites to identify if these forest types accumulate snow differently. We also measured forest structure variables to use as predictors when modeling maximum snow depth. Transects were 70 meters long, and snow depth and forest structure data were collected every five meters. Snow depths were measured four to six times throughout the winter. The maximum depth of each transect point was recorded and paired with the forest structure variables. For both studies, we used nonparametric tests and generalized linear mixed models to understand the interactions between forest types and their maximum snow depths or percent of a *Vaccinium sp*. plant browsed.

From the first study, we concluded that browse intensity was significantly different in thinned and old-growth forests ($P<0.01$). We learned that thinned stands with more slash reduce browse intensity. Slash (vertical obstruction) volume and time since thinning (metrics of slash decay) best explained percent of a plant browsed. From or second study, we found that thinned forests accumulated the same amount of snow on the forest floor as unforested sites. Moreover, old-growth and unthinned sites accumulated snow on the forest floor comparably during a relatively normal snow load year. Our findings regarding browse intensity showed that thinned forests have a delayed benefit to deer because of slash abundance. Our observations regarding snow accumulation showed that thinned forests have little value to deer in a winter with deep snow accumulation. Managers can use this information to better understand the extent of forage available to deer in recently thinned forest habitat. Our findings also demonstrated that the implementation of thinning treatments that minimize slash volume and accelerate decomposition will enhance benefits for deer.

Table of Contents Page

Abstract iii

List of Tables vii

Acknowledgments viii

Chapter 1: Introduction 1

1.1 Background 1

1.2 Motivation 4

1.3 Broader Relevance 4

1.4 References 6

Chapter 2: Reduced deer browse intensity in pre-commercially thinned forests in Alaska 9

2.1 Abstract 9

2.2 Introduction 9

2.3 Methods 13

Study Area 13

Browse surveys 15

Data analysis 17

2.4 Results 19

2.5 Discussion 25

2.6 Management Implications 28

2.7 Acknowledgments 29

2.8 References 29

Chapter 3: Snow accumulation in pre-commercially thinned forests, and its implications for Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) 35

3.1 Abstract 35

3.2 Introduction 36

3.3 Methods 38

Study Design 38

Data collection and Experimental Design 40

Data analysis 41

3.4 Results 42

3.5 Discussion 49

3.6 Acknowledgments 53

3.7 References 54

Chapter 4: Conclusion 59
  4.1 References 61

List of Figures

Page

Figure 2.1. Relationships between different forest types canopy cover and deer forage 11

Figure 2.2. Map of Prince of Wales Island 15

Figure 2.3. Depicts a box and whisker plot for the average percent of a plant browsed 21

Figure 2.4. Depicts the relationship between percent of a plant browsed and percent vertical 24

Figure 2.5. Depicts the percent of a plant browsed plotted across the year that thinning took place 25

Figure 3.1. Prince of Wales Island (POW) 42

Figure 3.2. Box and whisker plot depicting the response of maximum snow depth 44

Figure 3.3. Depicts the maximum snow depth vs percent canopy open 47

List of Tables

Table 2.1. Slash and deer forage (*Vaccinium sp.*) characteristic median values 20

Table 2.2. Median values and statistical differences of browsed, unbrowsed, and percent browsed 20

Table 2.3. Akaike Information Criteria (AIC) scores of GLMM models used to estimate effects 23

Table 2.4. Variable fixed effects from the best-fit generalized linear mixed model 23

Table 2.5. Kruskal-Wallis rank sum test for slash characteristics 23

Table 2.6. Pairwise Wilcoxon rank sum test comparing median percent browse 24

Table 3.1. Median results of maximum snow depth across different forest types 43

Table 3.2. Average forest structure characteristic values 45

Table 3.3. Kruskall-Wallis rank sum outputs 45

Table 3.4. Wilcoxon signed-rank test for percent canopy 46

Table 3.5. Model comparisons by Akaike information criterion (AIC) 46

Table 3.6. Model summary where forest type was used as a fixed effect 48

Table 3.7. Pairwise comparisons of estimated marginal means by forest type 48

Acknowledgments

This project was made possible by the many who helped in small and large contributions throughout the process. Fellow graduate students, former professors, and technicians that I have been fortunate enough to work with all played a role. From cold rainy days in the field to hours of editing this manuscript I have received tremendous support. Thank you to the many for your contribution.

I would like to first acknowledge my committee, Dr. Todd Brinkman, Dr. Teresa Hollingsworth, and Dr. Knut Kielland, for their steadfast advice and support throughout the process of developing, carrying out and analyzing this study. The chair of my committee, Dr. Todd Brinkman, provided unending support with autonomy in the study design, data collection and analysis portion of this project. Todd gave me the resources and helpful nudges to develop myself as a researcher, naturalist, writer, and ecologist. Todd instilled the importance of thoughtful and quality science through lessons learned in the lab and afield. He was very patient with me as a developing writer throughout the manuscript process and is always there for academic or life advice. Dr. Teresa Hollingsworth has been tremendously helpful with regard to pressing my knowledge of forest and plant succession in southeast Alaska. She has critiqued my study design, analysis and writing to help build skills I will use as an ecologist. Dr. Knut Kielland has always offered a great deal of encouragement and a pressing critique of my ecological understandings. For this I am thankful because it has shaped me into a thoughtful and continuously curious developing ecologist. I am thankful to my entire committee for their support and patience throughout this project.

I would like to thank the PNW Research Station, USDA Natural Resource Conservation Service, the Hoonah Forest Partnership and the UAF Department of Biology and Wildlife for their funding and project support. The USDA Forest Service Craig Ranger District and their employees maintained a network of safety communication and resources while I was on Prince of Wales Island. The network of safety resources and employees helped to carry out successful fieldwork. I would like to thank Jeff Barnard for

his help with logistics on the island. I would like to thank Ray Slayton for his help in conducting browse surveys throughout March and April of 2021. Ray collected data for this project, was a friend, and taught me how to shell crabs and fish for steelhead in the creeks of the island. I would like to thank Hollis resident Steve McCurty for his help in forest structure data collection and for teaching me the 12 bar blues on the guitar. Steve crawled through thinned and unthinned stands on many cold rainy mornings with no complaints. Steve and Ray helped with an arduous task of traversing slash that was difficult to work in to say the least. They both kept spirits high in the field and taught me a great deal about local ecology and history related to southeast Alaska. I am very thankful for both of Steve and Rays efforts in data collection and the passing on of their knowledge.

I would like to thank my loyal dog Paul for his companionship and love. Paul has been with me through my graduate school journey, and I couldn’t have done it without the home he helps create.

Chapter 1: Introduction

1.1 Background

Since its establishment, approximately 67% of high volume old-growth forest has been removed from the Tongass National Forest of Alaska (Albert and Schoen 2013; Beier et al. 2009). The effect of forest removal on Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) has been both positive and negative. Clearcuts generate a tremendous amount of summer forage for the first ten years, but after ten years, forage begins to decline, and after 25-30 years post clearcut these landscape units have nearly no value to deer. Indeed, second-growth forests provided very little deer forage for the next ~100 years (Alaback 1982; Crotteau et al. 2019). Waxing and waning logging operations result in localized fluctuations of deer, as well as perceived population changes by the public, largely because of changing visibility of deer from roads as the young growth obstructs field of view. Managing deer in southeast Alaska requires an understanding of how populations respond to different stages of forest succession. Pre-commercial thinned sites, which are second-growth forests where select trees are felled to leave a lower density of standing timber, are relatively new on the landscape and becoming more abundant across southeast Alaska. How the slash, or felled trees, produced from thinned sites and the snow accumulation in thinned sites are affecting access to winter deer forage is not well understood. Determining how slash volume affects browse intensity or access to forage, and how thinned forests accumulate snow compared to other forest types may inform managers how valuable thinned forests are for deer specifically.

In southeast Alaska old-growth forests are dynamic and heterogeneous in both understory and overstory (Thomas et al. 1988). Deer seek high-volume old-growth habitats during times of high snow depth because the multilayered forest canopy helps to intercept snow and enhance the availability of forage and facilitate easier movement through the forest (Bloom 1978; Farmer et al. 2006; Gilbert 2015; Hanley 1984; Klein and Olson 1960). Clearcut logging of old-growth is the beginning of forest succession, and within 20 to 30 years post-clearcut unproductive second-growth is present. As the canopy closes, deer forage is shaded out and the latter years (25-100) of second-growth are of less value to deer (Alaback 1982; Crotteau et al. 2019). Transitioning from second-growth to a dynamic old-growth stand requires an estimated 150-200 years of natural growth and forest disturbance (Thomas et al. 1988). The thinning of standing timber can accelerate tree growth and simulates natural disturbances like windthrow. However, the trees that are cut down are not removed. Downed trees that lay across the forest floor are referred to as slash. The consequences of thinning on deer habitat selection, forest characteristics, and forage abundance are unclear. For example, it is neither understood nor quantified in the literature how thinned forests keep snow off the ground, or how thinned forests are affecting deer by inhibiting access to forage via snow depth or slash obstruction.

Quantifying browse or biomass removal by ungulates is a way to approximate forage intensity, which can serve as a metric for ungulate presence and density (Paragi et al. 2015). A study on white-tailed deer (*Odocoelius virginianus*) used the percent of stems browsed on a plant to determine where browse intensity was higher among orchard species (Parker et al. 2020). Quantifying physical obstruction at the level a deer would encounter that obstruction provides insight into the extent that movement or access to forage affects them. For example, elk (*Cervus canadensis*) select habitats without slash and low snow depths (Lyon and Jensen 1989). Quantifying slash or any physical obstruction in areas where browse surveys have been conducted creates an opportunity to assess the relationship between physical obstructions and browse intensity. In southeast Alaska on Prince of Wales Island Sitka black-tailed deer are the sole browsing animal that removes woody mass from *Vaccinium sp.* (blueberry and huckleberry) plants. The research question related to the aforementioned relationships is: how do thinning and slash characteristics affect deer access to winter forage?

Deep snow can be an obstruction to ungulates (Parker et al. 1984). Models of habitat selection show that deer select against deep snows (Doerr et al. 2005). A 2016 study showed that a 10% increase in snow depth produced a 20-30% decrease in the probability of site selection by deer, with the selection of higher volume old-growth as snow depths increase (Gilbert 2015). In southeast Alaska very deep snow drives deer to the beach, where snow does not accumulate because of tidal activity, to forage on kelp/seaweed (Doerr et al. 2005). Snow accumulation in pre-commercial thinned forests has the potential to change localized deer movement depending on available forage, slash obstruction and snow depth. A comparison of snow depth in thinned forests, second-growth, and old-growth forests has not been quantified in the literature. Understanding how forest attributes contribute to snow accumulation on the forest floor could help managers predict snow depth in managed stands. Predicting snow depth accurately in different forest types can help identify when foraging sites become unavailable to deer. Mule deer (*Odocoileus hemionus*) are less willing to travel through snow depths that exceed 40cm, which likely applies to the smaller Sitka black-tailed deer (Lyon and Jensen 1989). Our second objective was to understand the relationship between forest attributes and snow accumulation as it impacts deer. We compared snow depth and forest attributes in thinned, unthinned, old-growth and unforested sites to determine how snow accumulation changes based on forest type and characteristics. How snow depth varies by forest type is then applied to existing knowledge of available forage to determine how deer might use the managed landscape across southeast Alaska.

The question for this research is: How do thinned, unthinned, old-growth and unforested sites accumulate snow, and what forest characteristics affect snow depth? The second study quantifies forest characteristics and snow depth in thinned, unthinned, old-growth, and unforested sites to understand how managed forest types accumulate snow in comparison to each other.

1.2 Motivation

Across the Pacific Northwest, approximately 80% of high volume old-growth timber has been logged (Thomas et al. 1988). Clearcut logging starts forest succession over and in southeast Alaska changes the forage species availability for herbivores compared to pre-clearcut (Hanley 1984). Clearcut logging creates short-term (~15 years) abundance in forage followed by long-term periods (~80+ years) of relatively low forage biomass when the forest is in a second-growth stage (Harris and Barnard 2017). Ungulates vary their use of the landscape based on forage abundance, and access to forage, among other factors (e.g., predators, hunting pressure). In southeast Alaska deer are valued as a consumptive resource and inherently as a north American native species (Kruse and Frazier 1988; Mazza 2003). As clearcuts change the landscape, the cascading effects on deer should be evaluated for the interest of deer population health, systems ecological health and the acknowledgment of indirect human interaction with wildlife.

1.3 Broader Relevance

Deer are the main subsistence game resource in southeast Alaska (Alaska Department of Fish and Game 2001; Kruse and Frazier 1988; Mazza 2003; Turek et al. 1998). Quantifying the cultural value of deer across southeast Alaska is challenging, but their value is apparent in the way communities use deer to thrive. In addition, monitoring deer populations in southeast Alaska is also challenging because of the dense forest that makes direct observation of deer difficult. Remote sensing (e.g., radio tracking, trail cameras), non-invasive collecting of fecal DNA, and attempting to understand deer through the quality of their habitat is a practical way to monitor deer in southeast Alaska.

By quantifying the effect of slash on deer browse intensity we are beginning to understand how pre-commercial thinned stands influence deer habitat use. As previously logged stands continue to transition to stem exclusion stages, and are thinned, the landscape becomes more abundant with slash. Deer browse intensity is likely affected by the volume of slash present and the rate of decomposition removing slash (Parker et al. 1984; Wallmo 1969; Wallmo and Schoen 1980). The relationship between slash and deer browse intensity may inform managers and researchers how pre-commercial thinning is impacting the ability of deer to browse successfully in the winter. Pre-commercial thinning treatments require a high proportion of labor to acreage thinned. Thinned areas are usually localized, small areas, but can create a high density of forage as compared to nonproductive second-growth. Thinned forests have the potential to affect localized deer populations and may create pockets of increased deer presence as slash decomposes (Doerr et al. 2005). Understanding what volume of slash excludes access to these stands informs managers when potential habitat hotspots, rich in forage, may become available. Information about habitat availability and concentrated populations helps managers plan for successful wildlife management.

We measured snow depth in different forest types to understand how forests in post-clearcut succession, including thinned forests, accumulate snow to a maximum depth and what forest characteristics control accumulation. By answering these questions, we may provide managers with information about how certain habitats may become effectively unavailable for deer in winter due to different rates of snow accumulation. The understanding that thinned forests produce understory biomass, and old-growth forests are important winter habitat is documented in the literature (Alaback 1982; Bloom 1978; Brinkman et al. 2011; Crotteau et al. 2019; Doerr et al. 2005; Gilbert 2015). How these thinned forests hold snow in the canopy and off deer forage is important for understanding the winter forage value of thinned stands. Managers could use this information to understand what proportion of habitat is currently available for deer as they track snow depth. This may provide managers with a better understanding of how rapid habitat change influences survival, forage availability, travel corridors or other metrics of population health and fitness.

1.4 References

Alaback, P.B. 1982. Dynamics of understory biomass in Sitka spruce-western hemlock forests of southeast Alaska. Ecology, 63(6):1932–1948.

Alaska Department of Fish and Game. 2001. Community profile database. Alaska Department of Fish and Game, Division of Subsistence, Douglas, Alaska, USA. http://www.state. ak.us/adfg/subsist/subhome.htm.

Albert, D.M., Schoen, J.W. 2013. Use of historical logging patterns to identify disproportionately logged ecosystems within temperate rainforests of southeastern Alaska. Conservation Biology, 27(4):774-784.

