

The Effects of Tree Thinning and Broadcast Burning on the Quality of Ungulate Winter Range: a case study within a Southern Interior Forest in British Columbia

by
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Abstract

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Food limitation on ungulate winter range (UWR) has been a suspected factor in the regional declines of *Odocoileus hemionus* (mule deer) in the Pacific Northwest. Accordingly, enhancing browse resources in this critical habitat is increasingly recommended. At a dry forest site in Southeast B.C. called Fiva Creek (IDF dm1), I investigated the effects of two commonly prescribed methods for enhancing browse production: tree thinning and prescribed burning. Treatments were implemented between 2005–2008 and included three levels of thinning (all burned) and control areas (uncut and unburned). The response variables I measured included browse cover, canopy closure, security cover, visibility, and pellet abundance. I also evaluated browsing pressure on the indicator plant, Saskatoon (*Amelanchier alnifolia*). Using linear mixed-effects ANOVA tests, I assessed how thinning (with follow-up burning) influenced forest and vegetation properties. There was no evidence of a treatment effect on browse production; however, browsing pressure was very high across the site (i.e., > 80% of *A. alnifolia* twigs showed evidence of browsing). Additionally, canopy cover was below recommended levels in all thinned treatments. My results suggested that restoration treatments actually diminished the quality of UWR at Fiva Creek. Further investigations are needed to develop effective UWR restoration methods.

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The field season of 2017 happened to fall within a record breaking hot, dry, and fire-scorched summer. Conditions in southern B.C.'s Christian Valley were no exception. Some days were clear, sunny, and +30 °C while others were enveloped by a thick smoky haze—a reminder of the severe fire season wreaking havoc across B.C. Needless to say, I'd like to pay homage to the incredible people who gave their time and sweat over long days in challenging conditions to help me conduct this research. Lisa Tedesco and Pat Stent (FLNRORD) put boots on the ground for several days in addition to sponsoring my MSc research, loaning me gear, offering guidance, and assisting with the logistics of coordinating rural field work. Jesse Foster was his characteristic—exceptionally helpful—self and worked flat out for three days to make this project feasible, and Kaitlin Hancock generously volunteered to help me complete the final stretch of sampling.

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List of Acronyms

B.C.	British Columbia
BEC	Biogeoclimatic
eDNA	Environmental DNA
IDF dm1	Kettle Dry Mild Interior Douglas-fir (BEC subzone)
FLNRORD	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
UWR	Ungulate Winter Range

1 Introduction

1.1 The Importance of Mule Deer

Across western North America from Mexico to Alaska *Odocoileus hemionus* (mule deer) have long played important ecological and cultural roles (Figure 1) (e.g., Hobbs 1996; Blood 2000; Kuhnlein and Humphries 2017). Large herbivores affect the physical structure and heterogeneity of ecosystems (Hobbs 1996; Gordon et al. 2004; Frerker et al. 2013; Foster et al. 2014); they can alter abiotic disturbance regimes, and they can function as ecological switches that direct the transition between alternative ecosystem states (Hobbs 1996; Gordon et al. 2004). In addition, mule deer support a variety of predators. For example, Blood (2000) describes how many cougar and wolf populations depend on this species while bears, bobcats, coyotes, wolverines, ravens, magpies and more opportunistically supplement their diets with mule deer. Beyond ecological functions, mule deer represent a culturally significant animal. Having provided a traditional source of food, clothing, and tools for thousands of years (Blood 2000; Kuhnlein and Humphries 2017), mule deer are embedded in the cultural fabric of several First Nations of western North America.

Mule deer are also a key aspect of the conservation paradigm in the American Northwest where they are a valued big-game animal that supports a major hunting industry and many rural communities (e.g., Blood 2000; deVos 2003; Gordon et al. 2004; Bergman et al. 2011; Bergman 2013). For instance, the revenue generated from deer license sales in Colorado alone was roughly \$15.36 million (USD) in 1998 (Bergman et al. 2011). Such revenue helps fund conservation programs that benefit numerous species (deVos 2003).

