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Understory Plant Development in Artificial Canopy Gaps in an 81-Year-Old Forest Stand on Chichagof Island, Southeast Alaska

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Cover: An artificial canopy gap created in an approximately 74-year-old stand at the Todd study site with untreated forest in the background in 2006. Photo by Mike McClellan.

Abstract

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This study assesses the understory plant response and associated effects on forage resources available to Sitka black-tailed deer (*Odocoileus hemionus sitkensis*), to the creation of artificial canopy gaps in a young-growth forest stand in the coastal temperate rain forest of southeast Alaska. The forest stand was approximately 58 years old when gaps were created and approximately 81 years old when the most recent set of data was collected in 2013. Plant canopy cover estimates were collected five times over the 23-year period following the creation of nine artificial canopy gaps. We estimated the biomass of individual plant species and plant groups in the gaps and adjacent untreated forest using canopy cover to biomass regression equations to convert the data into estimates of kilograms of plant material per hectare. We estimated “deer days” per hectare for several summer and winter scenarios, in the gaps and untreated forest, by using the Forage Resource Evaluation System for Habitat (FRESH) deer model. Results were analyzed with a Wilcoxon signed rank test ($P < 0.05$). Results indicated that plant biomass and deer days per hectare were significantly higher in the gaps than the adjacent untreated forest at 23 years following creation of the gaps, increasing over the 23 years with no apparent peak. Compared to understory plant response for three thinning studies from southeast Alaska, results from this study indicate that deer days per hectare for the summer scenarios were greater for the thinning treatments, but lower for the winter scenario where low-lying forbs would likely be buried by snow. However, data from the thinning studies are available for only a few years following the treatments, so the comparisons are not precise. Although the results from our gap study should not be considered representative for southeast Alaska because they are from only one stand, they do suggest that creating artificial canopy gaps in 58-year-old young-growth stands is a viable option for increasing forage resources for deer.

Keywords: Southeast Alaska, Sitka black-tailed deer, canopy gaps, forest ecology, FRESH deer.

Summary

In southeast Alaska, maintaining and enhancing forage for Sitka black-tailed deer in young growth stands is a priority for forest managers on the Tongass National Forest. Creating artificial canopy gaps is one technique to accomplish this. We assess the understory plant response in nine artificial canopy gaps that were created in an approximately 58-year-old stand over the following 23 years, a project known as the Todd gap study. We estimated the biomass of individual plant species and plant groups in the gaps and adjacent untreated forest as kilograms of plant material per hectare. Vegetation response was evaluated in terms of forage resources using the Forage Resource Evaluation System for Habitat (FRESH) deer model to quantify habitat value in terms of deer days per hectare, where one deer-day is the food required to maintain an adult female deer for one day at user-specified metabolic requirements.

Results indicate the following: In the gaps, the total mean understory vascular plant biomass increased by a factor of 35.5 within 23 years following the creation of the canopy gaps. Forbs (forest herbs) are a key forage group for deer. Mean forb biomass increased by 8.3 times over the 23-year monitoring period. *Vaccinium* species are key winter forage items. Their biomass increased by 17 times over the monitoring period.

In young growth treated with thinning or with artificial gaps, conifers can compete with and shade out understory forage, so monitoring their growth is an important consideration in understory vegetation studies. In this study, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) seedlings were absent in the gaps at one year after treatment. They did subsequently increase in biomass, but at a lesser rate than the shrubs.

FRESH deer analysis showed that at 23 years after gap creation, estimates of deer days per hectare were 8.1 times higher in the gaps than the untreated forest for the summer scenario with one adult female, 3.7 times in winter without snow, and 3.4 times in winter with snow.

Compared with recent studies of precommercially and commercially thinned stands, the thinning studies had more deer days per hectare than the Todd gaps for the two summer scenarios and the winter no-snow scenario, but fewer deer days per hectare than the Todd gaps for the winter with-snow scenario. The thinned and gap treatments all show a delayed forb response compared to the shrubs and conifers.

Estimates of both understory plant biomass and deer days per hectare in the gaps increased throughout the 23-year monitoring period without reaching an apparent peak. The results from our study suggest that canopy gaps can be a viable treatment option to improve forage in young-growth stands.

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Introduction

Creating artificial canopy gaps in young-growth forests to stimulate understory plant development is a common wildlife habitat restoration practice on the Tongass National Forest in southeast Alaska, yet the response of plants to this treatment is not well understood. Here, we report findings from a 23-year monitoring effort that examined the understory plant response to artificial canopy gaps at one study site. The results shed light on the persistence and magnitude of understory plant responses to this treatment.

Past timber harvest practices have had an impact on wildlife habitat in the coastal temperate rain forests of southeast Alaska. These practices have changed forest structure and plant species distribution, and hence have changed habitat conditions for many forest species (Orians et al. 2013). Investigations throughout southeast Alaska demonstrate a pattern of habitat change following harvest, particularly for Sitka black-tailed deer (*Odocoileus hemionus sitkensis*). Forest stand and understory plant development following clearcut harvest typically follows a pattern of natural tree regeneration and initially high understory plant biomass. Within about 30 years, however, the regenerated cohort of trees creates a closed canopy that shades the understory, resulting in a reduction in the biomass and diversity of plants. Without management intervention or other disturbance, this stem exclusion phase (Oliver and Larson 1996), with a forest floor relatively devoid of herbaceous and woody plants, can last 100 years or more (Alaback 1982, Nowacki and Kramer 1998).

Restoring and maintaining deer habitat is a priority for forest management on the Tongass National Forest, and Sitka black-tailed deer are an important subsistence resource for communities in southeast Alaska (Brinkman et al. 2009, Hanley 1993 Schoen and Kirchoff 2007). Restoring deer habitat has focused on improving light conditions for understory forage plants in young-growth forest stands. Light is considered the primary limiting factor in understory plant growth in southeast Alaska (Alaback 1982, Hanley et al. 2014, Tappeiner and Alaback 1989). Therefore, manipulating overstory canopy cover to increase light penetration through forest canopies is a key objective of thinning and restoration treatments.

The characteristics of high-quality deer habitat in old-growth forest serve as a guide to inform the habitat restoration in young-growth forests of southeast Alaska. High-quality habitat for deer results from the diversity of understory plant biomass and the ability of the forest canopy to intercept snowfall. Snow interception by the canopy leads to lower snow accumulation on the forest floor so that the highest

quality winter forage (low-lying evergreen forbs) can be available to deer. This forage resource can become unavailable to deer at snow depths of 10 cm and greater (Parker et al. 1999). At coarser scales, horizontal patchiness and forest edges increase these effects and provide structural habitat diversity (Schoen and Kirchoff 2007). Fine-scale tree mortality from disease and wind events provide this patchiness by creating natural canopy gaps, and is one of the most common disturbance mechanisms in southeast Alaska (Harris 1999, Hennon and McClellan 2003). Ott and Juday (2002) found that these natural canopy gaps vary in size and shape and have an equivalent mean diameter of approximately 16 m. Structural complexity has also been shown to increase biodiversity and is a generally accepted principle of multiple-use forest management, or what has been called ecological forestry (Lindenmayer and Franklin 2002).

The primary objective of thinning treatments is to improve tree growth and stand structure for future timber harvest. However, empirical studies of thinning treatments in young-growth forest stands in the stem exclusion stage have also shown promise for increasing understory plant biomass. By felling or girdling trees, thinning increases light penetration to the forest floor, which encourages understory plant growth. Without further management intervention, however, canopy closure can reoccur after 10 to 30 years, repeating the cycle of stem exclusion (Alaback 2010, Deal and Farr 1994, Hanley et al. 2013). Thinning can also result in reduced structural complexity (Lindenmayer and Franklin 2002). These general patterns differ depending on site conditions, such as stand age, harvest practices, soils, etc., and the details of the individual thinning treatments.

Therefore, a significant challenge is to treat young-growth stands to increase understory plant growth, biodiversity, and structural complexity, and to extend the time before the return to the stem exclusion phase. Creating artificial canopy gaps has shown promise for meeting these multiple objectives. Nearly 600 canopy gaps were created in young-growth stands on Prince of Wales Island between 1983 and 1993 (Alaback 2010). Additionally, an analysis of U.S. Forest Service stand data showed that 423 gaps were created in young-growth stands on Kruzof Island between 1991 and 1996. The Todd gap study described in this report is important as it represents the only study of gap treatments that were implemented in stands age 55 and older, and it is the longest term monitoring of gap treatments (23 years) in southeast Alaska. Therefore, it provides a unique opportunity to examine the long-term effects of this treatment type.

A significant challenge is to treat young-growth stands to increase understory plant growth, biodiversity, and structural complexity, and to extend the time before the return to the stem exclusion phase. Creating artificial canopy gaps has shown promise for meeting these multiple objectives.