Beier, C.M., Lovecraft, A.L., Chapin III, F.S. 2009. Growth and collapse of a resource system: an adaptive cycle of change in public lands governance and forest management in Alaska. Ecology and Society, 14(2):5.

Bloom, A.M. 1978. Sitka Black-Tailed Deer Winter Range in the Kadashan Bay Area , Southeast Alaska. Journal of Wildlife Management, 42(1):108-112.

Brinkman, T.J., Person, D.K., Chapin, S.F., Smith, W., Hundertmark, K.J. 2011. Estimating Abundance of Sitka Black-Tailed Deer Using DNA from Fecal Pellets. Journal of Wildlife Management, 75(1):232–242. https://doi.org/10.1002/jwmg.22.

Crotteau, J.S., Rue-Johns, A., Barnard, J.C. 2019. Eight- to Ten-Year Effects of Pre-Commercial Thinning on Understory Biomass and Forage of Sitka Spruce/Western Hemlock Stands in Southeast Alaska. Canadian Journal of Forest Research, 50:215–225. https://doi.org/10.1139/cjfr-2019-0268.

Doerr, J.G., Degayner, E.J., Ith, G. 2005. Winter Habitat Selection By Sitka Black-Tailed Deer. Journal of Wildlife Management, 69(1):322–331. https://doi.org/10.2193/0022-541x(2005)069<0322:whsbsb>2.0.co;2.

Farmer, C.J., Person, D.K., Bowyer, R.T. 2006. Risk Factors and Mortality of Black-Tailed Deer in a Managed Forest Landscape. Journal of Wildlife Management, 70(5):1403–1415.

Gilbert, S.L. 2015. Environmental Drivers of Deer Population Dynamics and Spatial Selection in Southeast Alaska. PHD Dissertation. University of Alaska Fairbanks.

Hanley, T.A. 1984. Relationships Between Sitka Black-Tailed Deer and Their Habitat. General Technical Report PNW-168:2–13.

Harris, S.H., Barnard, J.C. 2017. Understory Plant Development in Artificial Canopy Gaps in an 81-Year-Old Forest Stand on Chichagof Island, Southeast Alaska. USDA Forest Service - Research Paper PNW-RP 609 (June).

Klein, D.R., Olson, S.T. 1960. Natural Mortality Patterns of Deer in Southeast Alaska. Journal of Wildlife Management, 24(1):80–88.

Kruse, J., Frazier, R. 1988. Reports to the Communities of Southeast Alaska (one per community). Tongass Resource Use Cooperative Survey Institute of Social and Economic Research. University of Alaska Anchorage.

Lyon, J., Jensen, C.E. 1989. Management Implications of Elk and Deer Us of Clear-Cuts in Montana. Journal of Wildlife Management, 53(3):519–523. https://doi.org/10.1002/jwmg.ll3.

Mazza, R. 2003. Hunter demand for deer on Prince of Wales Island, Alaska: an analysis of influencing factors. U.S. Forest Service General Technical Report PNW-GTR-581.

Paragi, T.F., Seaton, C.T., Kellie, K.A., Boertje, R.D., Kielland, K., Young Jr, D.D., Keech, M.A., DuBois, S.D. 2015. Browse removal, plant condition, and twinning rates before and after short-term changes in moose density. Alces: A Journal Devoted to the Biology and Management of Moose, 51(1):1-21.

Parker, H.A., Larkin, J.T., Heggenstaller, D., Duchamp, J.,Tyree, M. C., Rushing, J.C.,Domoto, E. J., Larkin, J.L. 2020. Evaluating the Impacts of White-Tailed Deer (Odocoileus Virginianus) Browsing on Vegetation in Fenced and Unfenced Timber Harvests. Forest Ecology and Management, 473(118326). https://doi.org/10.1016/j.foreco.2020.118326.

Parker, K.L., Robbins, C.T., Hanley, T.A., 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management, 48(2):474-488.

Thomas, J.W., Ruggiero, L.F., Mannan, R.W., Schoen, J.W., Lancia, R.A. 1988. Management and conservation of old-growth forests in the United States. Wildlife Society Bulletin, 16(3):252-262.

Turek, M.F., Schroeder, R.F., Wolfe. 1998. Deer hunting patterns, resource populations, and management issues on Prince of Wales Island. Alaska Department of Fish and Game, Division of Subsistence, Juneau, Alaska, USA.

Wallmo, O.C. 1969. Response of deer to alternate-strip clear cutting of lodgepole pine and spruce-fir timber in Colorado. U.S. For. Serv. Res. Note RM-141. 4pp.

Wallmo, O.C., Schoen, J.W. 1980. Response of deer to secondary forest succession in southeast Alaska. Forest Science, 26(3):448-462.

Chapter 2: Reduced deer browse intensity in pre-commercially thinned forests in Alaska[1]

2.1 Abstract

Clearcut logging in southeast Alaska produces second-growth forests with closed canopies, and an understory lacking deer forage. To stimulate understory plant growth, improve timber quality, and improve deer habitat, forest managers pre-commercially thin second-growth forests. Thinning creates slash or downed trees on the forest floor which may influence deer movements and habitat use. We investigated the effect of recently thinned forests (zero to four years post thinning) on browsing by Sitka black-tailed deer (*Odocoileus hemionus sitkensis*). We conducted browse surveys in 16 thinned and old-growth forests. We performed a pairwise comparison of browse intensity between treatments and modeled the effects of thinned forest characteristics on browse intensity. Browse intensity was ~2.5 times greater ($P<0.01$) in old-growth forest (plot median = 22% of plant browsed) compared to adjacent thinned stands (plot median = 4% of plant browsed). A generalized linear mixed model indicated that the years since thinning and slash volume best predicted browse intensity. Our study suggests that browse availability in recently thinned stands is limited by the time required for forage to establish and the volume of slash left on the forest floor.

2.2 Introduction

Across the Pacific Northwest, including southeast Alaska, more than 80% of high volume old-growth timber has been removed (Thomas et al. 1988). Commercial timber harvest was a major industry in southeast Alaska from the late 1950s through the late 1990s. Approximately 67% of high volume old-

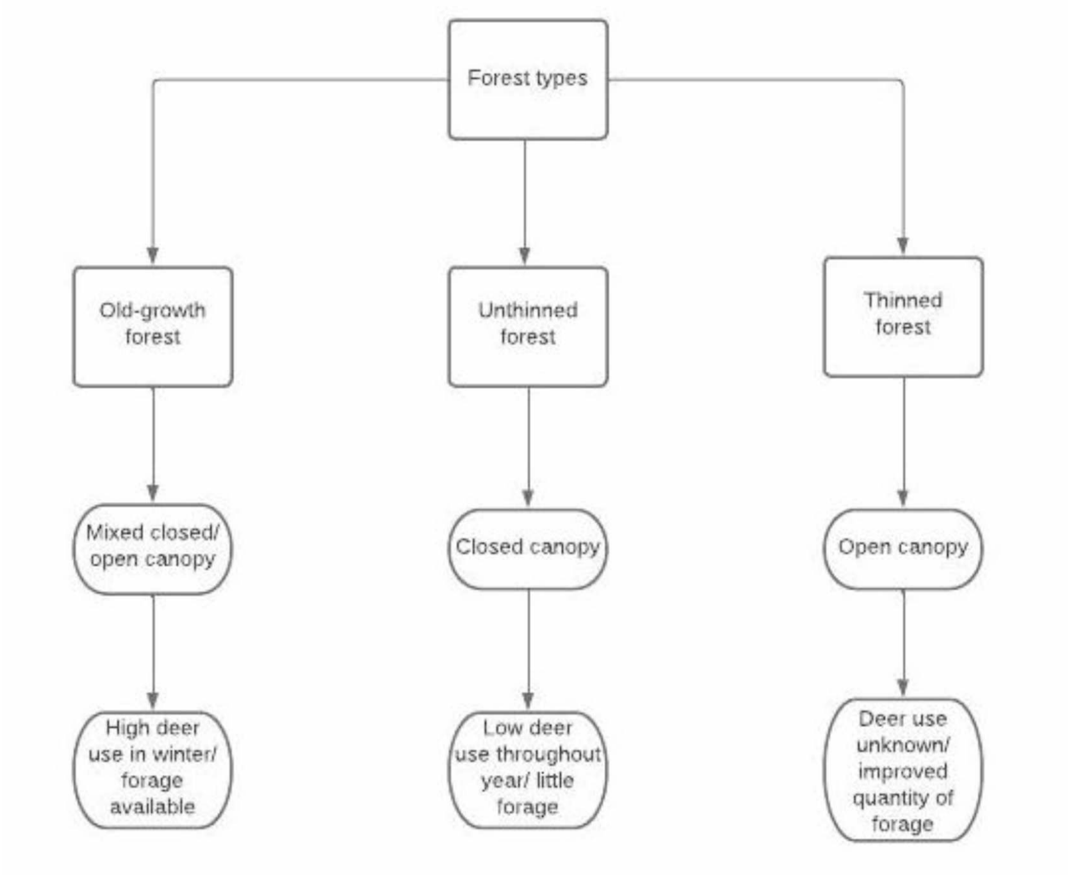
---

[1] Kellam, C. W., Brinkman, T. J., Hollingsworth, T. N., and Keilland, K. Reduced deer browse activity in precommercially thinned forests in Alaska. Prepared for submission to *The Canadian Journal of Wildlife Management.*

growth forest has been removed from the Tongass National Forest of Alaska, the largest National Forest in the United States, by clearcut logging (Albert and Schoen 2013; Beier et al. 2009). Clearcut logging opens the canopy, regenerating forbs and shrubs that dominate the forest understory for the next 15-20 years. The understory creates an abundance of forage during the snow-free season for forest herbivores such as Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) (Crotteau et al. 2019; Hanley et al. 2013). Young clearcut forests also create ideal hunting opportunities for subsistence and sport hunters because of improved deer occupancy, and an increase in visibility in the more open landscape, and good accessibility provided by adjacent logging roads (Brinkman et al. 2009; 2011; Harris and Barnard 2017).

The next five to 30 years (depending on site productivity) after a clearcut, conifers naturally regenerate and begin to dominate the forest stand, gradually closing the canopy and shading out forbs and shrubs. Roughly 20-30 years post clearcutting, depending on the productivity of the forest stand, the habitat transitions to a stem exclusion stage. The stem exclusion stage is characterized by a closed canopy with dense conifers and little deer forage (Crotteau et al. 2019) (Fig. 2.1). The stem exclusion stage also slows the growth of conifers. Without management intervention, stem exclusion may persist for at least 80 to 100 years until natural disturbances (e.g., windthrow) open canopy gaps and bring back forest heterogeneity (a mix of closed and open canopy) with pockets of diverse understory vegetation (Alaback 1982) (Fig. 2.1).

Figure 2.1. Relationships between different forest types, canopy cover, and deer forage were evaluated in this study. The closed/ open canopy characteristics of productive old-growth intercept snow keeping snow depths low and allowing deer to forage throughout the winter.



The negative effects of the stem exclusion stage on deer habitat and deer hunters have been well documented. For example, deer and deer hunters avoid forests in the stem exclusion stage (Brinkman et al. 2009; Farmer et al. 2006). The large area of forest that has transitioned to stem exclusion in southeast Alaska reduces habitat carrying capacity for deer, and for the food security and culture of people in the region (Brinkman et al. 2009). Sitka black-tailed deer are the main recreational and subsistence game resource in southeast Alaska (Alaska Department of Fish and Game 2001; Kruse and Frazier 1988; Mazza 2003; Turek et al. 1998). From the years 1987 to 2007 there was an annual average of 12,334 deer harvested legally, and on Prince of Wales Island (POW) an average of 73% of households use deer meat as a subsistence resource (ADF&G 2001). The cultural importance of deer to these communities is challenging to quantify, but it is obvious that great value exists.

To move forests out of the stem exclusion stage, managers implement pre-commercial thinning treatments, hereafter referred to as thinning (Hanley et al. 2013). Thinning treatments consist of cutting down selected trees to achieve a lower density of commercially preferable standing trees at a spacing that promotes faster growth. Approximately 42% of second-growth forests in southeast Alaska have received silvicultural treatment to increase productivity (Alaback et al. 2013; Hanley et al. 2013). In 2002, The USDA Forest Service implemented the Tongass Wide Young Growth Study (TWYGS) to support long-term monitoring of vegetation and forest succession in young-growth stands, including those receiving thinning treatments. Monitoring included measuring biomass, deer forage, and plant succession. Approximately ten years after thinning, TWYGS monitoring results indicated that understory biomass doubled in thinned stands compared to unthinned stands. (Crotteau et al. 2019). The authors acknowledged that thinning-induced snow accumulation likely covered available vegetation at a faster rate compared to unthinned stands, and the effect from thinning on deer forage within the first five years of succession was not explored (Crotteau et al. 2019; Hanley et al. 2013). The downed trees produced from thinning currently have no commercial value and are left on the forest floor, a product called slash. Thinning opens up the canopy and allows the regeneration of understory vegetation and deer forage (Crotteau et al. 2019). Therefore, thinning appears to have positive effects on deer habitat quality. However, the downed trees left on the forest floor can create abundant volumes of slash. Slash can be dense and has been shown to affect the movement of deer species in other ecosystems (Lyon and Jensen 1989).

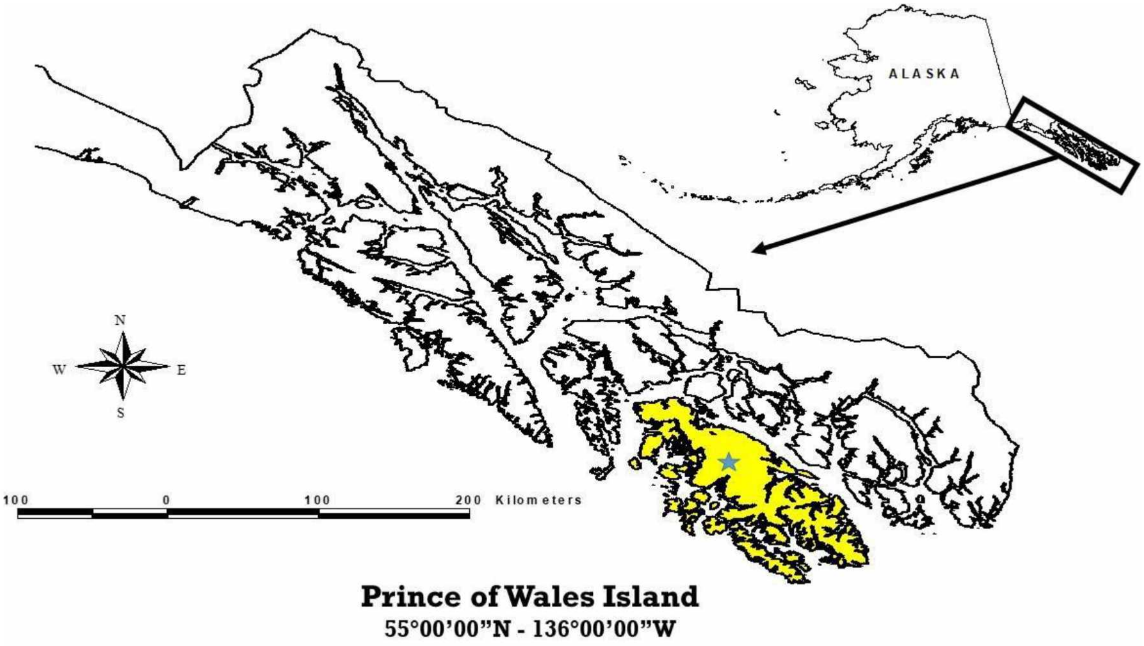
There is little information on how recently (less than five years) thinned stands affect Sitka black-tailed deer access to forage. However, a better understanding of how slash reduces deer access to forage will help improve our understanding of deer habitat quality, which assists land management plans and wildlife conservation goals. In addition, more information on browse intensity in thinned stands, and the factors that influence it, may inform how thinning practices can be altered to improve deer forage. Here, we ask; how do recent thinning events (less than five years) affect a deer's capacity to access forage? We compared browse intensity between thinned and immediately adjacent old-growth forests, and modeled the influence of forest variables within thinned stands on browse intensity.