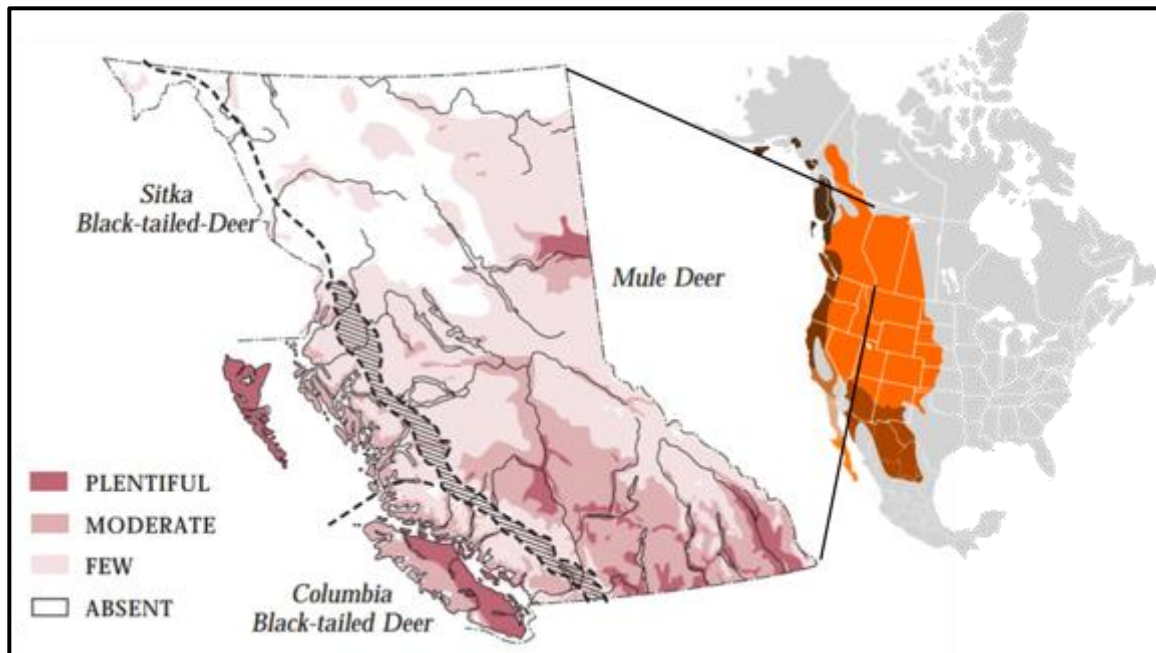


Figure 1. Global and provincial (British Columbia) distribution of mule deer (*Odocoileus hemionus*) subspecies modified from Feldhamer et al. 2003 and Blood 2000, respectively. Abundance levels of *O. hemionus* throughout British Columbia are indicated by colour from white (absent) to dark red (plentiful). Dashed lines represent range divisions between the three subspecies: *O. hemionus hemionus* (Rocky Mountain mule deer—the focus of this research), *O. h. sitkensis* (Sitka Black-tailed deer), and *O. h. columbianus* (Columbia Black-tailed deer). Distinct shades on the global map indicate ranges for 7 of the 10 subspecies.

Moreover, mule deer are an iconic animal (Bergman 2013, Bergman et al. 2014). While difficult to quantify, there is social value that stems from the public's frequent encounters and observations of this charismatic species (Blood 2000). Indeed, mule deer are considered one of North America's most economically and socially important animals (Keegan et al. 2011). Accordingly, sustainable management is a major responsibility and it requires a deep understanding of the unique ecology and life-history requirements of this species.

1.2 Mule Deer Ecology and the Role of Winter Range

Fortunately, mule deer have been the focus of extensive ecological research and reviews (e.g., Thomas 1979; Parker et al. 1984, 1999; Armleder et al. 1994; Gill et al. 1999; Peek et al. 2002; D'eon 2004; Hayden et al. 2008; Serrouya and D'eon 2008; Bergman 2013) and several key features that influence the functional effect of habitat on deer survival and productivity are well described (e.g., Parker et al. 1984; UWRTAT 2005; Serrouya and D'eon 2008; Bishop et al. 2009; Bergman 2013; Bergman et al. 2014; Gilbert et al. 2017). Emergent from this research is the critical role that winter plays in affecting mule deer survival and productivity in regions with high snowfall (Thomas 1979; Parker et al. 1984, 2009; Armleder et al. 1994, UWRTAT 2005; Hayden et al. 2008; Bergman 2013; Gilbert et al. 2017).

Analyses of diet and energetics (e.g., Parker et al. 1984, 1999; Serrouya and D'eon 2008; Bishop et al. 2009; Monteith et al. 2013) and extensive tracking and range mapping (e.g., Armleder et al. 1994; Poole and Mowat 2005; Serrouya and D'eon 2008; Gilbert et al. 2017) have demonstrated the functional importance of winter range for mule deer. Survival and productivity reflect a balance in the ability of deer to attenuate energy losses through maximizing quality forage intake while minimizing the energetic expense of locomotion through sinking snow (Parker et al. 1984; Armleder et al. 1986; UWRTAT 2005). Both of these factors need consideration because together they largely determine the balance of winter energy budgets (Armleder et al. 1986; Poole and Mowat 2005). Simply put, mule deer in northern ecosystems have a critical need for habitat with attributes that minimize bioenergetic losses during winter (Armleder et al. 1984); this "habitat" is termed Ungulate Winter Range (UWR).

While each season plays an important role in mule deer survival and productivity (Parker et al. 1999, 2009; D'eon 2004; Hayden et al. 2008; Serrouya and D'eon 2008; Monteith et al. 2013), the availability of refuge habitat with adequate food resources during winter is generally considered the most important limiting factor to mule deer populations in regions with high snowfall (Armleder et al. 1986; Hayden et al. 2008; Bergman 2013). Winter conditions are more severe relative to other seasons and both food availability and nutritional quality is lowest during this period (Parker et al. 1999, 2009; Bishop et al. 2009). As snow accumulates, food resources become buried, and locomotion through sinking snow dramatically increases energetic demands (Parker et al. 1984; Armleder et al. 1986; UWRTAT 2005). Consequently, deer body-fat reserves are depleted during winter months (Parker et al. 1999) with adult deer typically experiencing the greatest proportion of starvation and predation mortality through this period (Patterson and Power 2002; Monteith et al. 2013). Beyond increasing the risk of mortality, decreased body condition in winter (from the depletion of body fat reserves) has implications for individual and population-level productivity.