Methods

Study Site

The study site, hereafter referred to as Todd, is located on southeast Chichagof Island on Peril Strait near the historic Todd Cannery (fig. 1). Historical aerial imagery, U.S. Forest Service geographic information system (GIS) data, and increment cores were used to determine forest stand history. Based on these multiple sources of information, we estimate harvest occurred between 1929 and 1936, resulting in a stand age of approximately 58 years when gaps were cut, and subsequently a stand age of 81 at the time of the last field data collection in 2013. Figure 2 shows the portion of the stand where gaps were created.

A thorough review of available information on the Todd gaps reveals that specific gap locations within the stand were chosen subjectively based on professional judgment.¹ Criteria included: siting gaps where there was existing *Vaccinium* shrubs, having gaps evenly distributed throughout the stand (but avoiding the edges of the stand), and cutting gaps in a roughly oval shape with the north-south axis being longer. Slash was bucked and left on site. Although there was an intention to monitor the long-term plant response in the gaps, the gap locations were chosen to demonstrate the ability of canopy gaps to meet management objectives (improve understory forage resources for deer), and not under the guidance of an experimental design. There is no history of thinning in this stand, and the only management action following original harvest was the creation of the gaps.

The stand has a southern aspect, is at an elevation less than 100 m, and is within 400 m of the shoreline. The 13 gaps (of which 9 were monitored) described in this report were created in 1990. The gaps range in size from 150 to 430 m². The mean width is 18.3 m (ranging from 10.7 to 23.6 m). The stand comprising the gaps is in the Tongass National Forest plant association of western hemlock/blueberry-menziesia (Martin et al. 1995). The plant association was determined by observing existing vegetation at the time of the 2013 survey. The Tongass National Forest GIS soils layer identifies the western portion of the stand as Kupreanof-Tuxekan soil series with a median slope of 20.5 percent, non-hydric, site index 105; and the eastern portion of the stand as Kupreanof gravelly silt loam series with a median slope of 65.5 percent, non-hydric, site index 105. Bedrock geology is Cretaceous quartz monzonite and quartz diorite.

¹ Killinger, G.M. Unpublished memo dated September 19, 1990. Available from the authors. Also on file with: U.S. Department of Agriculture, Forest Service, Tongass National Forest, Sitka Ranger District, 204 Siginaka Way, Sitka, AK 99835.

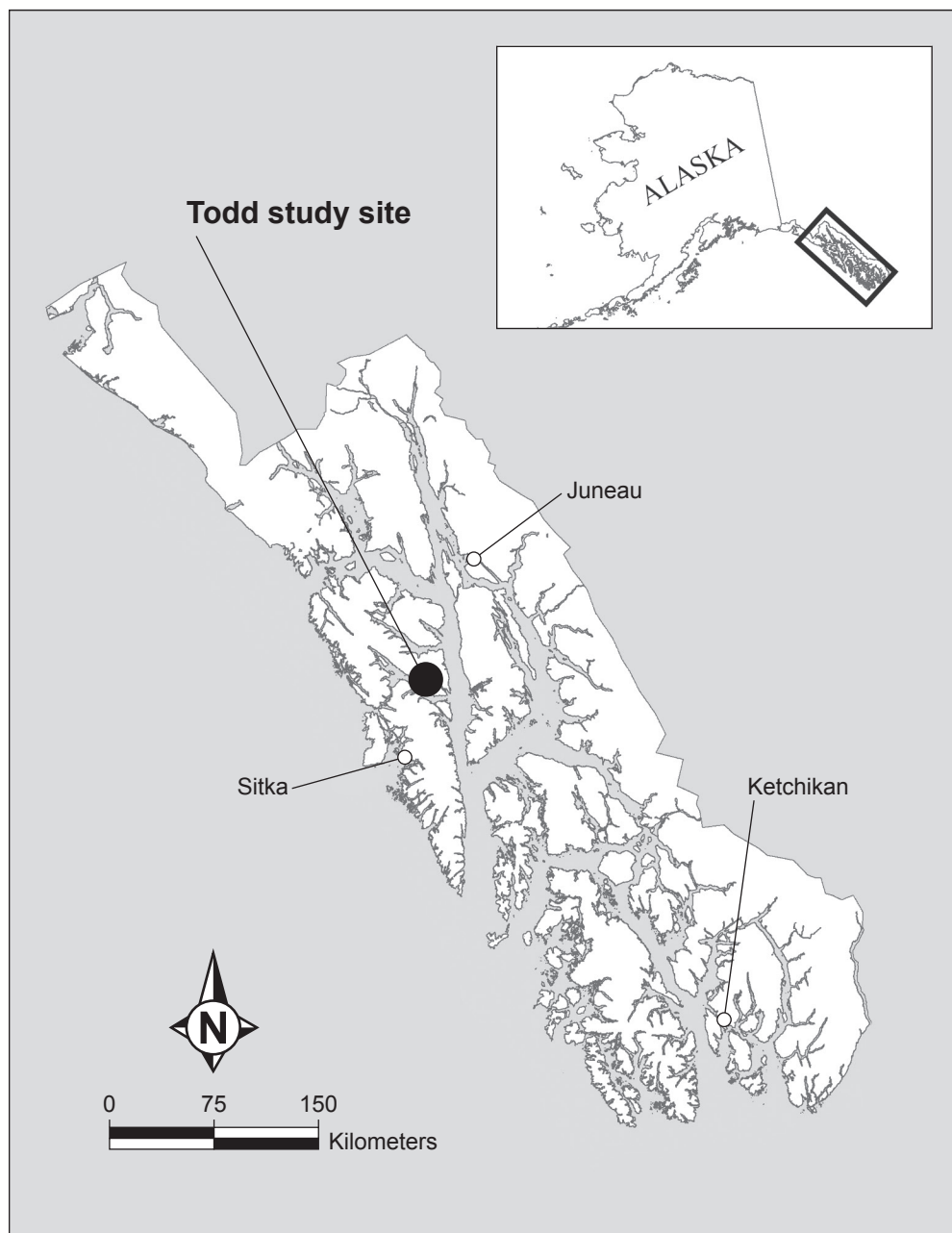


Figure 1—Location of the Todd study site on Chichagof Island, southeast Alaska.

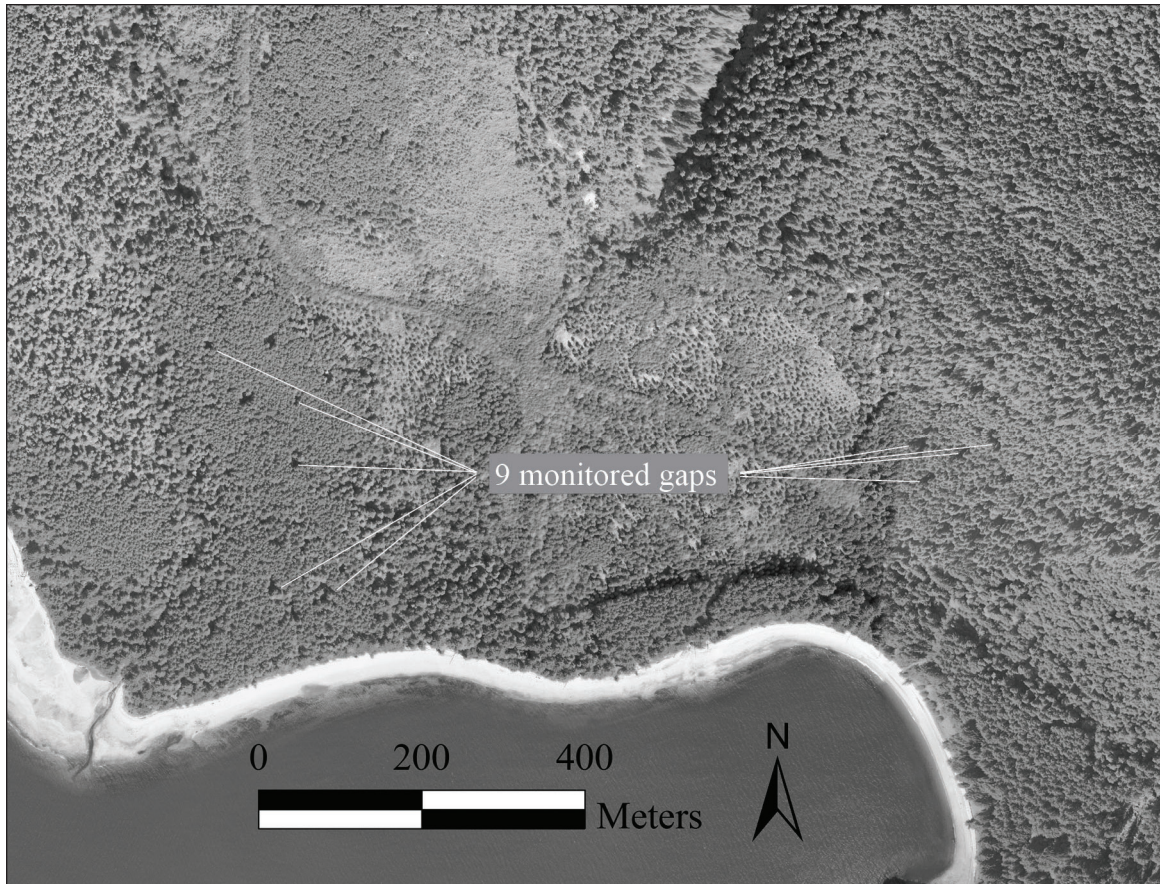


Figure 2—Composite aerial image (source image 2009, 30 cm resolution) showing the 13 artificial canopy gaps at the Todd study site, Chichagof Island, southeast Alaska. The nine gaps chosen for monitoring are identified. The clearcut in the center of the image occurred in 1975, and the gapped stands were harvested between 1929 and 1936. Gaps were cut in 1990, approximately 58 years after harvest.