2.3 Methods

Study Area

We conducted our study on Prince of Wales Island (POW) on the southern tip of the Alexander Archipelago in southeast Alaska (Fig. 2.2). Most of the island is within the Tongass National Forest. The island is a coastal temperate rainforest ecosystem with coastal estuary habitats, grass-covered shorelines, alpine habitats that extends to 1600 meters, and forests dominated by Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*) (Alaback 1982). Forest floor vegetation is similar to all areas of the Pacific Northwest. Important forage species for deer during winter (forage limiting season) are deciduous shrubs and evergreen forbs such as blueberry and huckleberry (*Vaccinium sp.*), dwarf dogwood (*Cornus canadensis)*, five leaved bramble (*Rubus pedatus*, *pyrola sp.*), and ferns of different genus and species. *Vaccinium sp.* is one of the most abundant and important winter forage items for deer, especially when snow is covering evergreen forbs (Hanley 1984, Hanley and Mckendrick 1985). Also, *Vaccinium sp.* are present across the entire study area. Therefore, *Vaccinium sp.* was the focus of our browse studies. Between 1980-2010, the annual mean temperature, rainfall, and snowfall on POW (Klawock airport, near sea level) was 7°C, 227 cm, and 10 cm, respectively (The Alaska Climate Research Center 2022). There are approximately 2,400 kilometers of road on POW, most of which is USDA Forest Service road (Prince of Wales Island Road System 2022). The road system connects several communities on POW with a total population of 6,000 people, with the biggest community being Craig (Pop. ~1200). Although there are rare sightings of moose (*Alces alces*) and elk (*Cervis elaphus*), deer are the only established ungulate population on POW. All quantifications of browse in this study can be attributed to deer because other browsing herbivores (e.g., porcupines (*Erethizon dorsatum*), hare (*Lepus americanus*)) are not present on the island. Wolves are the main predators of adult deer in southeast Alaska (Klein and Olson 1960), but black bears (*Ursus Americanus*) are important predators of fawns (Gilbert 2015), both of which can have an impact on localized deer populations (Farmer et al. 2006). However, environmental factors, such as deep snow which limits access to forage, is the main driver of population-level mortality of deer in southeast Alaska (Brinkman et al. 2011; Klein and Olson 1960; Klein 1965; MacDonald and Cook 1996; Wallmo and Schoen 1980).

Figure 2.2. Map of Prince of Wales Island (highlighted) where this study took place from February 2021 – June 2021. Our plots (under the blue star) were in the interior of the island in the Staney and Steelhead Creek watersheds.



Browse surveys

We conducted browse surveys from February to May of 2021 in thinned forest stands that were recently pre-commercially thinned (2017 to 2021). We sampled old-growth with moderate to high volume (timber class ≥5, where the average stand age is 150 years or greater) directly adjacent to use as a paired control. We conducted 32 survey transects (16 thinned and 16 paired control / old-growth stands). For the thinned forest type we had six replicates for stands thinned in 2017 and seven replicates for stands thinned in 2018. We had one stand thinned for each of the following years 2019, 2020, and 2021. A thinned stand or an old-growth stand qualified for surveying if we were able to layout the 50-meter transect and be a minimum of 20 meters away from any other habitat type or road/trail. Transect length and minimum distance were used to capture variability in stand characteristics and avoid the edge effect, respectively. We selected study sites that were within a 1.6km hike to a maintained road for logistic and safety reasons.

For all sites, a compass azimuth was shot in the direction that the stand spanned the furthest. To avoid bias, the hour hand of a watch was used to add a random number between one and 12 to the azimuth. We walked 50m transects and established survey plots every five meters for *Vaccinium sp*. data collection. Plots were of varying size because the closest four plants to plot center were used as the data source. We chose to only record data for the four closest plants, rather than all the plants in a fixed radius plot due to the variation of browsed and unbrowsed stems not changing after four plants. We did capture the number of *Vaccinium sp*. plants per m^2 (referred to as plant density) to identify if there were factors related to plant density affecting the number of browsed stems. Plant density was collected to compare available forage as a variable affecting browsing intensity between thinned and old-growth forest types. Any species in the *Vaccinium* genus that is present within plots along the transect was included. Data collected for each of the four plants included maximum height, the total number of browsed stems, and the total number of unbrowsed stems. If there were no *Vaccinium sp*. plants within five meters of the transect point there was a note made, but zeros were not entered or used in the analysis. We produced the percent of a plant browsed by dividing the number of browsed stems by the summation of browse and unbrowsed stems and then multiplying by 100. Plant height was an important metric to collect because it could reflect the availability of food at different snow depths, and potentially capture browse height preference. All *Vaccinium sp*. browse seen above moss level was documented.

Browse surveys occurred in late winter and spring before green-up. We sampled 16 thinned/treatment stands (thinned between 2017 to 2021) and 16 adjacent old-growth/control stands. Slash was quantified by measuring horizontal and vertical obstruction in the thinned stands only (slash was not present in old-growth / control stands). Horizontal obstruction was estimated by first laying a

150-centimeter pole with marked ten cm increments on the forest floor (Robel et al. 1970). The pole was then viewed from one meter above the center of the pole and the number of ten-centimeter increments obstructed by slash was divided by the total number of increments (n=15) to generate a horizontal obstruction percentage. An increment was considered obstructed if more than half of the ten-centimeter increment was obstructed by slash. Vertical obstruction was produced by standing the 150-centimeter pole up vertically in the slash at the plot center point, viewing the pole from one meter away and one meter off the ground, and counting the number of ten-centimeter increments that were obstructed by slash. We chose 1.5m horizontal and vertical obstruction assessment to represent the three-dimensional space that a deer occupies and can browse within on the forest floor. To account for browsing that had taken place during the current year, we only totaled a stem browsed if the epidermis of where the plant was bitten was still alive. Older browse on a stem that was dead was excluded. By ignoring browsed stems where the entire plant stem was dead, we avoided the representation of old browse that could have happened before thinning. By ignoring older browse we are better assessing how the effect of the current volume of slash on the forest floor affects browse intensity. We ended our surveys in late May as new growth and leaf-out began to impact our accuracy at totaling browsed and unbrowsed stems.

Data analysis

At the plot level (five-meter transect point), we quantified plant density (vaccinium plants / square meter), vertical and horizontal obstruction (as a percent and in thinned stands only), medians of browsed, unbrowsed, maximum plant height of the four plants closest to the transect point. We calculated plot averages across the four plants (or all plants present if less than four) closest to center of the plot. Nonparametric tests were used to examine the differences in average percent browsed stems because of the non-normal distribution of the data. We used a Wilcoxon signed-rank test to understand if there was a significant difference between the number of browsed stems and the number of unbrowsed stems across thinned and old-growth stands. Carrying out this Wilcoxon signed-rank test without the use of a fixed radius plot, as we did by selecting the four closest plants, requires the assumption that plant density was not different between thinned and old-growth forests. To confirm that plant density was not significantly different between the two forest types we used a Wilcoxon signed-rank test. To examine any significant difference between the percentage of browsed stems inside of recently thinned stands vs old-growth stands we used the same Wilcoxon signed-rank test (paired). We calculated effect sizes for the differences between browsed, unbrowsed, and percent browsed between treatment and control groups. The effect size of 0 to 0.2 would be considered small, 0.3 to 0.7 would be medium and 0.8 to 1.4 would be large (Sullivan and Feinn 2012).

To explore factors influencing variation on the percent of a plant browsed within thinned stands, we modeled the effects of density, mean maximum plant height, vertical obstruction, horizontal obstruction, year (time since thinning), site, and transect location on percent browse. Generalized linear mixed models (GLMM) were used with a gamma distribution to predict the percentage of a plant browsed. We treated site as a random effect in the model, and all other predictors were fitted as fixed effects. Treating the site as a random effect allowed us to assign autocorrelation among the data to the site level. Using the transect location as a random effect also allowed us to account for autocorrelation for transect points that were closer together. We transformed years of thinning into a categorical variable where one represented sites thinned in 2017, two represented sites thinned in 2018, and a three represented sites thinned in 2019-2021. We grouped years 2019 – 2021 because of the low number of sites within individual years. We converted vertical and horizontal obstructions to a percentage for ease of interpretation. We ran our models in Rstudio using the package “glmmTMB.” We used a generalized model because the data had a nonnormal distribution with a zero-heavy skew. The full model, including all predictors, was fitted and each parameter was evaluated using its associated p-value and beta coefficients. Parameters were removed when they did not have a significant effect on the response, and the model was reevaluated using the AIC (Akaike Information Criterion) score. The best fitting model was identified by the lowest AIC score.

2.4 Results

Horizontal obstruction was greatest at an average of 43 cm in stands thinned in 2019-2021, and smallest in stands thinned in 2017 at 13 cm (Table 2.1). Vertical obstruction was greatest at an average of 30 cm in stands thinned in 2019-2021, and smallest in stands thinned in 2018 at an average of 7 cm (Table 2.1). Plant density was inversely related to the year variable (year one = 2017, year three =2019-2021). Stands thinned in 2017 had an average of 3 plants per square meter and stands thinned from 2019-2021 had an average of 0 plants per square meter (Table 2.1). The maximum height of a plant increased with the year variable. Stands thinned in 2017 had an average max height of 43 cm, and stands thinned in 2019-2021 had an average max height of 57 cm. (Table 2.1). Across all years we found significant differences in the median number of browsed stems per plot ($P<0.01$) and median percentage of browsed stems per plot ($P<0.01$) between thinned and old-growth stands, both with a moderate effect size (Table 2.2). The median percent browsed in treatment and control stands was 4% and 22%, respectively (Table 2.2). There was not a significant difference between unbrowsed stems in treatment and control groups and as expected this produced a small effect size. The percent of a plant browsed was greater in old-growth forests (22%) compared to thinned forests (4%) and browsing appeared much more variable in old-growth (Fig. 2.3).

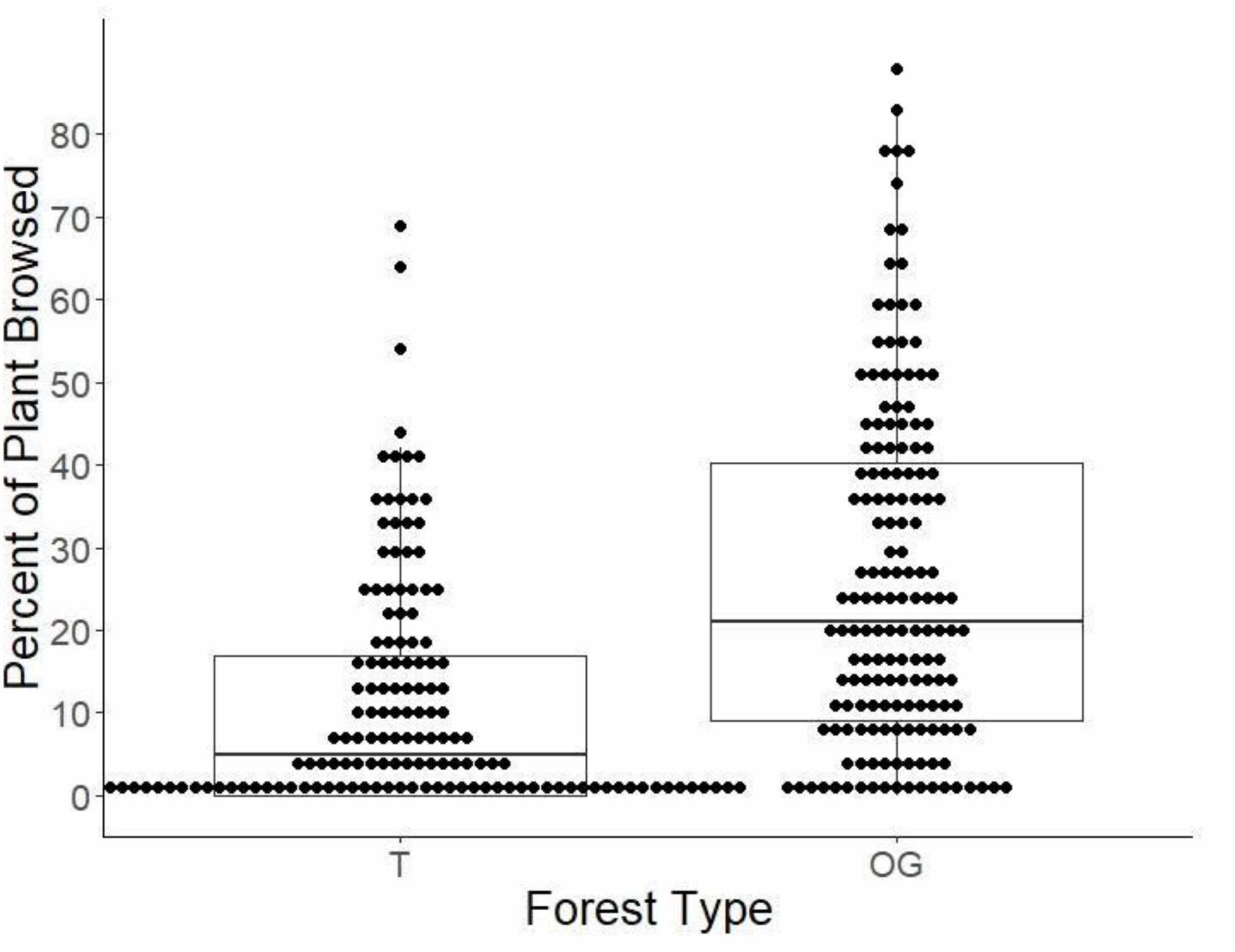
Table 2.1. Slash and deer forage (*Vaccinium spp.*) characteristic median values are displayed in the table. Slash and deer forage characteristics were collected in thinned stands (treatments) along browse survey transects on Prince of Wales Island, Alaska

Sample Size	Sites=16 Plots=160	Sites=6 Plots=60	Sites=7 Plots=70	Sites=3 Plots=30
Year Thinned	All	2017	2018	2019-2021
Horizontal Obstruction (%)	13 (29)	13 (3)	13 (4)	43 (11)
Vertical Obstruction (%)	13 (22)	7 (3)	7 (3)	30 (7)
Plant Density (plants / m^2)	1 (5)	3 (1)	1 (1)	0 (0.5)
Max Height (cm)	43 (34)	44 (3)	53 (4)	57 (11)

Table 2.2. Median values and statistical differences of browsed, unbrowsed, and percent browsed deer forage (*Vaccinium sp.*) in old-growth (control) and thinned (treatment) forest stands on Prince of Wales Island, Alaska. Percent browsed is the number of browsed stems divided by the summation of browsed and unbrowsed stems.