The body condition of female mule deer has direct consequences on the timing of birth, mass of offspring, and early survival of offspring (Parker et al. 2009; Monteith et al. 2013). In a study of *Rangifer* (caribou)—a fellow member of the Capreolinae subfamily—changes in body fat over winter was the most important factor that influenced whether females died, lived without reproducing, or lived and reproduced (Parker et al. 2009). Thus, the added energy requirements for gestating ungulates during winter exacerbates the functional importance of quality winter range (Pekins et al. 1998).

1.2.1 The Function of the Forest Canopy

In B.C., the idea that canopy cover may limit deer populations has dominated UWR policy (Serrouya and D'eon 2008). More broadly, in the Pacific Northwest there is a long-standing paradigm (Poole and Mowat 2005; Serrouya and D'eon 2008) of UWR management focused on maintaining closed-canopy forests to intercept snow (e.g., Thomas 1979; Armleder et al. 1986). Maintaining mature forests on UWR has major economic implications for the B.C. forest industry (Poole and Mowat 2005), and an emphasis on canopy cover can miss other important factors like browse quantity and quality (Parker et al. 1999; Peek et al. 2001; Poole and Mowat 2005; Serrouya and D'eon 2008). Nevertheless, the relationship between canopy closure and snow depth is of great importance to mule deer, as snow depth is the dominant driver of deer habitat selection in winter (Gilbert et al. 2017).

Heavy snow accumulation forces deer to seek habitat with critical refuge attributes essentially demonstrating the functional capacity of winter range. Snow depths, or more appropriately, sinking depths (Parker et al. 1984), ultimately determine the winter distributions of mule deer and other ungulates (Poole and Mowat 2005; Gilbert et al. 2017) and can regulate the carrying capacity of winter range in northern montane areas (Bergman 2013). Accordingly, guidelines to direct UWR management are pragmatically tied to snow depths (Table 1). In general, altering the forest canopy (e.g., by cutting trees) directly influences snow depths (Armleder et al. 1998; D'eon 2004). However, several factors influence the relationship between canopy closure and snow depth: including tree species and stand structure (Parker et al. 1984; Poole and Mowat 2005; Serrouya and D'eon 2008), aspect and slope (Armleder et al. 1986, 1994; D'eon 2004), and elevation (D'eon 2004). For instance, tree canopies at lower elevations and on warmer aspects demonstrate a stronger moderating effect on snow depth than

canopies at higher elevations and on cooler aspects (D'eon 2004). Sinking depths of 25 cm are sufficient to restrict mule deer movement while depths of 50+ cm severely restrict movement (Parker et al. 1984; UWRTAT 2005) and are selected against (Armleder et al. 1994; Serrouya and D'eon 2008; Gilbert et al. 2017). The latter depth is considered a critical threshold for mule deer mobility (UWRTAT 2005).

Table 1. Recommended stratification of ungulate winter range in relation to animal mobility, forage access, and habitat management guidelines. Table and descriptions modified from UWRTAT (2005).

Ungulate Winter Range Strata¹	Snow Depths	Animal Mobility and Access to Available Forage	Desired Conditions Objectives, Measures, Strategies
<i>Mild</i> winter range	Very shallow ² to shallow ³	High	Primarily forage-driven
<i>Moderate</i> winter range	Moderate ⁴	Medium	Provision of both forage and snow interception cover
<i>Severe</i> winter range	Deep ⁵	Low	Strongly snow interception cover-driven, but with provision of forage

¹ Ungulate Winter Range strata are based on typical winter snow depths (described below) and species-specific abilities (i.e., > 25 cm of snow typically inhibits mule deer while > 50 cm is considered a critical depth that severely restricts movements).

² Almost never deep enough to inhibit mule deer movements for several days

³ Occasionally deep enough to inhibit mule deer movements but rarely reaches critical depths for several days.

⁴ Depths sufficient to inhibit mule deer movements for periods of several days to weeks most winters. Snow occasionally reaches critical depth for several days.

⁵ Regularly exceeds depths sufficient to inhibit movements and reaches critical depths for mule deer for a period of weeks to months every year.