Field Data Collection

The percentage of understory plant-canopy coverage and gap characteristics were measured using the revised protocol developed by DeMeo². East-west transects were established and permanently marked before gaps were cut. Thirteen gaps were cut in September 1990; 9 of these were subsequently monitored at 1 year, 5 years, 10 years, and 23 years after treatment. Only 4 of the 9 gaps were monitored 15 years posttreatment. For each transect, understory plant cover estimates were recorded using 1 m × 2 m quadrats at 8 quadrats in the gap, 1 quadrat at the edge of the gap in the forest, and 8 quadrats in the adjacent untreated forest, as shown in figure 3. To minimize the effects of inconsistencies between the plant identification skills

² DeMeo, T. 1990. Gap Monitoring Program, Ketchikan Area, Revised April 1990. Unpublished protocols obtained from Greg Killinger, Sitka, AK: U.S. Department of Agriculture, Forest Service, Tongass National Forest. 13 p.

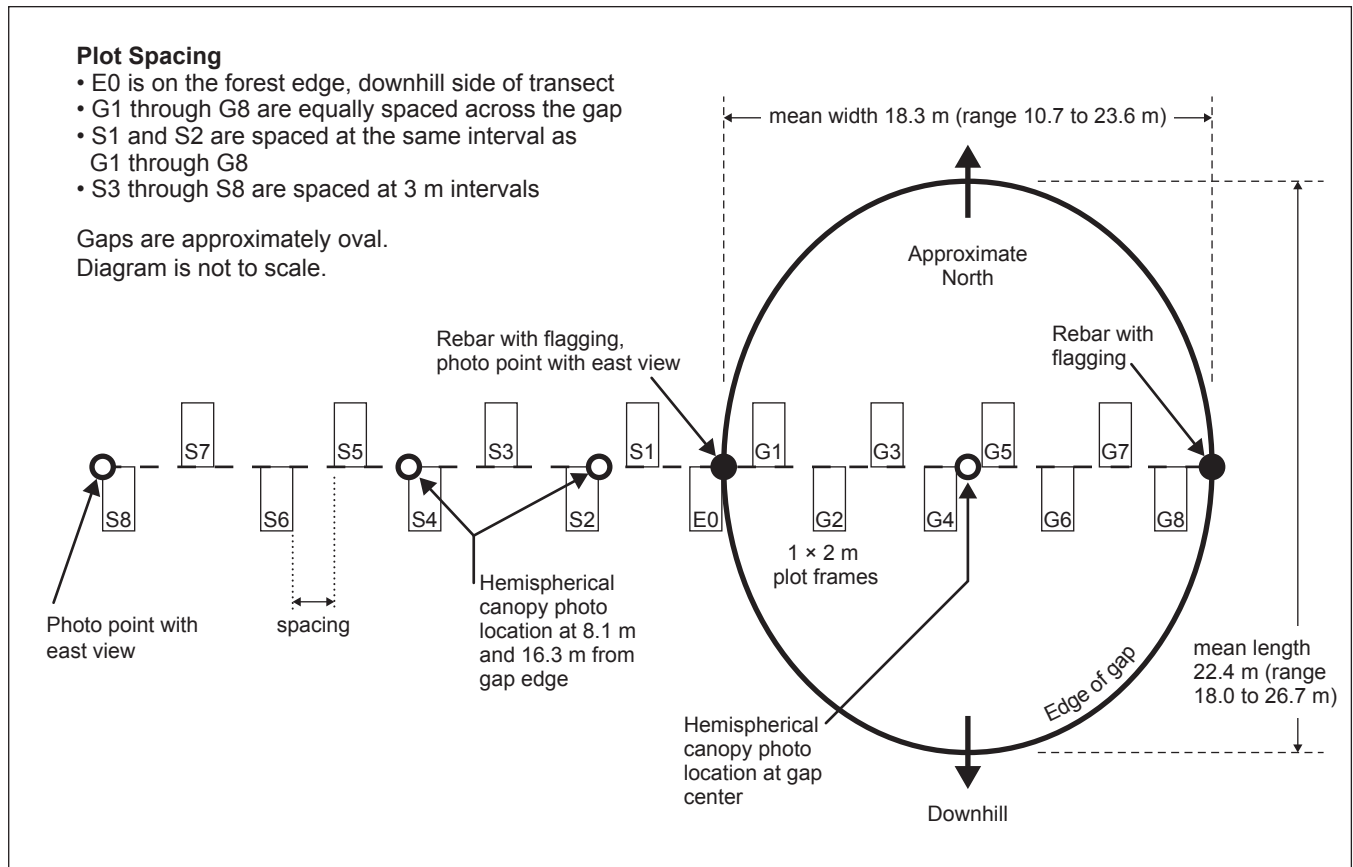


Figure 3—Transect layout for monitoring the Todd study site, adapted from DeMeo (1990). Dimensions are approximate dimensions of the 9 monitored artificial canopy gaps.

of observers, blueberry and huckleberry species (which included *V. alaskaense*, *V. ovalifolium*, and *V. parvifolium*) were all recorded as *Vaccinium* spp. The scientific names of plants for the Todd protocol are based on Hitchcock and Cronquist (1973).³

We recorded the percent canopy coverage of plants within the quadrat frame that would be available to deer, which we assumed to be at a height of 1.4 m or less. All “trace” observations were converted to 0.1 percent. In June 2013, we took hemispherical canopy photographs from gap center and from two locations along the transect in the adjacent forest, one at 8.1 m and one at 16.3 m from the gap edge in each of the gaps. All canopy photographs were taken on the same day, with the same exposure settings and a north orientation, from a tripod set to a camera height of 1.4 m, and levelled with a bubble level.

³ For the Prince of Wales Island Commercial Thinning project regression equations, we used the online USDA Plants database for plant nomenclature (USDA NRCS 2017). We compared the two species lists and found no inconsistencies between the two sources for the species in this study.

Analysis

Key objectives of this publication are to assess the forage resources available to deer following gap treatments and to compare the effects of gap and thinning treatments. To do this, we used the understory canopy cover data to estimate plant biomass and Forage Resource Evaluation System for Habitat (FRESH) “deer days” per hectare (Hanley et al. 2012). From the field data, the mean percentage of canopy coverage for each species and vegetation group (e.g., shrubs, forbs) was calculated for each of the nine gaps and for the untreated forest adjacent to the gaps. Biomass (kg/ha) of the understory vegetation was estimated using plant cover-to-biomass regression equations developed from the Prince of Wales commercial thinning study data⁴. Data from that study were pooled from three thinning treatments and untreated controls to form the regression models. The Prince of Wales commercial thinning study regression equations were used because they are the closest available in stand age (50 to 70 years at treatment) to the Todd stand. Deer days per hectare were calculated by using the biomass results as input to the FRESH deer model (Hanley et al. 2012). The FRESH deer model was developed to provide insight into deer habitat quality based on the assumption that forage sets the potential upper limit on the abundance of deer. The FRESH model integrates available forage biomass, nutritional quality of the forage, and the nutritional requirements of deer with user-specified scenarios with constraints such as season, snow cover, and animal condition. From the model, deer days per hectare represent the number of animal-use days that can be supported if all of the current annual growth of plant material in the unit area that are above the specified nutritional quality threshold is consumed by the animal. Because the model does not account for variables such as animal behavior, population size, predation, or animal-plant interactions, it estimates only the theoretical maximum number of deer that can be supported by the available forage, and therefore serves as an index.

We compared the deer days per hectare between the gap and adjacent untreated forest under two summer (one adult female and one adult female with one fawn) and six winter scenarios (snow levels of 0 cm, 20 cm, 40 cm, 60 cm, 80 cm, and 100 cm). While forbs (forest herbs) are generally highly nutritious, evergreen forbs are especially important in the winter no-snow FRESH deer scenario. They are the most nutritious forage available in winter. At 20 cm of snow and above they are buried, so the only species available for forage are the much less nutritious shrub twigs

⁴ Barnard, J.C.; McClellan, M.H. 2014. Unpublished data from the Prince of Wales commercial thinning study. On file with: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 11175 Auke Lake Way Juneau, AK 99801.

and conifer annual growth. In this study, we show the deer days for snow levels of 0 to 100 cm. These levels are meant to illustrate the gradual burial of shrubs. In the FRESH model, shrub burial by snow is assumed to be complete at 100 cm. At that point, the only forage available would be taller conifers. In the results and discussion sections, we report and compare results for two summer scenarios, but we focus on the two winter scenarios of 0-cm and 20-cm snow depths as more critical for understanding deer habitat requirements.