	Old-growth (control)	Thinned (treatment)	Related Samples Wilcoxon Signed-Rank Z Test	P-values	Effect Size
Sample Size	Sites=16, Plots=160	Sites=16, Plots=160			
Browsed	5 (6)	1 (4)	-7.42	<0.01	-0.41
Unbrowsed	20 (17)	17 (21)	-1.38	0.17	-0.08
Percent Browsed	22 (21)	4 (14)	-7.83	<0.01	-0.44
[a]P values <0.05 are considered significant [b]Effect sizes 0 to <0.2 are considered small, >0.2 to <0.5 medium, and >0.5 large.					

Figure 2.3. Depicts a box and whisker plot for the average percent of a plant browsed for the thinned forest stands (T) and old-growth forest stands (OG). The middle solid black lines inside of the rectangles depicts the median. The vertical boundaries of each box depict upper and lower quartiles marking where 50% of the data falls.



Our best-fit model (i.e., lowest AIC score) of percent browse included vertical obstruction and year as fixed effects, and site fitted as a random effect (Table 2.3). Percent browsed increased with year variable and decreased with vertical obstruction (Table 2.4). A visual representation of the negative relationship between percent browsed and vertical obstruction is depicted in figure 2.4. For the years variable, 2017 (4 years post thinning) was used as the reference category. Browse activity was significantly lower in 2019-2021 as compared to 2017. Browse activity was also lower in 2018 than in 2017, but the difference was not significant at the 0.05 p-value level (Table 2.4). Figure 2.5 displays the negative relationship between the year variable and percent browsed. Maximum plant height and horizontal obstruction were included in our second and third best-fit models respectively. A Kruskal-Wallis test revealed that slash characteristics (vertical and horizontal obstruction) between our levels of the year variable were significantly different (Table 2.5). When comparing median percent browse, using a Pairwise Wilcoxon rank-sum test, from 2017 to median percent browse in 2018 and 2019-2021, p-values < .05, showing the difference in browse between the years 2017 and the other years. Median percent browse in 2018 was not significantly different from the years 2019-2021 (Table 2.6).

We found that deer foraging activity, as indicated by *Vaccinium sp*. browse counts, was reduced in recently thinned stands compared to adjacent old-growth stands. Although forage and browse activity increases with each year following thinning, we found browse activity remains lower in thinned stands compared to old-growth for the first four years following thinning. Our models indicated that browse activity increased as plant (i.e., *Vaccinium sp.*) density increased, time since thinning increased, and slash volumes decreased. Stands thinned in 2019-2021 have significantly less browse activity compared to 2017. (Table 2.4). Stands thinned in 2017 and 2018 had an average vertical obstruction of 7 percent, while stands thinned in 2019-2021 had an average vertical obstruction of 30. (Table 2.2). Figure 2.4 depicts the relationship that around 75% of vertical obstruction plants are not likely to be browsed at all.

Table 2.3. Akaike Information Criteria (AIC) scores of GLMM models used to estimate effects of plot characteristics on percent browse in thinned (treatments) stands on Prince of Wales Island, Alaska. The lowest AIC value identifies the most useful model (bolded in the table). Plot characteristics used as

model predictors are vertical obstruction (VO), Horizontal obstruction (HO), max height, year and density.

Model	AIC	Deviance
VO + Year	**735**	**723**
Density + VO + Year	736	722
HO + year	736	724
Density + HO + Year	737	723
Null model	739	733
Density + VO + HO + Max height + Year	740	722

Table 2.4. Variable fixed effects from the best-fit generalized linear mixed model (vertical obstruction (VO) and year) of percent browse in thinned (treated) stands on Prince of Wales Island, Alaska.

Variable	Coefficient	Standard error	P-value	CI around estimates
intercept	2.91	0.27	<0.01	(2.37, 3.44)
Vertical Obstruction	-0.02	0.01	0.03	(-0.03, -0.01)
2018 thinning[1]	-0.53	0.36	0.14	(-1.23, 0.18)
2019-2021 thinning[1]	-1.27	0.52	0.01	(-2.29, -0.25)
[1]Reference category: Stands thinned in 2017				

Table 2.5. Kruskal-Wallis rank sum test for slash characteristics (vertical and horizontal obstruction) compared across year past variable.

	Kruskal-Wallis chi-squared	df	p-value
Vertical obstruction (%)	11.17	2	<0.01
Horizontal obstruction (%)	13.31	2	<0.01

Table 2.6. Pairwise Wilcoxon rank sum test comparing median percent browse across the year of thinning variable. Matrix depicts p-values produced from comparing years.

	2017	2018
2018	0.01	
2019-2021	<0.01	0.09

Figure 2.4. Depicts the relationship between percent of a plant browsed and percent vertical obstruction. As percent vertical obstruction increases the percent of a plant browsed decreases with little browse occurring after 75% of obstruction.

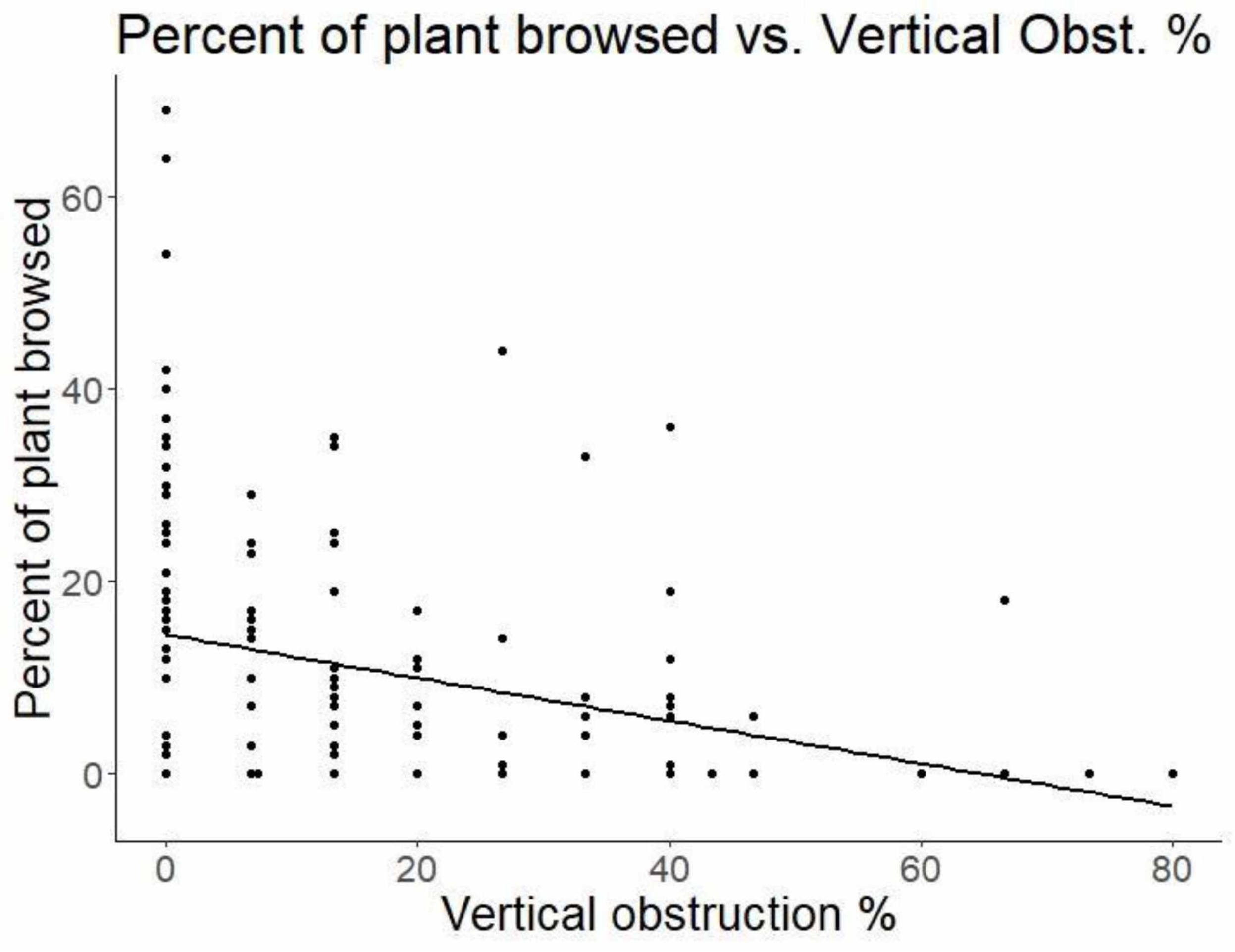
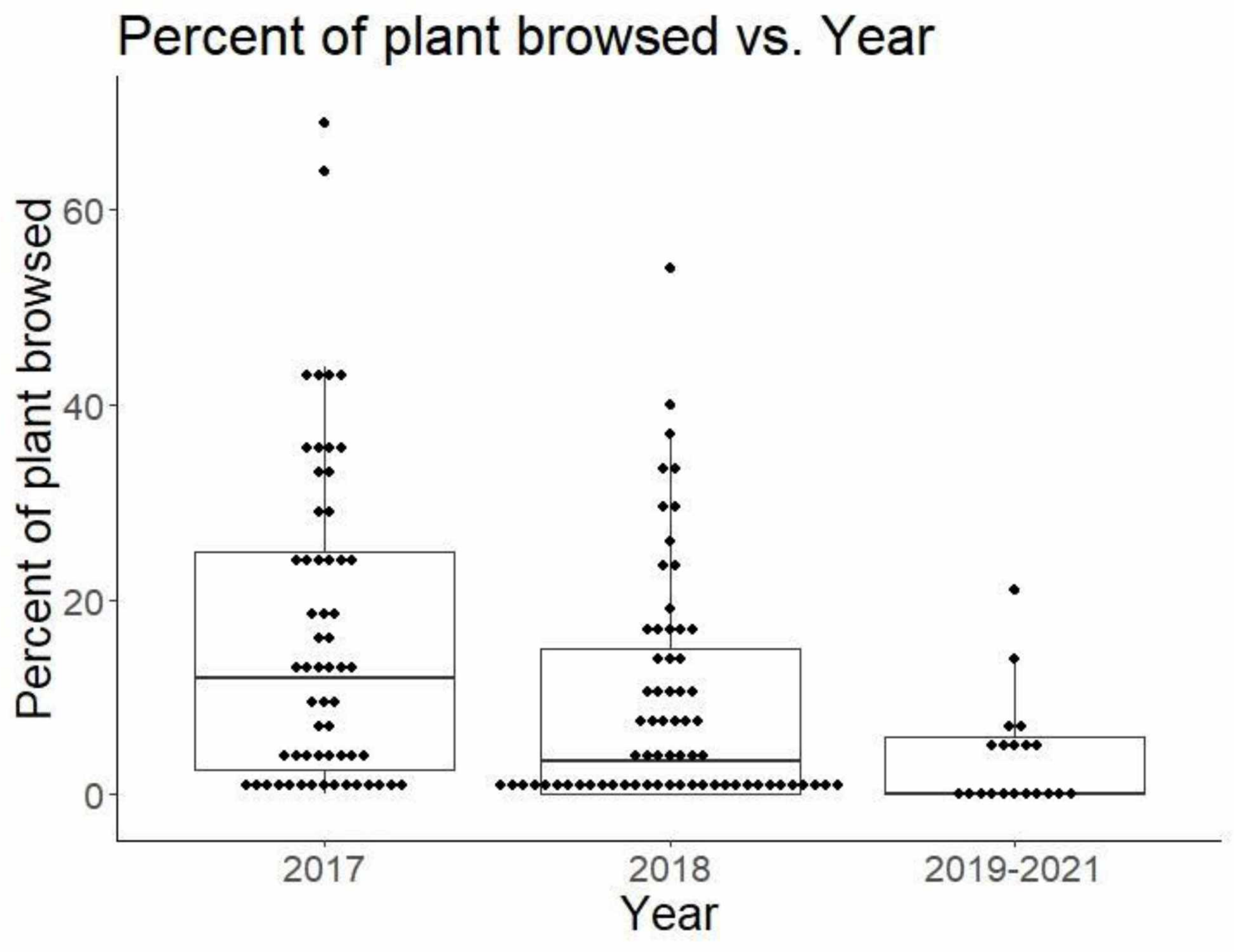


Figure 2.5. Depicts the percent of a plant browsed plotted across the year that thinning took place in a box and whisker format. As time since thinning decreases percent of a plant browsed decreases.



2.5 Discussion

There is little quantified information on how thinning treatments affect ungulates and their forage in the pacific northwest. It is assumed that the opening of the canopy and understory plant production is positive for deer. Our results, however, indicate that thinned stands reduce forage by deer compared to adjacent old-growth for the first four years (Table 2.2). Our model of deer browse shows an inverse relationship to vertical obstruction, indicating that slash impedes access to forage. In addition, we can conclude that the benefits of thinning on understory forage may not immediately return, and the volume of slash remaining may impede deer access to the forage that regenerates at least the first four years post thinning. Our results are consistent with other studies that have shown the presence of slash continues to reduce deer activity up to 9 years post thinning (McClellan et al. 2014).

Aside from slash as a constraint on access, the number of unbrowsed stems of plants should be considered as a habitat attractant for deer. The ideas around optimal foraging theory suggest that an animal would spend more time foraging in a habitat with more available forage (Pyke 2019). Despite plant density being higher in old-growth, the median number of unbrowsed stems was statistically similar between thinned and old growth stands. The insignificant difference of unbrowsed stems between thinned and old-growth suggests that fewer deer are occupying thinned stands, because they are browsed less. Alternatively, the same number of deer are visiting thinned stands (browsed less) as old-growth, but they are spending less time foraging as compared to adjacent old growth.

Although we found that the amount of deer forage was lower in recently thinned stands than in adjacent old growth, we predict that this would change five to ten years following thinning practices, based on the idea that slash will continue to decompose. Other experimental studies suggest that conifer density increases, but understory biomass decreases about eight to ten years after thinning (Crotteau et al. 2019). The decrease in understory biomass, in the decade after thinning, likely would not result in more browsing in adjacent unthinned stands compared to thinned stands, because there was still more biomass in thinned stands than unthinned stands (Crotteau et al. 2019). If thinned stands do produce more forage than unthinned stands or old-growth eight to ten years after thinning it would suggest that thinning does make the forest more productive in terms of understory biomass. The volume of slash on the forest floor will decrease every year following thinning. We predict that the absence of slash would cause an increase in browsing five to ten years after thinning. Deer will likely increase use of this habitat due to the declining slash volume and increase in understory biomass.

As forage returns to thinned stands, slash may continue to be an impediment for deer to access forage. This may be a problem specific to forest management in Alaska (the Tongass NF), because slash removal through prescribed fire and hand removal is common in other regions (Westover 2021). Vertical obstruction was found to explain slightly more variation (Table 2.3) in browse intensity than horizontal obstruction. The importance of vertical obstruction suggests that slash height may be more of an obstacle for deer than slash that has compacted lower to the forest floor. Stand productivity has an impact on the size of slash on the forest floor, because more productive stands will produce larger trees and greater quantities of slash (McClellan et al. 2014). When thinning takes place while trees are small in diameter (eight to 13 cm DBH), the slash will lay flat on the forest floor where contact with the soil and moisture can accelerate decomposition (Shorohova and Kapitsa 2014). We found small diameter trees to be considerably easier to navigate through compared to a stand that was thinned at an older or larger stage (>12.7cm DBH). The larger diameter trees also have larger and stronger lateral branches that help to hold the tree higher off the ground, contributing to greater vertical obstruction and slower decomposition (Table 1.2, 1.4).