Beyond affecting snow depths, canopy cover plays another important role: it influences the nutritional balance of mule deer by controlling the amount of available

forage in the understorey (Gill et al. 1999). Canopy cover is inversely related to rooted forage abundance (Peek et al. 2001). Yet, the effect of the forest canopy on winter food availability is not straightforward. With heavy snowfall, the availability of ground level forage declines more rapidly in exposed areas than underneath the forest canopy where browse is less likely to be buried (Harestad 1985). Additionally, mature tree stands (i.e., age-classes of 100+ years) of *Pseudotsuga menziesii* (Douglas-fir) and *Thuja plicata* (western redcedar) tend to provide a source of winter forage through litterfall and arboreal lichens (Parker et al. 1984; Armleder et al. 1986, 1994; Waterhouse et al. 1991). However, the nutritional value of tree foliage relative to understorey shrubs is an important consideration and there tends to be greater digestible energy in the latter (Robbins 1993 as cited in Parker et al. 1999). Thus, mule deer appear to derive a nutritional benefit from a winter diet higher in shrub rather than conifer content (Serrouya and D'eon 2008). Further, forage plants growing in early successional ecosystems (i.e., shade intolerant species) rather than late successional ecosystems (i.e., shade tolerant species) in the Pacific Northwest produced greater levels of digestible energy content for *Cervus elaphus* (elk) (Cook et al. 2016). Because mule deer have proportionately smaller digestive organs than elk, forage quality is of greater importance for deer and they must be more selective browsers than elk (Gill et al. 1999). Thus, in addition to areas with high canopy cover and correspondingly high snow interception, an interspersed mosaic of areas with low cover (and associated early successional plant communities) within the landscape is important to mule deer because of the increased abundance of quality forage that these areas provide (Poole and Mowat 2005; Serrouya and D'eon 2008; Gilbert et al. 2017). There is a growing recognition of the need to manage UWR for food availability and nutritional quality in addition to meeting snow depth requirements (Poole and Mowat 2005; Serrouya and D'eon 2008). Because the value of winter range to wildlife can be completely reversed as a consequence of snow

depths (Gilbert et al. 2017), it is important that habitat attributes like refuge and forage are interspersed and connected at the landscape level (Armleder and Dawson 1992).

1.2.2 Further Factors Affecting the Quality of UWR

Beyond forage availability and energetic considerations around snow levels, there are other factors that contribute to the quality of UWR. Vegetation not only provides forage but also shelter from wind and precipitation (i.e., thermal cover) and visual protection from predators (i.e., security cover) (Thomas 1979; Armleder et al. 1998). These properties, security and thermal cover, further influence the daily energy balance of mule deer. Winter thermal cover moderates body temperatures and reduces heat loss (deVos et al. 2003; Poole and Mowat 2005). Security cover can reduce the need and distance to flee (Armleder et al. 1998); and, it affects the perceived risk of predation and the use and selection of habitat (Camp et al. 2012; Iribarren and Kotler 2012; Olsoy et al. 2014). Consequently, security cover influences predator-prey interactions and opportunities for foraging and resting (deVos et al. 2003; Frerker et al. 2013).

There are two related but ecologically distinct aspects to security cover. Security cover affects the detectability of prey (e.g., deer) by predators (e.g., cougars) and the likely outcome of pursuit after prey are detected whereas visibility reflects the ability of prey to detect an approaching predator (Iribarren and Kotler 2012). In this way, visibility influences the time available for prey to make an escape, and thus, the perception of risk (Iribarren and Kotler 2012; Olsoy et al. 2014). While inextricably linked, the two variables reflect different ecological viewpoints: predator and prey.

1.3 Rationale and Purpose of Present Investigation

Mule deer populations in the Pacific Northwest and Southern Rocky Mountains have declined over several decades (e.g., Gill et al. 1999; Peek et al. 1999; Bergman et al. 2011; Bergman 2013). While there is no clear causal factor (Gill et al. 1999; deVos et al. 2003), the long-term deterioration of mule deer habitat has likely reduced the environment's capacity to support these deer (Gill et al. 1999). Altered fire regimes, overgrazing, and noxious weeds all contribute to successional changes which appear to degrade habitat quality for mule deer (Lutz et al. 2003, Bishop et al. 2009).

Mule deer populations may be experiencing food limitations on degraded winter ranges. In south-central Oregon, declining forage biomass caused by increasing forest cover (a legacy of fire suppression) was correlated with regional mule deer declines (Peek et al. 2001, 2002). And more directly, food availability was experimentally demonstrated to be a limiting factor for mule deer on winter range at the Uncompahgre Plateau, Colorado (Bishop et al. 2009).

Between the late 80's and early 90's, based on reduced hunter success, declines in mule deer populations in the Kootenay region of B.C.'s Southern Interior became apparent (Hatter et al. 1989 as cited in Mowat and Kuzyk 2009). A severe winter in 1996–1997 resulted in further substantial mortality of mule deer and other ungulates in the region (FLNRO 2012). While populations of *Odocoileus virginianus* (white-tailed deer) and *Cervus canadensis* (elk) in the region have recovered since, mule deer appear to have remained at reduced numbers or declined further (FLNRO 2012). In light of the declining trend and driven by the priority status of the mule deer species, managers and scientists have looked for ways to actively restore mule deer populations in the region (Poole and Mowat 2005).

Browse availability on winter ranges may be an important limiting factor for the recovery of mule deer populations in the Kootenays (Poole and Mowat 2005; Mowat and Kuzyk 2009). Cougar abundance in the region has remained low since 2000 and there hasn't been an antlerless hunt since 1998 (Mowat 2007). Restoring mule deer populations by enhancing forage biomass on winter range is increasingly emphasised (e.g. Peek et al. 2001, 2002; Poole and Mowat 2005; Bergman et al. 2014; Kramer et al. 2015) and common approaches include tree thinning and prescribed fire (e.g., Gill et al. 1999; UWRTAT 2005; Bergman et al. 2014; Kramer et al. 2015).