Statistical analyses were performed using SAS (2013) software. Distributions of the biomass and FRESH deer days output data were assessed with normal probability plots. Because the data were non-normally distributed, we used the Wilcoxon signed rank test to test for differences between paired data (between the gap and adjacent untreated forest quadrats), which is appropriate based on the study design. The α value for all tests was 0.05. We did not include the edge quadrats data in the analysis because there is only one edge quadrat per canopy gap transect.

We processed the hemispherical images first by using SideLook (Nobis 2005) software to threshold the images using edge detection. We then processed images using HemiView software (2008) to estimate the proportion of visible sky. From this data we were able to calculate a canopy cover index (CCI) for each image. FRESH deer uses CCI to estimate forest canopy snow interception as part of the winter habitat scenarios. We used the means from the gap and untreated forest CCI in the FRESH deer scenarios.

Results

Between 1991 and 2013, the mean total understory plant biomass in the gaps and adjacent untreated forest increased by a factor of 35.5 and 2.6, respectively (tables 1 and 2). *Vaccinium* species mean biomass in the gaps and adjacent untreated forest increased by a factor of 17.0 and 1.7, respectively. Mean forb biomass was estimated at low levels, but also increased between 1991 and 2013 by a factor of 8.3 in the gaps and 4.3 in the adjacent untreated forest. In the gaps, *Vaccinium* species and other shrubs show an increasing trend without any apparent peak through the monitoring period (fig. 4). The category of “other shrubs” is predominantly composed of rusty menziesia (*Menziesia ferruginea* Sm.) and has small amounts (never more than 1 percent mean canopy cover for any year) of stink currant (*Ribes bracteosum* Douglas ex Hook.), salmonberry (*Rubus spectabilis* Pursh), red elderberry (*Sambucus racemosa* L.), and devils club (*Oplopanax horridus* (Sm.) Miq.). Conifer seedlings and saplings, predominantly western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), were absent in the gaps and adjacent forests 1 year after treatment, then subsequently increased in mean biomass, but at a lower rate than shrubs. Sitka spruce

Conifer seedlings and saplings, predominantly western hemlock, were absent in the gaps and adjacent forests 1 year after treatment, then subsequently increased in mean biomass, but at a lower rate than shrubs.

Table 1—Mean (and standard error) oven-dry biomass of major understory vegetation types following the creation of artificial canopy gaps at the Todd site, Chichagof Island, southeast Alaska. Gaps (n = 9; n = 4 for 2005) were created approximately 58 years after harvest

Treatment	Ferns	Forbs	Graminoids	All shrubs	Conifer seedlings	Total biomass
<i>Kilograms per hectare</i>						
1 year posttreatment (1991):						
Untreated	2.21 (1.0)	0.35 (0.1)	0 (0)	9.92 (5.5)	0 (0)	12.48 (6.4)
Edge	0 (0)	0 (0)	0 (0)	6.67 (4.9)	0 (0)	6.67 (4.9)
Gap	0.48 (0.2)	0.57 (0.2)	0 (0)	4.77 (1.4)	0 (0)	5.83 (1.5)
5 years posttreatment (1995):						
Untreated	1.18 (0.8)	0.28 (0.2)	0.85 (0.8)	5.27 (3.5)	1.28 (0.5)	8.86 (4.0)
Edge	0 (0)	0.04 (0)	0.11 (0.1)	5.13 (4.0)	6.0 (1.7)	11.29 (4.6)
Gap	3.04 (2.5)	0.21 (0.2)	4.56 (4.5)	9.73 (5.0)	15.36 (3.0)	32.89 (10.1)
10 years posttreatment (2000):						
Untreated	0.98 (0.7)	0.62 (0.4)	0 (0)	8.76 (2.3)	8.08 (2.09)	18.45 (5.0)
Edge	0.03 (0)	0.04 (0)	0 (0)	25.45 (14.3)	35.6 (9.9)	61.12 (21.3)
Gap	11.14 (5.7)	0.28 (0.2)	0.85 (0.6)	33.06 (4.4)	57.75 (9.6)	103.08 (10.1)
15 years posttreatment (2005):						
Untreated	0.51 ((0.4)	0.05 (0)	3.81 (3.8)	2.93 (0.5)	0 (0)	7.3 (4.7)
Edge	0(0)	0 (0)	0 (0)	5.91 (3.2)	0 (0)	5.91 (3.2)
Gap	12.28 (7.8)	0.91 (0.7)	0 (0)	51.72 (5.8)	26.68 (15.4)	91.59 (24.1)
23 years posttreatment (2013):						
Untreated	2.78 (1.6)	1.49 (1.0)	0.02 (0)	19.78 (7.2)	8.36 (1.7)	32.43 (8.6)
Edge	4.28 (3.0)	0.98 (0.6)	0 (0)	69.86 (24.9)	22.44 (5.9)	97.55 (26.8)
Gap	12.78 (5.3)	4.83 (1.9)	0 (0)	122.76 (16.2)	66.66 (23.5)	207.03 (23.9)

Table 2—Mean (and standard error) oven-dry biomass of key forage species for Sitka black-tailed deer following the creation of artificial canopy gaps at the Todd site, Chichagof Island, southeast Alaska. Gaps (n = 9; n = 4 for 2005) were created approximately 58 years after harvest

	<i>Coptis asplenifolia</i>	<i>Cornus canadensis</i>	<i>Rubus pedatus</i>	<i>Tiarella trifoliata</i>	<i>Tsuga heterophylla</i>	<i>Vaccinium</i> spp. twigs	<i>Vaccinium</i> spp. leaves	<i>Mensiezia ferruginea</i> twigs	<i>Mensiezia ferruginea</i> leaves
Kilograms per hectare									
Treatment:									
1 year posttreatment (1991):									
Untreated	NR	NR	NR	NR	0 (0)	7.2 (4.1)	1.79 (1.0)	0.21 (0.2)	0.23 (0.2)
Edge	NR	NR	NR	NR	0 (0)	5.34 (3.9)	1.33 (3.9)	0 (0)	0 (0)
Gap	NR	NR	NR	NR	0 (0)	2.48 (0.7)	2.01 (0.6)	0.14 (0.1)	0.15 (0.2)
5 years posttreatment (1995):									
Untreated	0 (0)	0 (0)	0.01 (0)	0.01 (0)	1.28 (0.5)	3.62 (2.3)	0.9 (0.6)	0.34 (0.3)	0.38 (0.3)
Edge	0 (0)	0 (0)	0 (0)	0 (0)	5.75 (1.6)	1.98 (1.3)	3.07 (2.8)	0.02 (0)	0.02 (0)
Gap	0 (0)	0 (0)	0 (0)	0 (0)	15.15 (2.9)	1.72 (0.8)	1.4 (0.6)	0.18 (0.1)	0.2 (0.1)
10 years posttreatment (2000):									
Untreated	0.06 (0.1)	0.06 (0.1)	0 (0)	0.13 (0.1)	8.05 (2.9)	5.1 (1.2)	1.27 (0.3)	1.12 (0.5)	1.24 (0.6)
Edge	0.03 (0)	0.03 (0)	0 (0)	0 (0)	35.48 (9.9)	18.37 (10.9)	4.59 (2.7)	1.18 (0.6)	1.31 (0.7)
Gap	0.05 (0)	0.05 (0)	0 (0)	0 (0)	57.03 (9.5)	12.16 (1.9)	9.88 (1.5)	4.6 (0.9)	5.11 (1.0)
15 years posttreatment (2005):									
Untreated	0 (0)	0 (0)	0 (0)	0.02 (0)	0 (0)	1.99 (0.4)	0.5 (0.1)	0.21 (0.1)	0.23 (0.1)
Edge	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3.6 (1.9)	0.9 (0.5)	0.67 (0.5)	0.74 (0.5)
Gap	0 (0)	0 (0)	0 (0)	0 (0)	26.68 (15.4)	17.97 (8.4)	14.6 (6.8)	7.13 (2.1)	7.52 (2.3)
23 years posttreatment (2013):									
Untreated	0.02 (0)	0.02 (0)	0.05 (0)	0.13 (0.1)	8.24 (1.7)	12.49 (4.0)	3.12 (1.0)	1.97 (1.2)	2.19 (1.3)
Edge	0 (0)	0 (0)	0 (0)	0 (0)	22.2 (5.8)	33.77 (12.7)	8.44 (3.2)	13.11 (5.8)	14.55 (6.5)
Gap	0.02 (0)	0.02 (0)	0 (0)	0 (0)	63.92 (23.9)	42.17 (5.5)	34.27 (4.4)	21.13 (3.2)	23.46 (3.5)

NR = not recorded.