To improve upon the understanding of how pre-commercial thinning is impacting deer it will be important to examine how thinning affects the succession of forage species within the first five years post thinning. We only assessed browse on *Vaccinium sp.*, but we recognize that other forbs (particularly evergreen ones) and shrubs have value to deer and are present in thinned stands (Hanley 1984). Moreover, the effect of site productivity is likely to affect forage succession and slash volume. For example, thinning of a productive ten-year-old stand may produce as much slash as a 20-year-old unproductive stand. Understanding how variation in site productivity affects forage and slash quantity will give managers an idea of when and how to implement thinning practices to foster better outcomes for deer or deer hunters. Less deer activity and excessive slash may also present problems for deer hunters. Most of these thinned stands are adjacent to roads used for access by deer hunters on Prince of Wales Island (Brinkman et al. 2007, 2009). Limited forage and use of recently thinned stands by deer may be pushing deer away from areas easily accessed by hunters, further challenging hunting opportunities and causing local hunters to perceive a declining deer population because less deer are seen while driving logging roads. Most of the managed forest on Prince of Wales Island adjacent to roads is either in a stem exclusion stage of second-growth or has been thinned. Neither habitat type is preferred by island residents for deer hunting (Brinkman et al. 2007, 2009). Additional research is needed on the effects of thinning practices on deer hunting opportunities to confirm causal relationships. Just as the percentage of a plant browsed is reduced to almost zero at 75% of vertical obstruction, indicating deer are not able to traverse the slash, researchers found this height of slash to be difficult and hazardous.

2.6 Management Implications

Our findings suggest that thinning when stands are younger and trees are smaller, will reduce vertical obstruction and increase decomposition rates, which would increase the use of these stands by deer. Although TWYGS studies found that thinning an older stand (larger diameter) creates more forage biomass eight to ten years post thinning (Crotteau et al. 2019), these stands create a greater amount of vertical obstruction to impede access (Parker et al. 1984; McClellan et al. 2014). Managers must balance timing of thinning with operation costs, and how much timber stand improvement provided benefits will last. Thinning on small noncontiguous scales may offer deer a variety of habitat types in their home ranges. It also may be important to exclude adjacent old-growth from logging activities to maintain access to forage while the understory regenerates and slash decays in thinned stands. Based on our results, forest managers should consider creating corridors in slash that allow deer access into thinned stands and creates edge habitat that stimulates forage growth (McClellan et al. 2014), if improving deer habitat is a management objective. Second-growth forests and the practice of thinning creates challenges for deer in southeast Alaska (Wallmo and Schoen 1980; Cole et al. 2010). Understanding that there is less browse occurring in thinned stands, and vertical obstruction as well as time since thinning are important predictors of browse intensity will help managers predict how the changing landscape of southeast Alaska is affecting deer.

2.7 Acknowledgments

We would like to thank J. Barnard, R. Slayton, R. Dorendorf, T. Hasbrouck, B. Bennetsen, S. McCurdy, and staff at the U.S.D.A. Forest Service Thorne Bay Ranger District for project development and field work logistics. Funding was provided by the University of Alaska Fairbanks Biology and Wildlife Department, the USDA NRCS, the USFS Pacific Northwest Research Station, and the National Science Foundation (#1518563, #1026415).

2.8 References

Alaback, P.B. 1982. Dynamics of understory biomass in Sitka spruce-western hemlock forests of southeast Alaska. Ecology, 63(6):1932–1948.

Alaback, P., Nowacki, G., Saunders, S. 2013. Disturbance ecology of the temperate rainforests of Southeast Alaska and adjacent British Columbia. In: Orians, G., & Schoen, J. (eds) North Pacific temperate rainforests: ecology and conservation. University of Washington Press, Seattle, 73-88.

Alaska Climate Research Center. 2022. Data Portal Alaska Climate Research Center: The Alaska State Climate Center, University of Alaska Fairbanks. https://akclimate.org/data/.

Alaska Department of Fish and Game. 2001. Community profile database. Alaska Department of Fish and Game, Division of Subsistence, Douglas, Alaska, USA. http://www.state. ak.us/adfg/subsist/subhome.htm.

Albert, D.M., Schoen, J.W. 2013. Use of historical logging patterns to identify disproportionately logged ecosystems within temperate rainforests of southeastern Alaska. Conservation Biology, 27(4):774-784.

Beier, C.M., Lovecraft, A.L., Chapin III, F.S. 2009. Growth and collapse of a resource system: an adaptive cycle of change in public lands governance and forest management in Alaska. Ecology and Society, 14(2):5.

Brinkman, T.J., Chapin, T., Kofinas, G., Person, D.K. 2009. Linking Hunter Knowledge with Forest Change to Understand Changing Deer Harvest Opportunities in Intensively Logged Landscapes. Ecology and Society, 14(1):36. https://doi.org/10.5751/ES-02805-140136.

Brinkman, T. J., Kofinas, G. P., Chapin III, F. S., Person, D. K. 2007. Influence of hunter adaptability on resilience of subsistence hunting systems. Journal of Ecological Anthropology, 11(1):58-63.

Brinkman, T.J., Person, D.K., Chapin, F.S., Smith, W. III., Hundertmark, K.J. 2011. Estimating Abundance of Sitka Black-Tailed Deer Using DNA from Fecal Pellets. Journal of Wildlife Management, 75(1):232–242. https://doi.org/10.1002/jwmg.22.

Cole, E.C., Hanley, T.A., Newton, M. 2010. Influence of precommercial thinning on understory vegetation of young-growth Sitka spruce forests in southeastern Alaska. Canadian Journal of Forest Research, 40(4):619-628.

Crotteau, J.S., Rue-Johns, A., Barnard, J.C. 2019. Eight- to Ten-Year Effects of Pre-Commercial Thinning on Understory Biomass and Forage of Sitka Spruce/Western Hemlock Stands in Southeast Alaska. Canadian Journal of Forest Research, 50(1):215–225. https://doi.org/10.1139/cjfr-2019-068.

Farmer, C.J. Person, D.K., Bowyer, R.T. 2006. Risk Factors and Mortality of Black-Tailed Deer in a Managed Forest Landscape. Journal of Wildlife Management, 70(5):1403–1415.

Gilbert, S.L. 2015. Environmental drivers of deer population dynamics and spatial selection in Southeast Alaska. University of Alaska Fairbanks.

Hanley, T.A., Mckendrick, J.D. 1985. Potential Nutritional Limitations for Black-Tailed Deer in a Spruce-Hemlock Forest , Southeastern Alaska. Journal of Wildlife Management, 49(1):103–114.

Hanley, T.A. 1984. Relationships Between Sitka Black-Tailed Deer and Their Habitat. General Technical Report PNW-168: 2–13.

Hanley, T.A., McClellan, M.H., Barnard, J.C., Friberg, M.A. 2013. Precommercial Thinning: Implications of Early Results from the Tongass-Wide Young-Growth Studies Experiments for Deer Habitat in Southeast Alaska. USDA Forest Service - Research Paper PNW-RP, no. 593: 1–64. https://doi.org/10.2737/PNW-RP-593.

Harris, S.H., Barnard, J.C. 2017. Understory Plant Development in Artificial Canopy Gaps in an 81-Year-Old Forest Stand on Chichagof Island, Southeast Alaska. USDA Forest Service - Research Paper PNW-RP 609.

Klein, D.R. 1965. Ecology of deer range in Alaska. Ecological Monographs, 35(1):259–284.

Klein, D.R., Olson, S.T. 1960. Natural Mortality Patterns of Deer in Southeast Alaska. Journal of Wildlife Management, 24(1):80–88.

Kruse, J., Frazier, R. 1988. Reports to the Communities of Southeast Alaska (one per community). Tongass Resource Use Cooperative Survey Institute of Social and Economic Research. University of Alaska Anchorage

Lyon, J., Jensen, C.E. 1989. Management Implications of Elk and Deer Us of Clear-Cuts in Montana. Journal of Wildlife Management, 53(3):519–523. https://doi.org/10.1002/jwmg.ll3.

MacDonald, S.O., Cook., J.A. 1996. The land mammal fauna of Southeast Alaska. Canadian Field Naturalist, 110:571-598.

Mazza, R. 2003. Hunter demand for deer on Prince of Wales Island, Alaska: an analysis of influencing factors. U.S. Forest Service General Technical Report PNW-GTR-581.

McClellan, M.H., Hennon, P.E., Heuer, P.G., Coffin, K.W. 2014 Condition and deterioration rate of precommercial thinning slash at False Island, Alaska. Pacific Northwest Research Station. PNW-RP-594.

Parker, K.L., Robbins, C.T., Hanley, T.A., 1984. Energy expenditures for locomotion by mule deer and elk. Journal of Wildlife Management, 48(2):474-488.

Prince of Wales Island Road System. 2022. Alaska's Scenic Byways. Alaska Department of Transportation and Public Facilities. https://dot.alaska.gov/stwdplng/scenic/byways-pow.shtml. 1/13/2022.

Pyke, G. 2019. Optimal foraging theory: an introduction. In J. C. Choe (Ed.), Encyclopedia of animal behavior, 2(2):111-117. Elsevier Academic Press. https://doi.org/10.1016/B978-0-12-809633-8.01156-0

Robel, R.J., Briggs, J.N., Dayton, A.D., Hulbert, L.C. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Rangeland Ecology & Management/Journal of Range Management Archives, 23(4):295-297.

Shorohova, E., Kapitsa, E. 2014. Influence of the substrate and ecosystem attributes on the decomposition rates of coarse woody debris in European boreal forests. Forest Ecology and Management, 315(1):173-184.

Sullivan, G.M., Feinn, R. 2012. Using effect size—or why the P value is not enough. Journal of graduate medical education, 4(3):279-282.

Turek, M.F., Schroeder, R.F., Wolfe. 1998. Deer hunting patterns, resource populations, and management issues on Prince of Wales Island. Alaska Department of Fish and Game, Division of Subsistence, Juneau, Alaska, USA.

Thomas, J.W., Ruggiero, L.F., Mannan, R.W., Schoen, J.W., Lancia, R.A. 1988. Management and conservation of old-growth forests in the United States. Wildlife Society Bulletin, 16(3):252-262.

Wallmo, O.C., Schoen, J.W. 1980. Response of deer to secondary forest succession in southeast Alaska. Forest Science, 26(3):448-462.

Westover, R.H. 2021. Thinning the Forest for the Trees. Forest Service U.S. Department of Agriculture. https://www.fs.usda.gov/features/thinning-forest-trees

Chapter 3: Snow accumulation in pre-commercially thinned forests, and its implications for Sitka black-tailed deer (*Odocoileus hemionus sitkensis*)[2]

3.1 Abstract

Timber harvest and subsequent forest succession affect the structure and composition of forests which in turn may affect how snow accumulates on the ground. Snow can impede the movement of ungulate species, such as deer (*Odocoileus sp.*), and reduce available forage. We evaluated how different forest types accumulate snow in southeast Alaska to better understand the implications on winter habitat quality for Sitka black-tailed deer (*O. hemionus sitkensis*). We measured snow depth throughout the winter of 2021, in old-growth, thinned, unthinned, and unforested sites. We found that thinned and unforested plots accumulated snow to a maximum depth that was approximately double to that in old-growth and unthinned second-growth plots. Using a modeling approach, we found that no forest structure variables were significant predictors of maximum snow depth. However, canopy cover explained some variation (R^2=0.21-0.32, Fig. 3.3) in maximum snow depth in thinned and unthinned forest types. Consequently, thinned forests with their relatively abundant summer forage may no longer be accessible to deer in the winter after significant snow falls. Our study provides novel information on how thinned and unthinned forest types differentially accumulate snow in comparison to adjacent old-growth and unforested sites. Managers can use our findings to understand when habitat types like thinned stands are no longer available to deer due to snow. This may help forest managers and researchers develop landscape-level habitat quality maps for southeast Alaska and potentially other forested regions where snow impedes access to forage by ungulates.

---

[2] Kellam, C. W., Brinkman, T. J., Hollingsworth, T. N., and Keilland, K. Snow accumulation in different forest types in southeast Alaska, and the implications on Sitka black-tailed deer (*Odocoileus hemionus sitkensis*). Prepared for submission to *The Candian Journal of Forest Research*.

3.2 Introduction

In southeast Alaska, snowfall reduces winter forage available to Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) and makes locomotion energetically expensive (Gilbert et al. 1970; Kirchhoff and Schoen 1987; Parker et al. 1984). Snowfall also dictates the selection of forest types (forest type defined as a repeating tree species size and composition) by deer (Gilbert et al. 2017; Kirchhoff and Schoen 1987; White et al. 2009). Southeast Alaska is an amalgam of habitat types including pre-commercially thinned forests, unthinned second-growth, unharvested old-growth, clearcut forests, muskeg, and alpine habitats. Pre-commercially thinned forests are second growth stands where the standing tree density has been reduced by felling to even spacing, thus opening the canopy. Pre-commercially thinned forests are thinned at varying ages from ten to 30 years post clearcut (Crotteau et al. 2020). Previous studies on forest types other than pre-commercially thinned stands suggest that canopy cover, diameter at breast height (DBH), and tree spacing dictate snow depth on the forest floor (Hanley and Rose 1987; Kirchhoff and Schoen 1987; McNay et al. 1988). Thinned, unthinned and old-growth forests differ in forest characteristics like tree DBH, height and canopy cover (Taylor 1932). How thinned, unthinned, and old-growth forests accumulate snow has the potential to change the availability of winter forage for deer and overall habitat quality.

At 16.7 million acres, the Tongass National Forest makes up approximately 73% of southeast Alaska's landscape (USFS 2022; Campbell 2004). More than one million acres of the Tongass National Forest have been clearcut since the late 1950s (Southeast Alaska Conservative Council 2022), and most of this has been productive old-growth forests (i.e., high wood volume trees) (Albert et al. 2013). Roughly eight to ten years after a clearcut, conifers begin to dominate the stand. After 20 – 30 years post clearcut, the canopy gradually closes, shading out the understory forbs and shrubs. These even-aged second-growth stands are characterized by dense conifers, closed canopies (>60% canopy cover), with very little biomass in the understory (Hanley 2013). As these stands age, stem exclusion slows the growth of individual trees as canopies shade out other canopies. Without management intervention, stem exclusion may persist for at least 80 to 100 years. Stands may remain even-aged for 150-300 years, until trees begin to self-thin and natural disturbances such as windthrow create forest gaps with pockets of understory vegetation (Alaback 1984; Alaback 1990; Harries and Farr 1974). To hasten the transition of forests out of the stem exclusion stage, managers typically implement pre-commercial thinning treatments, hereafter referred to as thinning or thinned stands. Approximately 42% of second-growth forests in southeast Alaska have received a silvicultural treatment, most commonly thinning, to increase timber productivity (Alaback et al. 2013; Hanley et al. 2013). Thinning treatments consist of cutting down selected trees to achieve a lower density of commercially preferable standing timber at a spacing that promotes faster growth. Thinning also opens the canopy and allows the regeneration of understory vegetation and deer forage (Crotteau et al. 2019). The USDA Forest Service has shown thinned stands produce an abundance of summer deer forage compared to unthinned stands (Crotteau et al. 2019; Hanley et al. 2013). High volume old-growth forests exhibit a closed canopy with large trees and occasional canopy gaps (Harris and Farr 1974). Old-growth forests and their large gaps in the canopy allow sunlight to penetrate and produce productive understories. Old-growth forests are important habitats for deer in winter because of their interception of snow via closed canopies (Bloom 1978; Brinkman et al. 2011; Doerr et al. 2005; Hanley and Mckendrick 1985; Hanley 1984; Kirchhoff and Schoen 1987). Based on high volume second-growth and old-growth, as canopy cover and tree DBH increases, snow accumulates more in the canopy and less on the forest floor (Hedstrom and Pomeroy 1998; Kirchhoff and Schoen 1987; Martin et al. 2013; McNay et al. 1988; Storck et al. 2002). The pattern of snow accumulation in managed stands (thinned and unthinned) relative to old-growth forests may influence population distributions and dynamics of deer in southeast Alaska. Understanding factors such as snow accumulation that affect deer population dynamics have significant societal value because deer are the most important terrestrial species for recreational and subsistence hunting in southeast Alaska (Brinkman et al. 2009).