However, few studies have evaluated the effectiveness of these treatments. Experimental assessments of mechanical thinning treatments on browse production and fawn survival have been conducted in New Mexico and Colorado, respectively (e.g., Bergman et al. 2014; Kramer et al. 2015), but in the Pacific Northwest, assessments of thinning effects on browse (or mule deer population) productivity are lacking—although see Armleder et al. (1998) for an assessment of mule deer occurrence patterns in partial-cut treatments in B.C. and Cook et al. (2016) for an evaluation of browse nutritional quality for elk in relation to thinning treatments in the Pacific Northwest. Additionally, while mule deer use of both thinned and burned stands has been evaluated in Oregon—and showed no treatment effect on occurrence (Long et al. 2008)—the effects of these combined treatments on browse production remain understudied. To contribute to this knowledge gap and identify whether these commonly recommended treatments achieved the intended purpose of enhancing browse, I evaluated the effects of combined thin and burn treatments on browse cover and UWR quality in a dry forest in southern B.C. As mule deer populations in the region are suspected to be limited by browse availability on UWR (Mowat and Kuzyk 2009), this investigation will be of interest to

managers looking to inform efforts to restore degraded UWR for local mule deer populations.

2 Fiva Creek Case Study

The study site (referred to as Fiva Creek) covers 421 ha and is located 18 km northeast of Rock Creek, B.C., on the Kimberley plateau between 49°12'41"–49°13'30" north latitudes and 118°54'28"–118°51'49" west longitudes (Figure 2). Elevation across Fiva Creek ranges from 740–1260 m above sea level with a predominantly southern aspect (ranging from west to southeast). The site falls within the Kettle Dry Mild Interior Douglas-fir (IDF dm1) Biogeoclimatic (BEC) Unit (Braumandl and Curran 2002). This unit is characterised by very hot, dry summers and cool winters with light (Braumandl and Curran 2002) to moderate (Lloyd et al. 1990) snowfall. Based on mule deer specific requirements, the UWR guidelines prepared by UWRTAT (2005) assign IDF dm1 to the moderate snowfall category. Local weather stations provide supporting data that this category is appropriate for Fiva Creek (Appendix A). The site includes very xeric areas (e.g., ridges and rocky areas) and mesic zones (e.g., in draws and near creeks) (Przeczek and Winter 2002). Summer conditions in this BEC unit typically cause soils to dry out for short to long periods in late summer (Braumandl and Curran 2002).