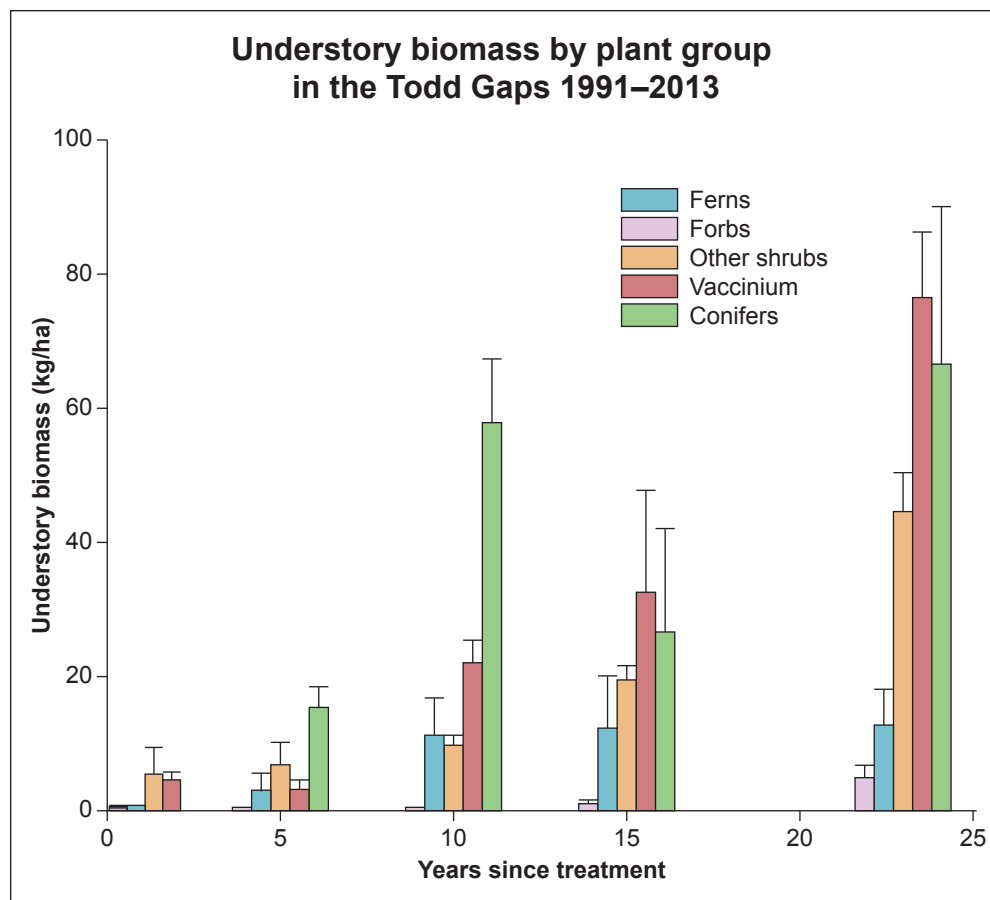


Figure 4—Temporal response, in biomass kilograms per hectare, of functional plant groups to the creation of artificial canopy gaps ($n = 9$) at the Todd study site, Chichagof Island, southeast Alaska. Bars represent the mean biomass in the 9 gaps (with standard error), for each monitoring event at 1, 5, 10, 15, and 23 years following creation of the gaps. The gaps were created in an approximately 58-year-old young-growth forest stand.

(*Picea sitchensis* (Bong.) Carrière) was the only other conifer species observed and never represented more than 5 percent of the biomass of the combined conifer seedling category for any year.

FRESH deer analysis showed that, for the 5 years immediately following treatment, there was no significant difference between deer days per hectare in the gaps versus the untreated forest (tables 3 and 4). At 10 years posttreatment (in 2000), deer days per hectare differed significantly between the gaps and adjacent forest for winter scenarios with 20 cm or more of snow. This was also the case for all summer and winter scenarios for data collected 23 years posttreatment (in 2013). At 23 years posttreatment, estimates of deer days per hectare were higher in the gaps than the untreated forest by a factor of 8.1 times for the summer scenario with one adult female, 3.7 times for the winter 0-cm snow scenario, and 3.4 times for the winter 20-cm snow scenario.

At 23 years posttreatment, estimates of deer days per hectare were higher in the gaps than the untreated forest by a factor of 8.1 times for the summer scenario with one adult female, 3.7 times for the winter 0-cm snow scenario, and 3.4 times for the winter 20-cm snow scenario.

Table 3—Mean (and standard error) deer days per hectare estimated by the FRESH deer model for selected scenarios following the creation of artificial canopy gaps at the Todd site, Chichagof Island, southeast Alaska. Gaps (n = 9; n = 4 for 2005) were created approximately 58 years after harvest

Treatment	n	Maintenance	Maintenance + lactation	0 cm snow	20 cm snow	40 cm snow	60 cm snow	80 cm snow	100 cm snow
<i>Mean (SE)</i>									
1 year posttreatment (1991)									
Untreated	9	4.32 (2.1)	0.66 (0.2)	5.99 (3.4)	5.99 (3.4)	5.62 (3.2)	4.84 (2.8)	4.05 (2.3)	3.27 (1.9)
Edge	9	1.33 (0.9)	0 (0)	4.44 (3.3)	4.44 (3.3)	4.16 (3.1)	3.58 (2.6)	3.0 (2.2)	2.43 (1.8)
Gap	9	3.24 (0.9)	0.80 (0.5)	2.06 (0.6)	2.06 (0.6)	2.0 (0.5)	1.72 (0.5)	1.4 (0.4)	1.17 (0.3)
5 years posttreatment (1995)									
Untreated	9	3.67 (1.7)	1.19 (0.7)	4.19 (2.0)	3.06 (1.9)	2.83 (1.8)	2.43 (1.6)	2.04 (1.3)	1.64 (1.0)
Edge	9	3.7 (3.3)	0.16 (0.1)	1.74 (1.0)	1.74 (1.0)	1.55 (1.0)	1.33 (0.9)	1.12 (0.7)	0.90 (0.6)
Gap	9	10.05 (5.9)	4.48 (3.9)	2.71 (1.0)	1.48 (0.6)	1.39 (0.6)	1.20 (0.5)	1.0 (0.42)	0.81 (0.34)
10 years posttreatment (2000)									
Untreated	9	5.64 (1.9)	0.84 (0.4)	7.01 (2.3)	4.24 (1.03) ^a	3.98 (1.0) ^a	3.42 (0.8) ^a	2.85 (0.7)	2.32 (0.6) ^a
Edge	9	8.29 (4.3)	0.3 (0)	15.39 (9.0)	15.27 (9.0)	13.74 (8.6)	11.83 (7.4)	9.92 (6.2)	8.0 (5.0)
Gap	9	34.46 (6.7)	2.61 (0.9)	11.24 (1.4)	10.11 (1.6) ^a	9.49 (1.5) ^a	8.17 (1.3) ^a	5.73 (1.0)	5.52 (0.9) ^a
15 years posttreatment (2005)									
Untreated	4	4.99 (4.2)	2.29 (2.2)	1.95 (0.3)	1.66 (0.3)	1.56 (0.3)	1.34 (0.3)	1.12 (0.2)	0.91 (0.2)
Edge	4	1.97 (1.1)	0 (0)	2.99 (1.6)	2.99 (1.6)	2.8 (1.5)	2.42 (1.3)	2.03 (1.1)	1.64 (0.9)
Gap	4	45.88 (14.1)	8.88 (3.9)	35.1 (22.1)	14.94 (7.0)	13.79 (6.6)	12.07 (5.7)	10.12 (4.7)	7.85 (3.9)
23 years posttreatment (2013)									
Untreated	9	12.81 (4.0) ^a	2.47 (1.1) ^a	18.45 (5.7) ^a	10.39 (3.3) ^a	9.75 (3.1) ^a	8.34 (2.7) ^a	7.03 (2.3) ^a	5.86 (1.8) ^a
Edge	9	38.13 (14.7)	3.89 (2.1)	41.99 (18.1)	28.07 (10.6)	26.3 (9.9)	22.46 (8.5)	18.57 (7.2)	14.79 (5.8)
Gap	9	104.29 (14.8) ^a	17.81 (5.3) ^a	68.51 (13.3) ^a	35.06 (4.5) ^a	32.91 (4.3) ^a	28.33 (9.3) ^a	23.74 (3.1) ^a	19.16 (2.5) ^a

^a Results with mean differences that are significantly different from zero in pairwise tests. $\alpha = 0.05$. Edge quadrats were not tested. SE = standard error.