Deer populations in southeast Alaska are limited by winter snow depth and often move to coastal habitats where snow does not accumulate due to warmer temperatures as compared to higher elevations inland (Bloom 1978; Brinkman et al. 2011; Doerr et al. 2005; Hanley and Mckendrick 1985; Hanley 1984; Kirchhoff and Schoen 1987). Snow can cover forage in the form of reaching a maximum height of the plant or through stem bending. Stem bending of *Vaccinium sp*., or any species of blueberry or huckleberry, results in the burial of a plant before snow depth reaches the maximum height of a plant (White et al. 2009). Understanding what forest types keep forage available to deer in the winter is important when modeling deer habitat occupancy, carrying capacity, or deer movement (Gilbert et al. 2017).

Understanding the positive relationship between canopy openness and snow depth is intuitive and would lead us to predict that thinned forests, with their open canopy, would have greater amount of snow on the forest floor, compared to unthinned and old-growth stands. We also hypothesized that unthinned forests would have greater snow depths on their forest floor than old-growth forests due to the relatively smaller trees associated with unthinned forests. To address this idea, we investigated how snow depth varied across these forest types in southeast Alaska, as well as what forest characteristics affected snow accumulation.

3.3 Methods

Study Design

To examine the interactions between managed forests and snow depth, we measured snow depth throughout managed and unmanaged forests on Prince of Wales Island (POW), Alaska, USA (Fig. 3.1). The coastal temperate rainforests of POW consist of coastal estuary habitats with grass-covered shorelines, alpine habitats extending to 1600 meters, and vast forests in between. Forests on POW are mainly comprised of Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*) (Alaback 1982). Forest floor vegetation includes ferns, bryophytes, and herbaceous vascular species (Olmsted and Curtis 1947). Sitka black-tailed deer is the only established ungulate population on POW. Deer rely on evergreen forbs and deciduous shrubs such as *Vaccinium sp., Cornus canadensis, Rubus pedatus, pyrola sp.*, and various fern species during winter (forage-limiting season) (Hanley 1984; Hanley and Mckendrick 1985). Between 1980-2010, the annual mean temperature, rainfall, and snowfall on POW (Klawock airport, near sea level) was 7°C, 227cm, and 10cm (Alaska Climate Research Center 2022). There are approximately 2400 kilometers of road on POW, most of which were constructed and maintained by the USDA Forest Service.

Forest types being compared are old-growth, thinned, unthinned, and unforested habitats. We required approximately one square kilometer groupings to encompass all four forest types to compare snow depth. Groupings allowed us to assume that differences in snow depth can be attributed to forest type differences, rather than differences in snow precipitation within the area. We used a split-split plot design to measure snow depths (Federer and McCulloch 1991). A split-split plot design can be characterized as a three-tiered unit study (whole plot, subplot, sub-subplot). Our whole plot unit is the grouping of forest types, referred to as sites. Our subplot is a sampling transect in each forest type. Our sub-subplot is a point along the transect where snow depth and forest characteristics were measured.

Our study had a total of four sites (i.e., groupings) identified using GIS. We selected sites within walking distance from a road to facilitate logistics for frequent site visits. Old-growth forest types were at least class four timber volume (>3000 board feet (7.08 cubic meters) per hectare, >150 years of age). Our thinned forest types were 30 to 40 years post-clearcut and having undergone a thinning treatment. Pre-commercial thinning was typically prescribed as a 3.7 – 4.6 meter minimum distance between trees. Unthinned stands were forests that were 30 to 40 years post-clearcut and had no manipulation.

Unforested sites (e.g., treeless muskegs or recent clearcuts) were established to quantify snow depth with no forest affecting snow accumulation, and they represent a control. All sites were within inland watersheds of the Tongass National Forest with elevation between 90-270m. Coastal sites were not chosen because they accumulate less snow compared to more interior sites. Sites that accumulate more snow were targeted in case the year proved to be a low snow year with little snow to measure.

Data collection and Experimental Design

We measured snow depth four to six times from February to April, 2021, along transects with different forest type treatments (transects: n =16). We established a 70-meter transect within each forest type. Transects were centered around a pin placed inside the forest type using the Avenza mapping program (Avenza Systems 2022). The use of Avenza established transects with the removal of selection bias, because the pin was placed before surveyors were in the field. Transects were orientated along the maximum length of the forest type of interest. Snow depth was measured every five meters. We established four replicate transects per forest type. Forest structure data (percent canopy openness, tree spacing, diameter at breast height (DBH), and tree height) was collected at each five-meter point. Forest structure data were collected for all trees within a three-meter radius sub-sub plot. Each sub-sub plot was centered at the five-meter point along the transect where snow was measured. The average tree spacing (distance from transect point to tree pith), average DBH, and average tree height for all trees inside of the three-meter radius sub-subplot were assigned to each transect point where snow depths were measured. Repeatedly measuring snow depth in proximally located but different forest types allowed us to assume that treatments (forest types) are receiving similar snowfall events and differences in snow depth across treatments can be assumed to be related to the forest structure.

We recorded snow depths through a single winter in the four forest types. We compared and modeled the effects of forest structure on maximum snow depth. Elevation, slope, and aspect were measured at the center of the transect. Transect sites ranged in elevation from approximately 90 to 270 meters. Aspects ranged from 60 to 300 degrees, and slope ranged from zero to 21 degrees. Median values in the results are based on a different number of total plots per forest type because some forest types had more replicates. Sub-subplot level snow depth averages and medians were calculated from all points along a transect (n=14) at each location. Two transects were not used (n=28) due to our inability to revisit the site during maximum snow depth.

Data analysis

To understand how maximum snow depth varied across different forest types we compared the median of maximum snow depths across different forest types. The median was compared using nonparametric tests due to the non-normal distribution of the data. We used the maximum snow depth for each sub-subplot taken from all remeasurements as a response variable and looked at the relationship of this variable with forests structure measurements. A Kruskal-Wallis test and Wilcoxon signed-rank test were used to test for significant differences in maximum snow depths and forest structure measurements between forest types. We used a generalized linear mixed model (GLMM) to estimate the influence for forest type and forest structure variables on maximum snow depth. The experimental unit in the study was a sub-subplot or five-meter point along the transect, and the response variable (i.e., dependent) is maximum snow depth reached at the sub-subplot level. Forest structure variables differed in each sub-subplot, justifying the choice to treat the sub-subplot as the experimental unit. Forest type and structure (DBH, distance, height, percent of canopy open) variables were used as fixed effects in our model and a transect specific ID variable was a random effect to account for autocorrelation among plots on the same transect. We used the *glmmTMB* package within Rstudio (Rstudio Team 2022). Using a generalized linear model was required to account for the non-normal distribution of the data, and the mixed model accounts for sources of variability among the data. Additionally, we used estimated marginal means (estimated means for forest types) produced from the model to compare across forest types. Estimated marginal means give equal representation to the forest type variable to estimate means for each forest type (Searle et al. 1980). The model assumed a gamma distribution of the data. Models were evaluated using the AIC (Akaike Information Criterion) score. The model with the lowest AIC was assumed to have the best fit (Burnham and Anderson 2002). If top models had AIC scores within 2 points of each other, we selected the most parsimonious as the best.

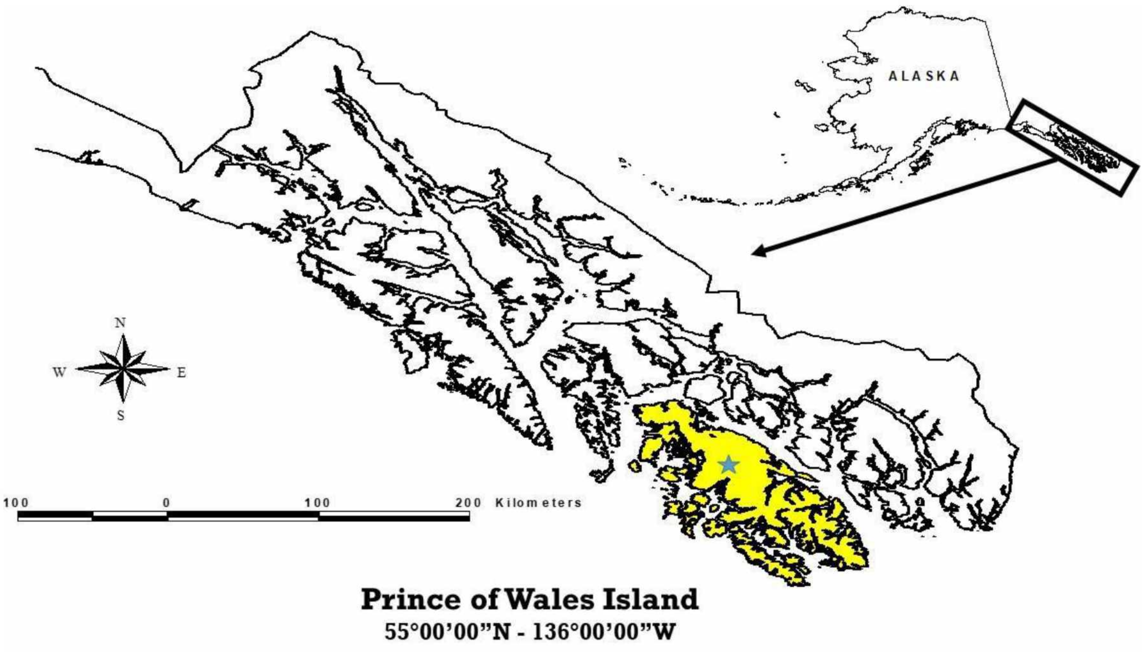


Figure 3.1 Prince of Wales Island (POW) is a 6,670 square kilometers island at the southern end of the Alexander Archipelago, shown highlighted on the above map. Study sites are located under the star.

3.4 Results

Medians for unforested sites were based on 266 plots, the largest sample size per forest type, and the median for thinned sites was 196 and the smallest sample size (Table 3.1). Median maximum snow depth ranged from 50 cm (unforested sites) to five cm (unthinned sites) (Table 3.1). Our unforested and thinned sites had approximately three times greater average maximum snow depths compared to old-growth and unthinned forest types (Table 3.1). Unforested and thinned forest types accumulated snow with a similar skew towards higher snow depths, compared to old-growth and unthinned which were skewed to lower snow depths (Fig. 3.2).

Forest Type	**N (sub-subplots)**	**Median max snow depth (SD)**
Unforested	266	50 (2)
Thinned	196	35 (2)
Unthinned	294	5 (1)
Old-growth	243	10 (1)

Table 3.1. Median results of maximum snow depth across different forest types. Median maximum snow depths (cm) were calculated from sub-subplot level max snow depth values.

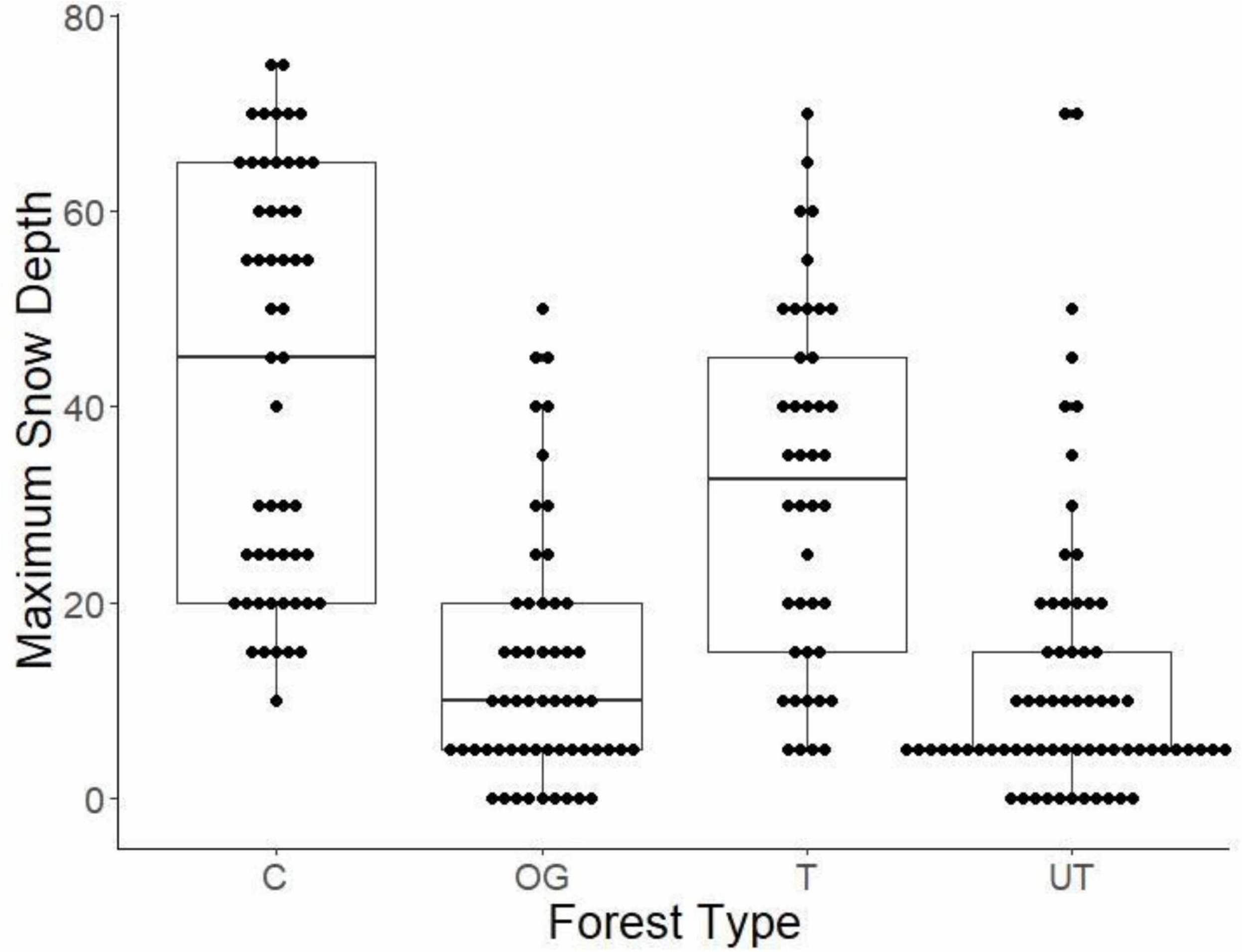


Figure 3.2 Box and whisker plot depicting the response of maximum snow depth in centimeters across unforested (UF), old-growth (OG), thinned (T), and unthinned (UT) forest types. The solid black lines inside of the boxes depicts the median. The vertical boundaries of the boxes depict upper and lower quartiles marking where 50% of the data falls. Vertical lines leading to the edge of the data depict outer quartiles.