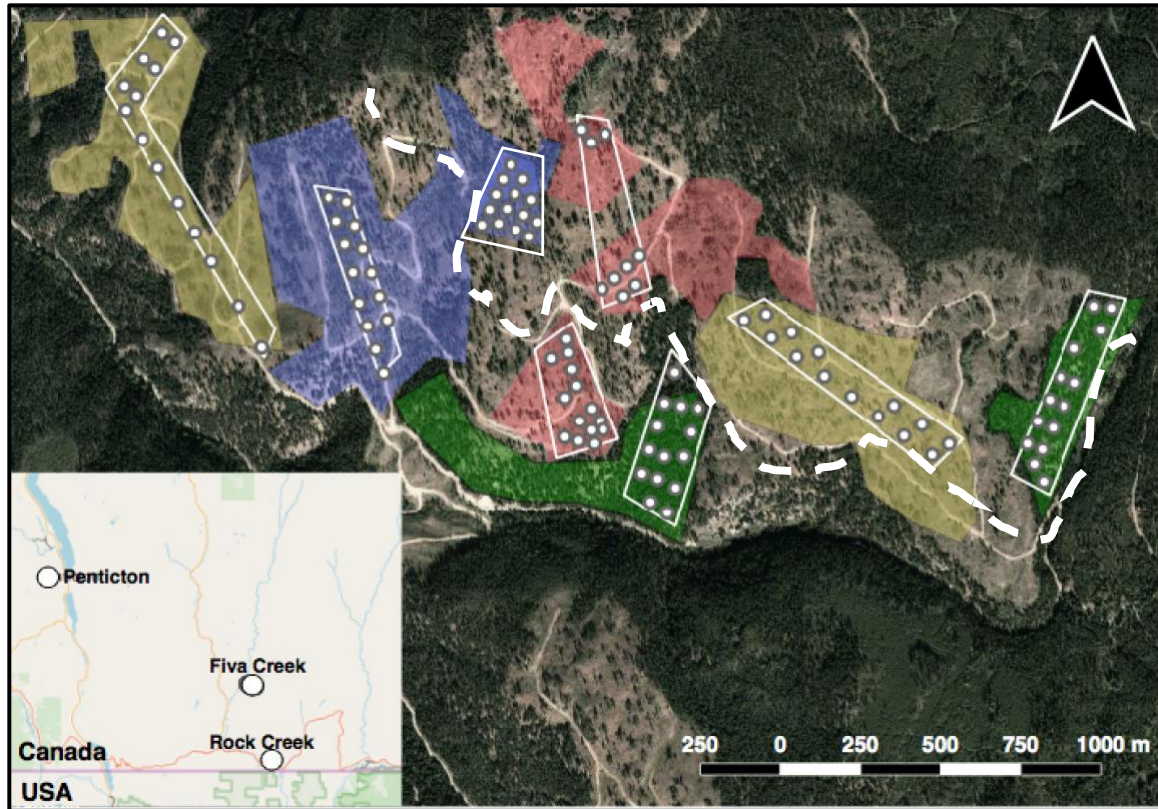


Figure 2. Location of Fiva Creek study site and overview of sampling layout. Coloured polygons indicate the level of thinning derived from satellite-imagery (red = clear-cut, yellow = patchy clumps, blue = thinned forest, green = control). The 1120 m contour line was used to split the site into two blocks and is indicated by the dashed line. Image prepared using QGIS (QGIS Development Team 2009).

2.1 Site History

Douglas-fir forests between 800–1200 m in the Kettle Valley have high capability to function as winter range for mule deer (Gyug and Simpson 1991). This capability led Fiva Creek to be designated as a priority area for UWR enhancement and ecosystem restoration by the B.C. Ministry of Environment and the B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development (Przeczek and Winter 2002). Following initial site visits, Hebert and Halko (2001) and Przeczek and Winter (2002) described the over-browsed sparse condition of forage at Fiva Creek. Heavy browsing of shrubs and grasses was evident and attributed to both white-tailed and mule deer

(Przeczek and Winter 2002). As well, juvenile conifers (mostly Douglas-fir and *Pinus ponderosa* (Ponderosa Pine)) were expanding into meadows across the site (Hebert and Halko 2001; Przeczek and Winter 2002). The conifer ingrowth suggested that fire exclusion was altering the ecological trajectory of the site and potentially limiting browse productivity in the understorey (e.g., Braummandl and Curran 2002). Forests in IDF dm1 are naturally prone to frequent fires that maintain open stand structure (Parminter 1995); thus, fire exclusion likely enabled the typically open forests of Fiva Creek to fill in with conifers (Hebert and Halko 2001; Przeczek and Winter 2002). Practitioners reasoned that if the forest stand was opened via tree thinning (selective-cut logging and slashing) and followed with a prescribed broadcast burn, understorey vegetation would sprout vigorously and increase browse availability and the value of the habitat for mule deer (Hebert and Halko 2001). Such a project could provide a beneficial example of restored UWR in B.C.'s Southern Interior and assist efforts to reverse declining populations of mule deer (Hebert and Halko 2001). Key objectives for restoration included enhancing productivity of preferred forage for mule deer and enhancing winter range quality in the long term (Przeczek and Winter 2002). Thinning treatments were implemented in 2005 and then followed by a broadcast prescription burn in the spring of 2008. The completion of the burn operations concluded active restoration treatments at Fiva Creek.

2.2 Present Investigation: Questions and Objectives

To identify whether thin and burn treatments enhanced browse production and the quality of UWR at Fiva Creek, I compared four intensities of thinning (ranging from clear-cutting to no cutting and all burned except for the uncut control) for effects on five response variables: browse cover, security cover, canopy closure, visibility, and pellet abundance. I also assessed the level of ungulate browsing across the site using the widespread and preferred forage species, *Amelanchier alnifolia* (Blower 1982) as an

indicator. The investigation—which took place twelve years after thinning and nine years after broadcast burning—addressed three research questions:

- 1) How have thin and burn treatments influenced the forest and vegetation structure at Fiva Creek?
- 2) More specifically, has restoration increased winter forage availability?
- 3) Did any treatment produce superior UWR qualities?

Questions 1 and 2 were addressed quantitatively with a focus on thinning levels (Section 2.3.4) while question 3 required a qualitative assessment: i.e., I compared the outcome of different thinning levels (all burned except the control) with published guidelines and considered the biological significance of the observed effects. Enhancing browse plants was the primary purpose of treating the site (Hebert and Halko 2001). Thus, for a treatment to be deemed successful, browse enhancement relative to the control was the primary metric of success. My objectives were twofold:

- 1) Provide a description of the condition of UWR at Fiva Creek and develop recommendations to enhance restoration effectiveness (if necessary); and
- 2) Identify key lessons learned and provide information to assist future restoration efforts on UWR in similar ecosystems.

2.3 Methods

During the summer of 2017 (July 25th to August 17th), I sampled Fiva Creek vegetation and forest structure, browsing levels, and pellet abundance using a two-stage sampling method. At the experimental level, I sampled eight units (i.e., 4 levels of thinning x 2 elevation blocks). In an effort to collect a representative sample from a heterogeneous landscape, within each unit, I subsampled 14 plots (except one unit where only 9 plots were subsampled).