Table 4—Mean (and p value for tested comparisons), deer days per hectare estimated by the FRESH deer model for selected scenarios following the creation of artificial canopy gaps at the Todd site, Chichagof Island, southeast Alaska. Gaps (n = 9; n = 4 for 2005) were created approximately 58 years after harvest

Treatment	Maintenance	Maintenance + lactation	0 cm snow	20 cm snow	40 cm snow	60 cm snow	80 cm snow	100 cm snow
<i>Mean (Pr > S)</i>								
1 year posttreatment (1991):								
Untreated	4.32 (0.94)	0.66 (0.57)	5.99 (0.29)	5.99 (0.29)	5.62 (0.46)	4.84 (0.46)	4.05 (0.46)	3.27 (0.46)
Gap	3.24 (0.94)	0.80 (0.57)	2.06 (0.29)	2.06 (0.29)	2.0 (0.46)	1.72 (0.46)	1.4 (0.46)	1.17 (0.46)
5 years posttreatment (1995):								
Untreated	3.67 (0.37)	1.19 (0.93)	4.19 (0.64)	3.06 (0.94)	2.83 (1.0)	2.43 (1.0)	2.04 (1.0)	1.64 (1.0)
Gap	10.05 (0.37)	4.48 (0.93)	2.71 (0.64)	1.48 (0.94)	1.39 (1.0)	1.20 (1.0)	1.0 (1.0)	0.81 (1.0)
10 years posttreatment (2000):								
Untreated	5.64 (0.1)	0.84 (0.1)	7.01 (0.16)	4.24 (0.01) ^a	3.98 (0.01) ^a	3.42 0.01) ^a	2.85 (0.05)	2.32 (0.01) ^a
Gap	34.46 (0.1)	2.61 (0.1)	11.24 (0.16)	10.11 (0.01) ^a	9.49 (0.01) ^a	8.17 (0.01) ^a	5.73 (0.05)	5.52 (0.01) ^a
15 years posttreatment (2005):								
Untreated	4.99 (0.12)	2.29 (0.12)	1.95 (0.12)	1.66 (0.25)	1.56 (0.12)	1.34 (0.12)	1.12 (0.12)	0.91 (0.12)
Gap	45.88 (0.12)	8.88 (0.12)	35.1 (0.12)	14.94 (0.25)	13.79 (0.12)	12.07 (0.12)	10.12 (0.12)	7.85 (0.12)
23 years posttreatment (2013):								
Untreated	12.81 (>0.01) ^a	2.47 (>0.01) ^a	18.45 (>0.01) ^a	10.39 (0.01) ^a	9.75 (>0.01) ^a	8.34 (>0.01) ^a	7.03 (>0.01) ^a	5.86 (>0.01) ^a
Gap	104.29 (>0.01) ^a	17.81 (>0.01) ^a	68.51 (>0.01) ^a	35.06 (0.015) ^a	32.91 (>0.01) ^a	28.33 (>0.01) ^a	23.74 (>0.01) ^a	19.16 (>0.01) ^a

^a = Results with mean differences that are significantly different from the test statistic in pairwise tests. $\alpha = 0.05$. Edge quadrats were not tested.

The edge quadrat on the monitoring transect is included to monitor the effect of side lighting on understory vegetation response. Side lighting is oblique light from the canopy gap opening coming into the surrounding untreated densely shaded forest. Areas affected by side lighting increase the total area affected by the canopy gap treatments. There is only one edge quadrat per transect, so we did not conduct statistical tests comparing the edge with the gap or untreated forest data. The edge quadrats had higher total plant biomass than the untreated forest quadrats at 5, 10, and 23 years posttreatment.

We only had hemispherical photos taken in 2013 (23 years posttreatment) for use in this study, so we used the CCI from 2013 for the FRESH deer winter scenarios for all years analyzed. The average CCI in the both the gaps and untreated forest was estimated to be 89 percent (fig. 5). Qualitative observations of changes in canopy gaps following treatments throughout southeast Alaska allow us to suggest that CCI was likely lower; in other words, the canopy was more open in the Todd gaps prior to 2013. Using the higher CCI estimate (from 2013) for all years was unlikely to substantially influence estimates of available forage estimated by FRESH because it is at 90 percent and greater where CCI makes a large difference in the snow interception estimates by FRESH.

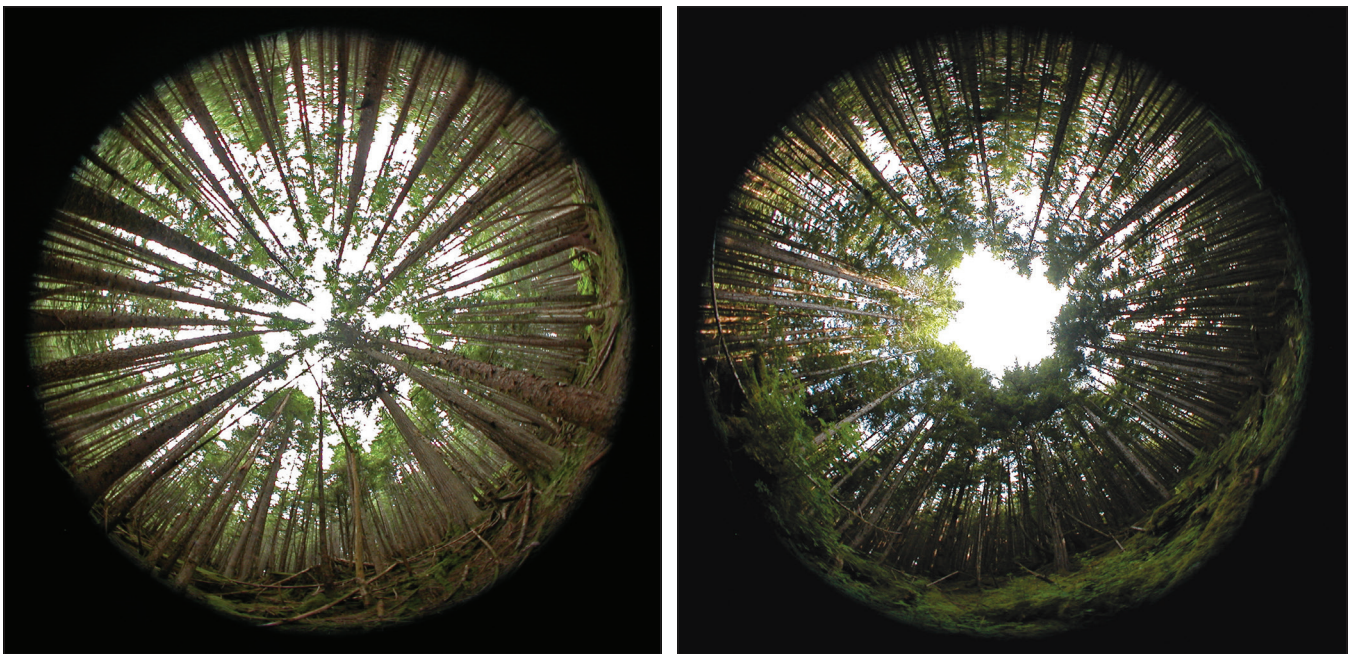


Figure 5—Typical hemispherical canopy photos from the Todd study site of the untreated forest (left) and treated gap (right) from 2013, 23 years posttreatment; stand age is approximately 81 years. Both images are 89-percent canopy cover index (CCI).

Discussion

In any discussion of habitat treatments, two of the most important considerations are magnitude and persistence of the treatment effect. Empirical studies of both thinning and gap treatments in southeast Alaska, including the Todd study, consistently show an increase in understory vegetation following treatment. For comparison, the only other study of canopy gaps in southeast Alaska is Alaback's (2010) unpublished study of 76 gaps created in stands age 13 to 41 (median 23) years on Prince of Wales Island. He found a strong understory response in the gaps 20 years posttreatment, with forb and *Vaccinium* biomass significantly higher than controls. For the winter no-snow scenario, he used FRESH deer to estimate 44 deer days per hectare. He did not report winter results with snow.

We can also draw some inferences about gap treatments in southeast Alaska by comparing with thinning studies in similar age stands. Figures 6 and 7 compare the FRESH deer days per hectare for the winter no-snow and winter 20-cm snow scenarios, from 3 thinning studies, 2 gap studies, and an old-growth forest reference condition from southeast Alaska. The old-growth reference is calculated from biomass data for the "blueberry-bunchberry" community type from Hanley and Brady (1997).

The Tongass Wide Young Growth Study⁵ (TWYGS) experiment 4 treated stands at a mean age of 35 years. The data presented are the mean results from 23-foot-spaced thinned stands with three different slash treatments (Hanley et al. 2013). At 5 years posttreatment, TWYGS 4 biomass was 5 to 10 times greater than Todd, and estimated deer days per hectare were greater for the winter 0-cm snow scenario (77 for TWYGS versus 3 for the Todd gaps) and the winter 20-cm snow scenario (14 for TWYGS versus 1 for the Todd gaps). At 10 years posttreatment (see footnote 4), understory biomass was about 10 times greater than in the Todd gaps. Deer days per hectare for the winter 0-cm snow scenario were higher (214 for TWYGS versus 11 for the Todd gaps) but lower for the winter 20-cm snow scenario (5 for TWYGS versus 10 for Todd gaps).

Results from the Prince of Wales commercial thinning study are available only for 5 years posttreatment. Biomass and deer days per hectare estimates are the mean of three thinning treatments in stands age 52 to 73 years at treatment: crown thinning (103 trees per acre, or tpa) thinning of dominants (134 tpa) and thinning from below (68 tpa). Biomass was greater than the Todd 5-year results, about six times overall. Deer days per hectare for the winter 0-cm snow scenario were higher

⁵ Hanley, T.A. 2014. Unpublished data from the SGMP study. On file with: USDA Forest Service, Pacific Northwest Research Station, 11175 Auke Lake Way, Juneau, AK 99801.