Canopy varied from 100% open (unforested) to 20% (old-growth and unthinned) (Table 3.2). Thinned and unforested sites had approximately twice the average canopy openness when compared to old-growth and unthinned at 44% (Table 3.2). Old-growth forests had the largest trees, quantified by an average DBH of 25 cm and average tree heights of 20m (Table 3.2). Thinned and unthinned forests had similar DBH averages at 10 cm and 12 cm (Table 3.2). Distance between trees varied from 186cm (old-growth) to 207cm (thinned) of the forested forest types (Table 3.2). Unthinned and old-growth forests had similar distance averages at 190 and 186 cm (Table 3.2). Although, the comparison of the median distance between forest types was found to be not significantly different based on a Kruskal-Wallis rank sum test (p-value > 0.05, Table 3.3). A Wilcoxon rank sum test for canopy openness values were not significantly different between unthinned and old-growth forests (p-value = 0.22, Table 3.4). The Wilcoxon test for canopy found that all other forest types were significantly different (p-value < 0.05, Table 3.4).

Forest type	**N (plots)**	**Canopy open % (SE)**	**DBH (cm) (SE)**	**Dist (cm) (SE)**	**Height (m) (SE)**
Unforested	266	100	0	0	0
Thinned	196	44 (1)	10 (0.4)	207 (3)	7 (0.3)
Unthinned	294	20 (0.4)	12 (0.3)	190 (2)	9 (0.2)
Old-growth	243	20 (0.4)	25 (1)	186 (5)	20 (0.4)

Table 3.2. Average forest structure characteristic values calculated from plot-level averages for each forest type. Canopy open % represents the percent that the canopy is open. DBH stands for diameter at breast height. Breast height is measured at 137 cm. Distance was an average distance between trees per sub-subplot. And height represents the height of the tree.

	Chi-squared	**P-value**
Canopy open %	72.19	<0.01
DBH (cm)	34.56	<0.01
Distance (cm)	2.23	0.33
Height (m)	30.80	<0.01

Table 3.3. Kruskall-Wallis rank sum outputs for comparisons of medians of canopy open %, DBH, distance and height values across forest types. Canopy open % represents the percent that the canopy is open. DBH is the diameter taken at breast height or 137 cm. Distance represents a calculated average distance between trees on the sub-subplot level, and height represents the height of the tree.

	UF	**OG**	**T**
OG	<0.01	<0.01	<0.01
T	<0.01	<0.01	<0.01
UT	<0.01	0.22	<0.01

Table 3.4. Significance values (i.e., P values) from Wilcoxon signed-rank test for percent canopy cover across unforested (UF), old-growth (OG), thinned (T), and unthinned (UT) forest types.

Model parameters	**AIC**	**Deviance**
Forest type	1208	1162
% Canopy Open + DBH + Distance + Height + Forest type	1209	1155
% Canopy Open + height + Forest type	1208	1158
% Canopy Open + DBH + Distance + Forest type	1207	1155
% Canopy Open + Forest type	1207	1159

Table 3.5. Model comparisons by Akaike information criterion (AIC) and deviance when the response is maximum snow depth. Model predictors as fixed effects are shown under the model parameter column. Lower AIC values reflect better performing models. The model with only forest type as a parameter is placed on top because it is the model most referenced in the discussion.

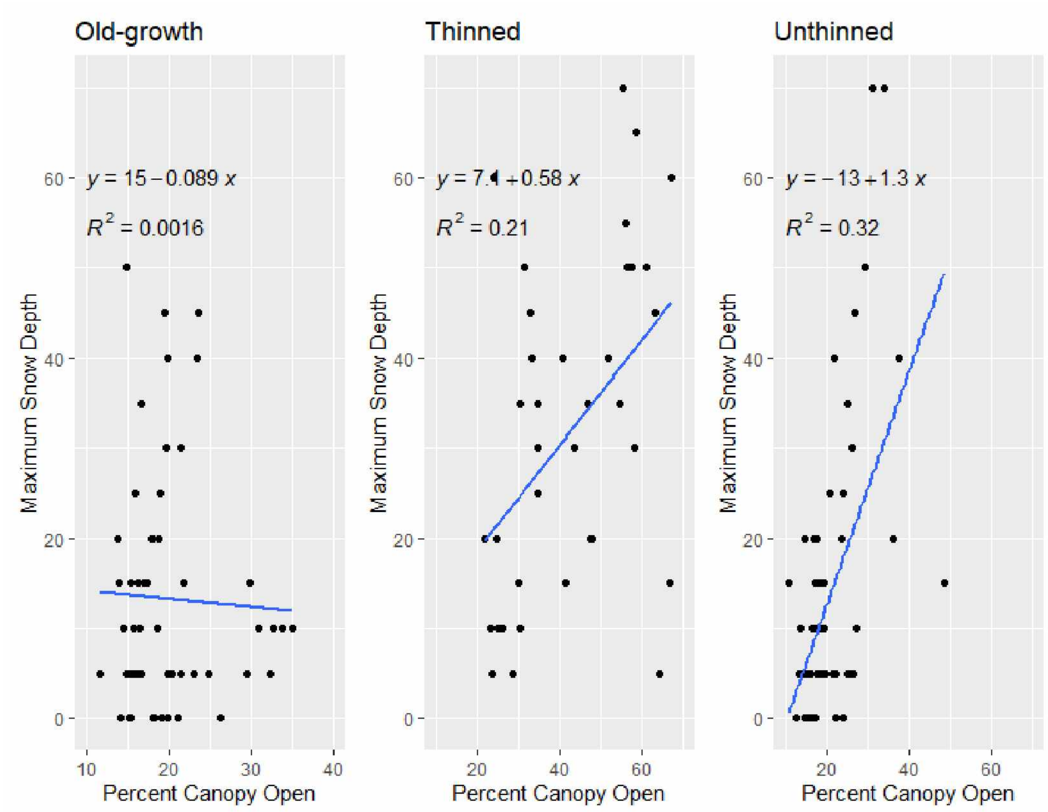


Figure 3.3 Maximum snow depth vs percent canopy open graphed as a scatter plot for old-growth, thinned and unthinned forest types. The trend line (blue line) and line equation (top left) with associated R-squared value are provided.

Generalized linear mixed models identified no forest structure variable as a significant predictor in the best model. No strong relationship was found when plotting maximum snow depth vs. percent canopy open in the old-growth forest types (R^2=0.0016), but positive relationships were found when plotting the same x and y-axis for thinned and unthinned forest types (Fig. 3.3). A model including forest type as a fixed effect produced an AIC of 1208 (Table 3.5). AIC values did not change more than three points when other forest structure variables were added to the model (Table 3.5). A model estimating maximum snow depth with forest type as a fixed effect shows that thinned forests are significantly (p = 0.04) different from old-growth (reference category), but unthinned are not significantly different from old-growth (p = 0.36) (Table 3.6.) The model with forest type as a fixed affect produced positive coefficients for thinned and unthinned forest types, reflecting positive trends when compared to the old-growth forest type (Table 3.6). Exponentiated coefficients are listed in Table 3.5 are for the applied interpretation of the effect of a parameter on maximum snow depth. The largest exponentiated coefficients were the effect of thinned forests (4.59), while the smallest effect was for unthinned forests (1.85). To further understand the relationship between forest type and maximum snow depth accumulated we did a pairwise comparison of estimated marginal means on the GLMM by forest type including unforested sites. The emmeans (estimated marginal means) pairwise comparison showed that all forest types were not significantly different when comparing maximum snow depth, except unforested and old-growth sites (p = 0.025, Table 3.7).

Effect	Coefficient	95% C.I. for exp. coefficients	P-value
Intercept	1.92	(2.60, 17.76)	<0.01
Thinned	1.52	(1.07, 19.69)	0.04
Unthinned	0.62	(-2.02, 6.92)	0.36
Reference category: Old-growth			

Table 3.6. Model summary where forest type was used as a fixed effect. Coefficients and P-values are displayed for each forest type as they compare to Old-growth sites. Significance reflects if the forest type is significantly different from old-growth (the reference category)

Contrasts	Estimate	SE	DF	P-value
UF - OG	1.40	0.49	191	0.03
UF - T	0.26	0.53	191	0.96
UF - UT	1.24	0.49	191	0.06
OG - T	-1.14	0.57	191	0.14
OG - UT	-0.16	0.53	191	0.99
T - UT	0.98	0.57	191	0.25

Table 3.7. Pairwise comparison of estimated marginal means by forest type. UF represents unforested, OG represents old-growth, T represents thinned, and UT represents unthinned.

3.5 Discussion

To understand the interaction between forest type and snow depth our objective was to identify relationships between maximum snow depth and forest structure variables across forest types. To accomplish this objective, we remeasured snow depth in old-growth, thinned, unthinned, and unforested plots. Our results show that thinned and unforested sites accumulated snow to a maximum depth median almost three times as much compared to old-growth and unthinned forests (Table 3.1), which corresponds to a difference in canopy openness (Table 3.2). We expect that old-growth and unthinned stands having similar canopy openness values produced similar maximum snow depth medians. Although, we were surprised that canopy openness was not a variable that was significant in predicting maximum snow depth. A pairwise comparison across forest types informed us that median canopy openness was significantly different for all forest types, except old-growth and unthinned (p=0.22, Table 3.4), which we expected to be similar because of their closed canopies. Our results suggesting that canopy openness is insignificant as a predictor of maximum snow depth does not align with other researchers work (Hanley and Rose 1987). The seemingly stochastic variation seen in maximum snow depth values plotted across percent canopy open and DBH values in old-growth forests gives explanation as to why canopy openness was not found to be a predictor (Fig. 3.3). Positive relationship trends were identified when plotting maximum snow depth across percent canopy values for thinned and unthinned forests (Fig. 3.3). Thinned and unthinned forests are homogenous in their tree size and canopy over large areas. Old-growth forests are more heterogenous in tree size and canopy due to large canopy gaps created by wind throw disturbances. We think that the heterogenous nature of the old-growth canopy affects snow depth at a larger or smaller scale than was captured with our fish eye lens photos used to estimate percent canopy open. While the fish eye lens photos were adequate to capture the scale of canopy that affects snow accumulation on the ground in thinned and unthinned forests. We also acknowledge that using a split–split plot design with low whole plot sample size produces little statistical power. Split-split plot design captures extensive variability at a small scale (lots of sub-subplot replication) but requires extensive effort to increase the sample size at the treatment level (forest type or whole plot). Our study lacked whole plot replication and in turn had a low sample size of four replicates per forest type.

Snow accumulates in thinned forests similarly to unforested sites. Our thinned forest type had a max snow depth median of 35 cm and unforested sites had a median of 50 cm of snow (Table 3.1). When testing the difference between modeled maximum snow depth means thinned forests were significantly different compared to old-growth (p-value = 0.04), but unthinned was not significantly different from old-growth (p-value = 0.36). Our box and whisker of maximum snow depth across forest types (Fig. 3.2), Table 3.1 and 3.2, shows thinned forests do accumulate more snow compared to forests with less canopy openness (old-growth and unthinned). From this data we can assume that thinned forests although rich in winter deer forage are not to be assumed to be available habitat during winters where snow depth exceeds 40 cm in unforested areas. Managers should incorporate the idea that thinned forests are of less value in winter into habitat-carrying capacity models, if thinned forests make up a significant portion of a deer's home range or area of management. Table 3.1 shows that old-growth and unthinned had an approximate maximum snow depth of one quarter the value compared to thinned and control sites (unforested/thinned = 40cm, old-growth/unthinned = 7 cm). The positive correlation between maximum snow depth and canopy openness suggests that snow interception via the canopy explains similar average snow depths in old-growth and unthinned as well as thinned and unforested sites (Table 3.1 and 3.2). Previous studies found that as canopy openness increases there is less snow accumulation in the canopy and more on the forest floor. For example, large Douglas fir (*Pseudotsuga menziesii*) canopies accumulate 60% of the snowfall within the tree's canopy perimeter, supporting this interpretation of the relationship between closed canopies and low snow depths on the ground (Martin et al. 2013; Storck et al. 2002).

Thinned forest structure attributes are smaller in all measurements (DBH, distance, and height) when compared to unthinned and old-growth (Table 3.2). We expect that by keeping elevation and aspect relatively constant for our sites they received similar snow fall events, meaning differences seen in maximum snow depth across sites would be due to forest structure. POW island received approximately 40 cm of snow at sea level for the winter of 2020-2021 (The Alaska Climate Research Center 2022). Our study sites were all at least 400 meters above sea level allowing them to receive more snow with maximum values above 40 cm for all forest types (Fig. 3.2). How the maximum snow depth between old-growth and unthinned would compare under a greater snowfall than we experienced is not understood. We expect that with a greater snow load DBH could have had a greater impact on snow accumulation in the canopy, because larger trees are likely to hold more snow in the canopy before collapsing, which would create lower snow depths in old-growth and greater snow depths in unthinned forests (Hedstrom and Pomeroy 1998; Kirchhoff and Schoen 1987; McNay et al. 1988).

We chose to examine a model with forest type as a fixed effect to understand the differences in snow depth across forest types. A key feature when interpreting our model summary is if the coefficient values are positive or negative because this reflects the relationship between forest type snow accumulation. Our reference category is old-growth, meaning the listed forest types are being compared to old-growth. The positive value associated with our exponentiated coefficients tells us that more snow accumulates in thinned or unthinned compared to old-growth. The greater magnitude of the exponentiated coefficient for thinned forest types, compared to the exponentiated coefficient for unthinned forests, tells us that more snow will accumulate in thinned forest types than unthinned compared to old-growth. Finding no forest structure characteristics to be significant in our model, as well as forest types (as a factor) to not be significantly different was surprising, but does not allow us to reject our prediction that unthinned forest types accumulate snow differently than thinned or old growth. The patterns seen in Fig. 3.2 support the idea that snow accumulates differently in thinned forests compared to unthinned and old-growth and this is likely due to canopy. Data collected from thinned stands was collected from stands that were thinned 30 to 40 years after clear cutting. It is more common to thin when stands are 15 to 30 years post clearcut. The fact that the stands we evaluated had relatively larger trees due to more time since clearcut could mean that younger/smaller thinned stands may behave differently when modeling maximum snow depth. If we were to model maximum snow depth (using old-growth as the reference category) in younger thinned stands we would expect a greater difference in snow depth in thinned stands compared to old-growth, because smaller trees would presumably hold less snow in the canopy.

We were incorrect in predicting that old-growth forests would have a lower mean maximum snow depth compared to unthinned. The prediction that old-growth would have lower snow depths was expected under the assumption that larger-diameter trees would hold more snow in the canopy. Other studies have shown evidence that tree diameter affects snow accumulation in the canopy (Hanley and Rose 1987; Kirchhoff and Schoen 1987). Old-growth forests did not hold more snow in the canopy, but we recognize that at 40 cm of snow at sea level for the year there may not have been enough snow for branch size (positively correlated with DBH) to influence snow held within the canopy. We surmise that a greater snow load, or younger stands could cause unthinned forest canopies to collapse earlier than old-growth forest canopies, depositing more snow onto the ground of unthinned forests.