2.3.1 Experimental unit selection

Because of the post-hoc and observational nature of this assessment, I was unable to randomly assign treatments. Instead, I determined four levels of thinning treatments by evaluating post-logging stand structure with satellite imagery (Google Earth 2006). I created polygons around stands having one of four visually-derived structures: i.e., clear-cuts with single tree reserves, patchy clumps of leave-tree clusters, thinned forest, and uncut control forest. Areas that were natural clearings before treatment were excluded from analysis. Next, the polygon layers created in Google Earth were imported into ArcGIS (ESRI 2011) and the four treatment levels were grouped into two elevation blocks (lower block = 740–1120 m; upper block = 1120–1260 m). The largest polygon of each treatment level within each elevation class was selected to represent an experimental unit. Polygon boundaries (sampling areas) were retracted 30-m inwards to reduce the potential influence of edge effects when sampling experimental units. The final map was then exported to Avenza Maps software (Avenza Systems Inc. 2017) for use in the field.

2.3.2 Transect layout

Transects were oriented for maximum coverage in each treatment unit (i.e., direction was non-random). Once I reached the treatment unit boundary, I began each transect by selecting a random number to determine how far inside the polygon the first plot would be established. The distance was selected randomly from 0–50, 0–75, or 0–100 m with the range dependent on polygon size (larger polygons incorporated more spacing to increase coverage). Subsequent plots were systematically spaced a predetermined distance of 50, 75, or 100 m—again, depending on polygon size. Parallel transects were spaced approximately 50-m apart. Site features unrelated to the

treatment (e.g., road, rocky outcrop, retained *Populus* (aspen) stands, or riparian areas) were excluded from sampling. When plots landed on these features, a new plot was established 20-m further along the transect. Plots were located using Avenza Maps software (Avenza Systems Inc. 2017).

2.3.3 Data Collection

At each plot ($n = 107$), I measured six indicators of UWR quality: tree-canopy closure, security cover, sightline visibility, percent cover of browse plants, browse pressure, and abundance of pellet groups (Figure 3). Sampling details for each indicator are described below.

Estimating Canopy Closure

With the help of a field assistant, densiometer (spherical concave) readings were collected by photograph 30 m in each cardinal direction from plot center (Figure 3; # 1). I analyzed each photograph ($n = 428$) to estimate canopy closure following Lemmon (1956); however, non-woody deciduous plant parts were excluded to better approximate canopy closure available during winter.

Estimating Security Cover

To estimate security cover for an adult mule deer, a cover board (140 cm x 40 cm; 2 x 7 grid of 14, 0.2 cm x 0.2 cm, white squares) was set-up with the bottom about 90 cm from the ground. Cover board dimensions and height were based on Anderson et al. (1974) to approximate the size of a standing mule deer (adult doe). The cover board was photographed from four locations 30 m in each cardinal direction from plot center (Figure 3; # 2). I analyzed each photograph ($n = 428$) by counting the number of squares at least 50% obscured by vegetation and converted values to the percentage of squares

concealed (Camp et al. 2012). Plant parts that were non-woody and deciduous were excluded from the assessment to better approximate security cover available during winter. Photos obstructed by topography were removed from the dataset ($n = 23$).