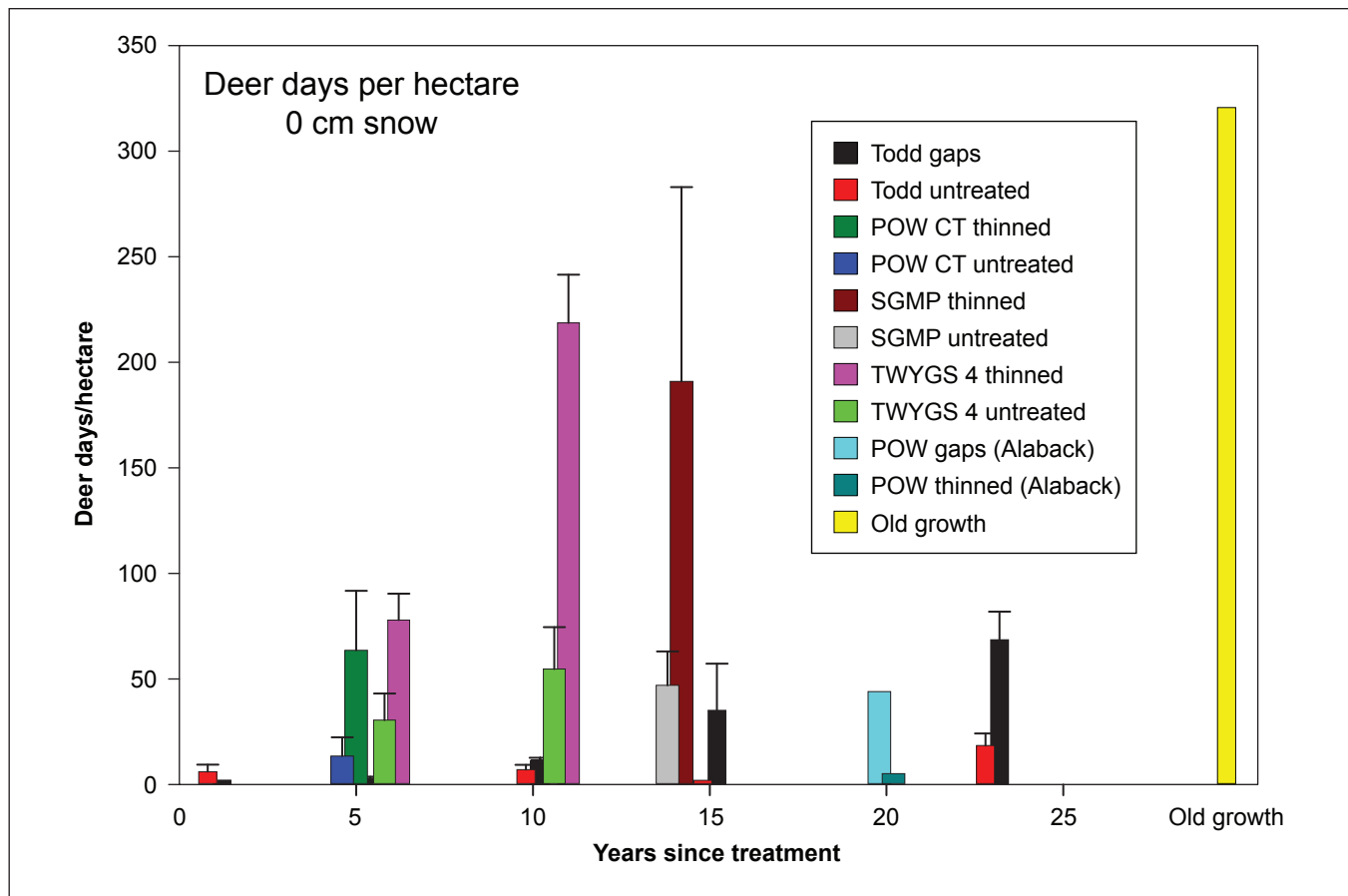


Figure 6—Comparison of deer days per hectare (with standard error) calculated by the FRESH deer model for the winter 0-cm snow scenario for the Todd gaps and adjacent untreated forest, with other thinning and gap studies, and old-growth conditions in southeast Alaska. The Todd gaps ($n = 1$) were created in a 58-year-old stand. The POW commercial thinning (with 3 types of thinning treatments), ($n = 3$) occurred in stands 52 to 73 years old. The SGMP thinning treatments (thinned $n = 4$, unthinned $n = 5$) occurred in stands >56 years old. The TWYGS 4 treatments (thinning with 2 types of slash treatments, $n = 17$) occurred in stands with a mean age of 35 years old. The POW gaps are from Alaback's (2010) study. The POW gaps ($n = 76$) were created in stands aged 13 to 41 years old. Alaback's POW study also included measurements in thinned stands ($n = 29$) of the same age. Old growth (Hanley and Brady 1997) is a dataset for the "blueberry-bunchberry" plant community type for old-growth forest conditions.

(63 for the commercial thinning study versus 3 for the Todd gaps) but lower for the winter 20-cm snow scenario (less than 1 for the commercial thinning study versus 1 for the Todd gaps).

The other thinning study of similar stand age is the second-growth management demonstration project (SGMP) (Zaborske et al. 2002). Results are from 14 years posttreatment. Treatments included thinning at 20- to 25-foot spacing in stands age 49 to 64 at treatment. At 14 years posttreatment, thinned stands showed a strong treatment response compared to untreated controls. Hanley (footnote 5) recalculated the original published FRESH deer days results. The updated FRESH deer days results showed the same pattern as the other thinning studies. Compared to the 15-year posttreatment Todd results, deer days per hectare for the winter 0-cm snow