Understanding how precommercial thinning increases snow accumulation should help managers understand which habitat types are available and valuable to deer throughout the year. Deer are impeded by snow deeper than approximately 40cm (Gilbert et al. 1970). Thinned forest types averaged 35cm in the winter of 2020-2021. Thinned forest types are preferred by deer five to ten years after thinning because the resulting open canopy promotes the production of forage species (Crotteau et al.

2019). Unforested sites and thinned sites both accumulated maximum snow depths to approximately 40cm (Table 3.1), a result showing they behave similarly in snow accumulation. Unforested and thinned sites behaving similarly in snow accumulation is evidence to advise that wildlife and forest managers assume when unforested areas become unavailable due to snow depth, thinned stands do as well. Unthinned forests accumulated snow to a maximum depth like old-growth forests, giving the impression that unthinned forests are as valuable to deer as old-growth in the winter. Old-growth forests offer important winter habitat because the large trees keep the snow in the canopy, leaving forage available longer compared to other habitat types (Brinkman et al. 2011; Bloom 1978; Doerr et al. 2005; Hanley and Mckendrick 1985; Hanley 1984; Kirchhoff and Schoen 1987). Unthinned forests offer little forage value to deer because of the low abundance of forage species (Crotteau et al. 2019). Although unthinned forests keep habitat available into the winter, the lack of deer forage compared to old-growth means it is poor winter habitat for deer.

We found that in thinned forests snow accumulates as if there is no forest structure present. Managers should not assume thinned forests have forage value once unforested areas of similar elevation have become unavailable to deer due to snow. Thinned forests and the slash they hold may elevate snow levels by snow accumulating on top of dense slash. Our study focused on thinned forests that had been thinned within the past five years. Managers should integrate forage abundance information with observations of snow accumulation to better understand how forest management may be impacting deer. Thinned areas may have an abundance of forage, but the forest structure offers little to no snow accumulation in the canopy, meaning thinned forests are of little value for foraging during deep snow years.

3.6 Acknowledgments

We would like to thank J. Barnard, R. Slayton, R. Dorendorf, T. Hasbrouck, B. Bennetsen, S. McCurdy, and staff at the U.S.D.A. Forest Service Thorne Bay Ranger District for project development and field work logistics. Funding was provided by the University of Alaska Fairbanks Biology and Wildlife Department, the USDA NRCS, the USFS Pacific Northwest Research Station, and the National Science Foundation (#1518563, #1026415).

3.7 References

Avenza Systems. 2022. Avenza Maps. Avenza Systems Inc. https://www.avenza.com/avenza-maps/

Alaska Climate Research Center. 2022. Data Portal Alaska Climate Research Center: The Alaska State Climate Center, University of Alaska Fairbanks. https://akclimate.org/data/.

Alaback, P.B. 1982. Dynamics of understory biomass in Sitka spruce-western hemlock forests of southeast Alaska. Ecology, 63(1):1932–1948.

Alaback, P.B. 1984. Plant succession following logging in the Sitka spruce-western hemlock forests of southeast Alaska: implications for management. Gen. Tech. Rep. PNW-173. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 26.

Alaback, P.B. 1990. Dynamics of old-growth temperate rainforests in Southeast Alaska. In Proc. Glacier Bay Sci. Symp, 2(1):150-153.

Alaback, P., Nowacki, G., Saunders, S. 2013. Disturbance ecology of the temperate rainforests of Southeast Alaska and adjacent British Columbia. Orians, G., & Schoen, J. (eds) North Pacific temperate rainforests: ecology and conservation. University of Washington Press, Seattle, 73-88.

Albert, D.M., Schoen, J.W., 2013. Use of historical logging patterns to identify disproportionately logged ecosystems within temperate rainforests of southeastern Alaska. Conservation Biology, 27(4):774-784.

Bloom, A.M. 1978. Sitka Black-Tailed Deer Winter Range in the Kadashan Bay Area, Southeast Alaska. Journal of Wildlife Management, 42(1):108–112.

Brinkman, T.J., Chapin, T., Kofinas, G., Person, D.K. 2009. Linking hunter knowledge with forest change to understand changing deer harvest opportunities in intensively logged landscapes. Ecology and Society, 14(1):36.

Brinkman, T.J., Person, D.K., Chapin, S.F., Smith, W., Hundertmark, K.J. 2011. Estimating Abundance of Sitka Black-Tailed Deer Using DNA from Fecal Pellets. Journal of Wildlife Management, 75(1):232–242. https://doi.org/10.1002/jwmg.22.

Burnham, K.P., Anderson, D.R. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretical Approach. 2d ed. New York: Springer-Verlag.

Campbell, S.J. 2004. Southeast Alaska forests: inventory highlights (No. 609). US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Crotteau, J.S., Rue-Johns, A., Barnard, J.C. 2019. Eight- to Ten-Year Effects of Pre-Commercial Thinning on Understory Biomass and Forage of Sitka Spruce/Western Hemlock Stands in Southeast Alaska. Canadian Journal of Forest Research, 50(1):215–225. https://doi.org/10.1139/cjfr-2019-0268.

Crotteau, J.S., Rue-Johns, A.Z., Barnard, J.C. 2020. Effects on understory biomass and forage 8–10 years after precommercial thinning of Sitka spruce–western hemlock stands in southeast Alaska. Canadian Journal of Forest Research, 50(2):215-225.

Doerr, J.G., Degayner, E.J., Ith, G. 2005. Winter habitat selection by Sitka black-tailed deer. Journal of Wildlife Management, 69(1):322–331. https://doi.org/10.2193/0022-541x(2005)069<0322:whsbsb>2.0.co;2.

Federer, W.T., McCulloch, C.E. 1991. Multiple comparisons in split block and split-split plot designs. Technical Report. Cornell University. BU-1132-MA

Gilbert, S.L., Hundertmark, K.J., Person, D.K., Lindberg, M.S., Boyce, M.S. 2017. Behavioral plasticity in a variable environment: snow depth and habitat interactions drive deer movement in winter. Journal of Mammalogy, 98(1):246-259.

Gilbert, P.F., Wallmo, O.C., Gill, R.B. 1970. Effect of Snow Depth on Mule Deer in Middle Park, Colorado. Journal of Wildlife Management, 34(1):15–23.

Hanley, T.A., Rose, C.L. 1987. Influence of Overstory on Snow Depth and Density in Hemlock-Spruce Stands: Implcations for Management of Deer Habitat in Southeastern Alaska. Research Note PNW-RN-459, 1–11. https://doi.org/10.1016/0003-6870(73)90259-7.

Hanley, T.A. 1984. Relationships Between Sitka Black-Tailed Deer and Their Habitat. General Technical Report PNW-168: 2–13.

Hanley, T.A., McClellan, M.H., Barnard, J.C., Friberg, M.A. 2013. Precommercial Thinning: Implications of Early Results from the Tongass-Wide Young-Growth Studies Experiments for Deer Habitat in Southeast Alaska. USDA Forest Service - Research Paper PNW-RP, no. 593: 1–64. https://doi.org/10.2737/PNW-RP-593.

Hanley, T.A., Mckendrick, J.D. 1985. Potential Nutritional Limitations for Black-Tailed Deer in a Spruce-Hemlock Forest , Southeastern Alaska. Journal of Wildlife Management, 49(1):103–114.

Harris, S.A., Farr, A.W. 1974. The Forest Ecosystem of Southeast Alaska. Forest Ecology and Timber Management. USDA Forest Service General Technical Report PNW-25. https://www.fs.fed.us/pnw/pubs/pnw_gtr025.pdf

Hedstrom, N.R., Pomeroy, J.W. 1998. Measurements and Modelling of Snow Interception in the Boreal Forest. Hydrological Processes, 12(10–11):1611–1625. https://doi.org/10.1002/(SICI)1099-1085(199808/09)12:10/11<1611::AID-HYP684>3.0.CO;2-4.

Kirchhoff, M.D., Schoen, J.W. 1987. Forest Cover and Snow : Implications for Deer Habitat in Southeast. Journal of Wildlife Management, 51(1):28–33.

Martin, K.A., Van Stan, J.T., Dickerson-Lange, S.E., Lutz, J.A., Berman, J.W., Gersonde, R., Lundquist, J.D. 2013. Development and Testing of a Snow Interceptometer to Quantify Canopy Water Storage and Interception Processes in the Rain/Snow Transition Zone of the North Cascades, Washington, USA. Water Resources Research, 49(6):3243–3256. https://doi.org/10.1002/wrcr.20271.

McNay, R.S., Peterson, L.D., Nyberg, J.B. 1988. The Influence of Forest Stand Characteristics on Snow Interception in the Coastal Forests of British Columbia. Canadian Journal of Forest Research, 3(2):54–67. http://repositorio.unan.edu.ni/2986/1/5624.pdf.

Olmsted, N.W., Curtis, J.D. 1947. Seeds of the forest floor. Ecology, 28(1):49-52.

Parker, K.L., Robbins, C.T., Hanley, T.A., 1984. Energy expenditures for locomotion by mule deer and elk. The Journal of Wildlife Management, 48(2):474-488.

RStudio Team. 2022. RStudio: Integrated Development for R. RStudio Inc, Boston, MA http://www.rstudio.com/.

Searle, S.R., Speed, F.M., Milliken, G.A. 1980. Population Marginal Means in the Linear Model: An Alternative to Least Squares Means. The American Statistician, 34(4):216–221. https://doi.org/10.2307/2684063

Southeast Alaska Conservative Council. 2022. The Tongass National Forest. https://www.seacc.org/our-work/tongass/

Storck, P., Lettenmaier, D.P., Bolton, S.M. 2002. Measurement of Snow Interception and Canopy Effects on Snow Accumulation and Melt in a Mountainous Maritime Climate, Oregon, United States. Water Resources Research, 38(11):5-16. https://doi.org/10.1029/2002wr001281.

Taylor, R.F. 1932. The Successional Trend and Its Relation to Second-Growth Forests in Southeastern Alaska. Ecological Society of America, 13(4):381–91.

United States Forest Service. 2022. Welcome to the Tongass National Forest. https://www.fs.usda.gov/tongass/

White, K.S., Pendleton, G.W., Hood, E. 2009. Effects of snow on Sitka black-tailed deer browse availability and nutritional carrying capacity in southeastern Alaska. Journal of Wildlife Management, 73(4):481-487.

Chapter 4: Conclusion

My research investigated how thinned forest types are impacting Sitka black-tailed deer directly by influencing physical obstructions to forage, and indirectly by changing the way landscapes accumulate snow. When exploring how thinned forest types and the slash they produce affect the proportion of a plant browsed, we found that there is significantly less browse in thinned forests compared to old-growth. We also found that thinned forest types compare to unforested sites in how they accumulate snow. Thinned forests accumulate snow and their forage becomes unavailable because their canopies intercept little to no snow. These findings offer evidence that thinned forests negatively impact the capacity of deer to access forage the first four years after thinning.

The proportion of a plant browsed served as an index of browsing intensity. Browse surveys were conducted in thinned and old-growth forests to compare browsing intensity. We found that browsing intensity is less in thinned stands than in adjacent old-growth. The best predictors for variation of plants browsed were vertical obstruction of slash and time since thinning. An increase in vertical obstruction caused a decrease in the percent of a plant browsed. The more time between the survey and the thinning prescription (year variable) caused an increase in browsing intensity. Both vertical obstruction and time since thinning have to do with slash as an obstacle to forage. Time post thinning reflects time that the slash has been able to decompose. Our findings imply that the benefits of thinning on deer forage will take time since the volume of slash remaining may impede the effective access of deer to forage. As this slash layer decreases via decay forage becomes easier to access. Approximately 75% vertical obstruction stops foraging. To increase the opportunity for deer to access forage stands should be thinned earlier to produce smaller volumes of slash, ideally less than 75% of vertical obstruction. To move research forward with an understanding of slash as an obstruction we recommend that researchers investigate stands thinned at an earlier successional age as ours were relatively later and investigate stands thinned greater than four years ago. We also recommend that site specific productivity be evaluated as an indicator of slash size or browse intensity. Productivity has a large impact on slash abundance, and we did not account for it as a predictor of browse intensity.

By remeasuring snow depths in replicated thinned, unthinned, old-growth and unforested (control) sites we identified patterns in how these forest types accumulate snow to a maximum depth. We also used the data to understand what forest structure attributes best predict maximum snow depth. We found thinned stands accumulate snow similar to unforested sites. We also found that unthinned stands accumulate snow similar to old-growth sites. Thinned and unforested sites accumulated approximately twice the snow depth compared to unthinned and old-growth forest types. Our lack of statistical significance separating the unforested and thinned grouping from the old-growth and unthinned grouping was probably due to the study design. Thus, the use of a split-split plot design is not recommended for a snow study where transects and forest types are to be replicated. Replication across forest types that are adjacent and likely to experience similar snowfall events requires traveling far on POW making data collection difficult. Variability in snow depth must be captured across the forest type of interest which requires a transect or random sampling. This study lacked adequate replication across forest types which probably resulted in our inability to detect true differences among stands (i.e., type II error).

Thinned stands reduce foraging compared to old growth and the best predictors of foraging intensity in thinned stands are slash characteristics (vertical obstruction and year of thinning or decomposition time). These ideas lead to the conclusion that slash negatively impacts foraging opportunities at least the first four years of slash decomposition (we did not investigate outside of this time period). Thinned stands also accumulate snow as if no forest structure is present. Deer forage and access to forage is reduced by snowfall devaluing habitat as snow accumulates. Snow accumulation and slash of thinned stands make for poor winter deer habitat at least the first four years post thinning. Poor winter and spring deer habitat (reflected by snow covered or inaccessible forage (Hanley and

McKendrick 1985), is a limiting factor for population size. These ideas suggest that thinned forests have the potential to limit localized deer populations, although unlikely at the current scale of thinning. These managed forest types are local to communities who subsist from deer. Thinning events and the potential to negatively impact deer has implications for success of deer harvest by local communities.

This research investigated how thinned stands within four years of thinning affect browse intensity, and how stands thinned zero to approximately ten years ago affect snow accumulation. How more time post thinning affects browse intensity or snow accumulation requires more data collection and analysis. Specifically, we suggest that researchers examine stands thinned up to ten years post thinning and measure browse intensity and maximum snow depth in these stands at the same time, as this time range includes a known increase in forage biomass and a greater range of slash decomposition (Crotteau et al. 2020). When conducting a snow study across multiple forest types, we do suggest the use of a split-split plot design. Focus data collection efforts on replication across forest types, although variability does need to be captured per forest type with the use of transects or other random sampling.

4.1 References

Crotteau, J.S., Rue-Johns, A.Z., Barnard, J.C., 2020. Effects on understory biomass and forage 8–10 years after precommercial thinning of Sitka spruce–western hemlock stands in southeast Alaska. Canadian Journal of Forest Research, 50(2):215-225.

Hanley, T.A., McKendrick, J.D. 1985. Potential nutritional limitations for black-tailed deer in a spruce-hemlock forest, Southeastern Alaska. Journal of Wildlife Management, 49(1):103–114.