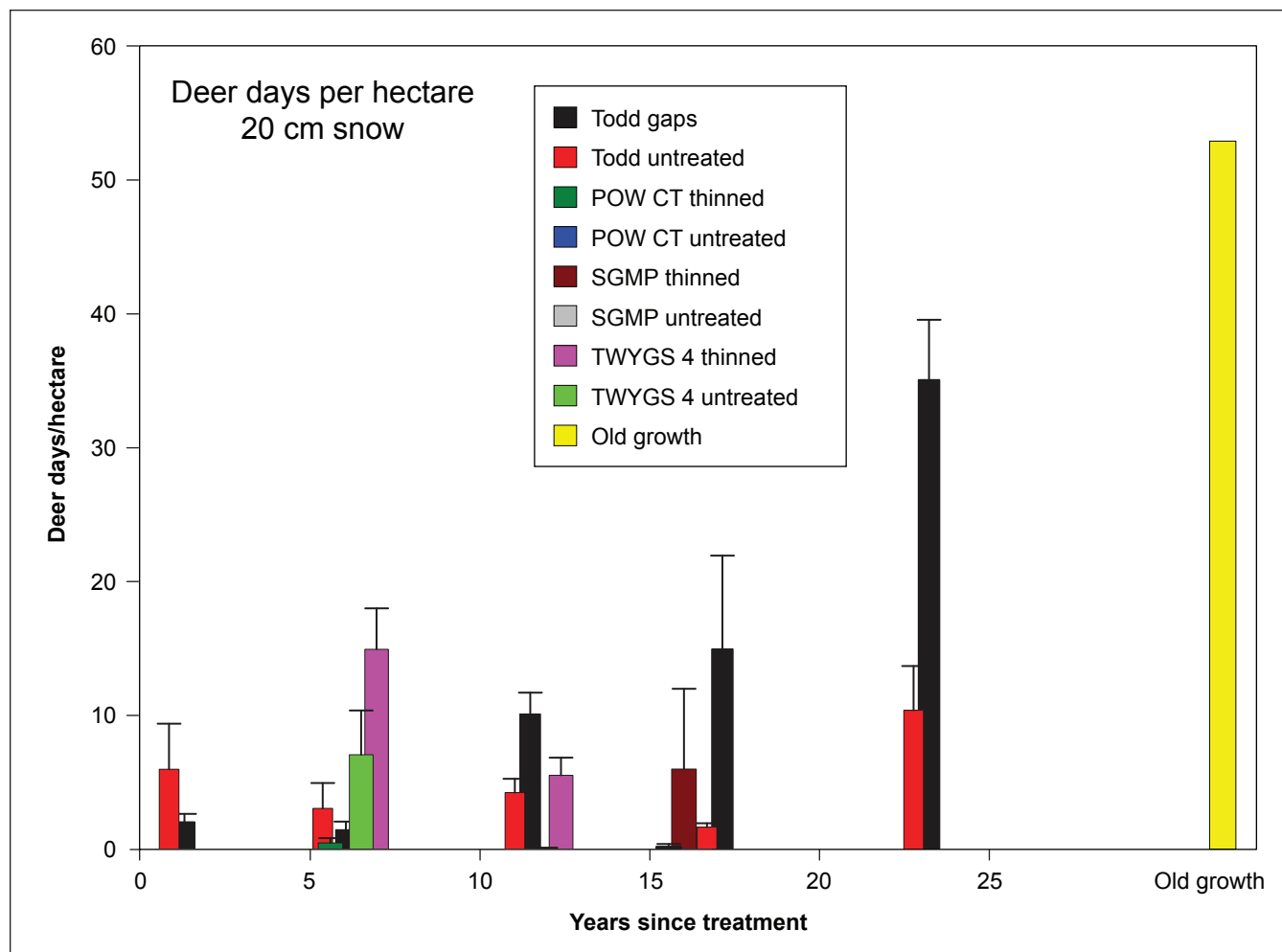


Figure 7—Comparison of deer days per hectare (with standard error) calculated by the FRESH deer model for the winter 20-cm snow scenario for the Todd gaps and adjacent untreated forest, with other thinning studies, and old-growth conditions in southeast Alaska. The Todd gaps ($n = 1$) were created in a 58-year-old stand. The POW CT thinning ($n = 3$) (with 3 types of thinning treatments) occurred in stands 52 to 73 years old. The SGMP thinning treatments (thinned $n = 4$, unthinned $n = 5$) occurred in stands >56 years old. The TWYGS 4 treatments (thinning with 2 slash treatments, $n = 17$) occurred in stands 35 years old. Old growth (Hanley and Brady 1997) is a dataset for the “blueberry-bunchberry” plant community type for old-growth forest conditions.

scenario were higher (191 for SGMP versus 35 for the Todd gaps) but lower for the winter 20-cm snow scenario (6 for SGMP versus 15 for the Todd gaps).

These comparisons with thinned treatments show a general pattern. The three thinning studies discussed had more deer days per hectare than the Todd gaps for the two summer scenarios (not shown in figures) and winter no-snow scenario, but fewer deer days per hectare than the Todd gaps for the winter 20-cm snow scenario. The thinned and gap treatments all show a delayed forb response compared to the shrubs and conifers. At 20 cm of snow, the evergreen forbs are buried and only *Vaccinium* and a few other shrub twigs and conifer seedlings, saplings, and branches are available as forage.

The thinning studies discussed for the most part have observations for only a few years posttreatment, so they do not yet offer much insight on the persistence of treatment effect. Alaback's (2010) gap study on Prince of Wales Island included understory plant measurements in 29 thinned stands with similar site characteristics as the gaps in the same study. These 20-year posttreatment measurements showed that understory plants were nearly undetectable under the forest canopy that had closed in the years following the thinning treatments.

The rapid growth of conifer seedlings in thinned and gapped stands has been suggested to reduce the habitat benefits of both treatments. For the Prince of Wales Island gap study, Alaback (2010) divided gaps into three size classes: small, medium, and large (<250 to 1100 m²). His analysis found no significant differences in species richness, biomass, percentage of cover, or tree seedling density among the three groups of gaps. He had expected to see greater rates of tree colonization in the larger gaps but instead found them highly variable. This is significant because Deal and Farr (1994) observed that increased light into thinned or clearcut stands will promote the rapid growth of conifer seedlings (often called "hemlock flush") that can shade out other understory vegetation. Cole et al. (2010) observed similar effects in a 7-year posttreatment study. The Todd gaps initially followed this pattern. The biomass of conifer seedlings exceeded shrub biomass for the first 10 years following treatment, and subsequently trailed behind shrubs for the remaining measurements. We would expect understory plants in the small Todd gaps (150 to 430 m²) to receive less light than in the Prince of Wales commercial thinning and TWYGS experiment 4 thinned stands with relatively wide spacing, so it is reasonable to expect the understory response to be greater at age 5 and 10 for the thinned stands. Additionally, with only 5 and 10 years of monitoring data available for the Prince of Wales and TWYGS experiment 4 studies, it is too early to reach conclusions about the eventual conifer growth in the treatments.

We used canopy cover index (CCI) as input to the FRESH deer model to estimate the canopy interception of snow for this study. However, CCI does not characterize the light environment experienced by understory plants very well. Better light-environment information would come by collecting standard forestry overstory data and leaf area index measurements. Besides bringing more light into the treated area, we would assume that treatments bring more light into the adjacent untreated forest (side lighting). For our study, we did see greater shrub and conifer response compared to the untreated forest for the edge quadrats by year 23; but we did not do statistical analysis because of the small sample size. Alaback (2010) in his Prince of Wales Island gap study wasn't able to detect any significant side-lighting effect on shrubs in his analysis.

Herbivory by deer can influence the measured plant response to thinning or gap treatments. Hanley and Barnard (2014) discussed the results of simulated herbivory experiments on understory plants and warn that the larger landscape context must be considered when designing silviculture treatments. Small, resource-rich areas such as canopy gaps surrounded by lower quality habitat can focus herbivory on the small treated areas, which could decrease the measured effects of the treatments. McClellan et al. (2014) visited various field sites in the Peril Strait area in 2006, including some of the Todd gaps. In the gaps they observed abundant light but lower than expected understory vegetation and evidence of heavy deer browse of the vegetation, including western hemlock



Figure 8—Heavily browsed understory vegetation (western hemlock and *Vaccinium*) in one of the Todd study site artificial gaps on Chichagof Island, southeast Alaska. July 2006.

The most significant result of the Todd study is the persistence of the treatment effect. That is, understory plant biomass and deer days per hectare have steadily increased over the 23-year period following treatment and are consistently higher than in the adjacent untreated forest.

seedlings (fig. 8). Similar to the results of the Hanley and Barnard (2014) study, they suggested that the large extent of forest in the stem exclusion phase that surrounded the gaps and the associated depauperate understory attracted deer to the more abundant understory vegetation available in the gaps. This browse activity suggests that our estimates of biomass and deer days per hectare in the Todd gaps are likely underestimates of the response.

In addition to the differences in the light conditions experienced by understory plants, factors such as stand history, soils (and associated site productivity), topography, hydrology, and animal interactions, including herbivory, can play major roles in the observed variability. Further work is needed to help clarify these interactions. Additionally, the Todd gap treatment sites were chosen to maximize the understory response. Managers viewed the treatments as demonstrations of concept rather than experimental units. Even with these caveats, the most significant result of the Todd study is the persistence of the treatment effect. That is, understory plant biomass and deer days per hectare have steadily increased over the 23-year period following treatment and are consistently higher than in the adjacent untreated forest. The data show no apparent peak for both these measures.

Mike McClellan

Conclusions

Our results show that 23 years following the Todd gap treatments, understory plant biomass and forage resources for deer are higher in the Todd gaps than in the adjacent untreated forest. Estimates of both understory plant biomass and deer days per hectare in the gaps increased throughout the 23-year monitoring period without reaching an apparent peak. Comparing the Todd results with three thinning studies, the FRESH deer model estimated that deer days per hectare were lower in the Todd gaps for the summer and no-snow scenarios, but higher for the winter 20-cm snow scenario. However, we can only make limited conclusions about comparisons with thinning studies, because the thinning studies have data available only for 14 years posttreatment.

The results from the Todd gap study are from only one stand, so results should not be considered representative of southeast Alaska. This study adds important information to our understanding of canopy gap treatments and the dynamics of older young-growth stands. The persistence of the understory plant response in gap treatments is particularly encouraging. The empirical results from both the Alaback and Todd studies suggest that canopy gaps are a viable treatment option to improve forage resources for deer in young-growth forest stands, including older stands such as the Todd site.

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English Equivalents

When you know:	Multiply by:	To find:
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Hectares (ha)	2.47	Acres
Square meters (m ²)	10.76	Square feet
Grams (g)	0.0352	Ounces
Kilograms (kg)	2.205	Pounds

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Appendix: Scientific and Common Names of Plant Species in This Publication^a

Scientific name	Common name
<i>Coptis asplenifolia</i> Salisb.	Fernleaf goldthread
<i>Cornus canadensis</i> L.	Bunchberry dogwood
<i>Menziesia ferruginea</i> Sm.	Rusty menziesia
<i>Oplopanax horridus</i> (Sm.) Miq.	Devils club
<i>Picea sitchensis</i> (Bong.) Carrière	Sitka spruce
<i>Ribes bracteosum</i> Douglas ex Hook.	Stink currant
<i>Rubus pedatus</i> Sm.	Strawberryleaf raspberry
<i>Rubus spectabilis</i> Pursh	Salmonberry
<i>Sambucus racemosa</i> L.	Red elderberry
<i>Tiarella trifoliata</i> L.	Threeleaf foamflower
<i>Tsuga heterophylla</i> (Raf.) Sarg.	Western hemlock
<i>Vaccinium ovalifolium</i> Sm.	Oval-leaf blueberry
<i>Vaccinium parvifolium</i> Sm.	Red huckleberry

^a Source: Hitchcock and Cronquist (1973) for the Todd protocol and online USDA Plants database for the Prince of Wales Island Commercial Thinning data.

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