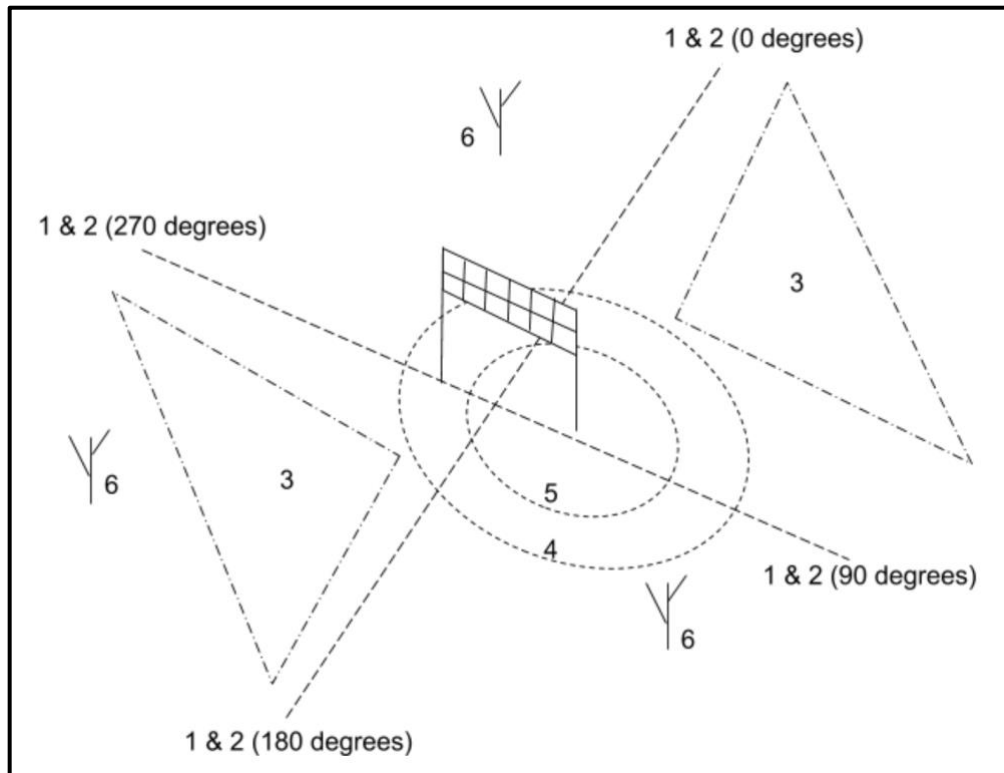


Figure 3. Illustration of plot design used to subsample experimental units of UWR at Fiva Creek from July 25th to August 17th, 2017. Estimates ($n = 4$) of canopy closure (1) and security cover (2) were recorded from 30 m in each cardinal direction; two estimates of visibility within 30 m were recorded from plot center for compass quadrants 0–90° and 180–270° (3); browse percent cover (4) and pellet group abundance (5) were recorded in 25 m² and 12.5 m² sub plots, respectively; and the extent of browsing on the three closest indicator shrubs was assessed (6). Experimental units ($n = 8$) were subsampled with 9–14 plots and response variables were averaged to unit means for comparisons among experimental units.

Estimating Visibility

From plot center, I estimated visibility in the two compass quadrants: 0–90° and 180–270° from roughly 1.7 m off the ground (Figure 3; # 3) (Iribarren and Kotler 2012). Scanning each 90° horizon, I used the width of my pointer finger from an outstretched

arm to approximate 2° and quantified the percentage of each quadrant where visibility (e.g., of approaching predators) was obstructed by vegetation. Any object blocking visibility within 30 m was quantified as an obstruction.

Estimating Browse Percent Cover

I recorded percent cover of browse plants in a fixed-radius sub plot ($r = 2.82$ m) (Figure 3; # 4). All browse plants within 0.2–2.0 m of the ground were included to approximate the browse zone available during winter. This zone was based on the typical browsing height of 1.5–1.8 m for deer (Stoddart et al. 1975 as cited in Wikeem and Wikeem 2005) and an assumed snow depth of 20 cm (average January snow depth on southern aspects within the Boundary Forest District was reported by Hebert and Halko (2001) as 27 ± 1 cm from two low snowfall years).

Evaluating Browsing Pressure

To evaluate ungulate browsing pressure at Fiva Creek, I used *A. alnifolia* as an indicator. This species is highly preferred by mule deer (Blower 1982) and was frequently encountered across the site; thus, it was well suited as an indicator (Keigley et al. 2002). Within 30 m of each plot, up to three shrubs (range 0–3) were selected for assessment of plant architecture and quantification of browsing intensity (Figure 3; # 6) (Patton and Hall 1966; Keigley et al. 1997, 2002, 2003; Wikeem and Wikeem 2005). Twig samples were assessed for evidence of herbivory and absent annual growth within the winter browsing zone (0.2–2.0 m). Plant specimen were selected by proximity to plot center with the nearest candidate chosen.

Estimating Pellet Abundance

Following a modified RISC standard method (i.e., only one search pass), I recorded the abundance of ungulate pellet groups in a fixed-radius sub plot ($r = 1.99$ m) (Figure 3; # 5) (Resources Information Standards Committee 1998).

2.3.4 Data Analysis

To assess how thinning (with follow-up burning) influenced forest and vegetation properties at Fiva Creek, I compared each respective response variable (i.e., canopy closure, security cover, visibility, total browse cover, preferred browse cover, and pellet groups/m²) across the four thinning treatments (i.e., clear-cut, patchy clumps, thinned forest, and uncut control) using linear mixed-effects ANOVA tests ($\alpha = 0.05$). The models incorporated two effects: the factor of primary interest—thinning—was included as a fixed effect with four levels while block was included as a random effect. Thinning effects were evaluated using Kenward-Roger's F test for linear mixed-effects models (Halekoh and Hojsgaard 2014). Indicators with ANOVA outputs below the alpha value (< 0.05) were assessed for treatment-level differences using Tukey's HSD post-hoc analysis ($\alpha = 0.05$).

To account for the co-dependent nature of nested sub plots in this two-stage design, I averaged values among sub plots within each experimental unit. Thus, I used unit means for ANOVA tests—a method that is accurate, powerful, and robust to imbalance at the sub-unit level (Picquelle and Mier 2011). This design was balanced at the experimental unit level; however, the nested sub plots were not balanced (i.e., there were 9–14 sub plots per unit). The ANOVA based on unit means represents a suitable and simple method to address such an imbalance (e.g., Picquelle and Mier 2011).

Parametric assumptions of normality and equality of variance were not violated (see Appendix B for residual plots). All analyses were conducted in R Studio Version 1.1.423 (R Core Team 2017) using the following packages: LmerTest (Kuznetsova et al. 2017), emmeans (Lenth 2018), and pbkrtest (Halekoh and Hojsgaard 2014). Graph outputs were constructed in R Studio using ggplot2 (Wickham 2009) and ggplotthemes (Arnold 2017).

3 Results

A significant treatment effect was detected for every response variable assessed except browse cover (Table 2).

Canopy Closure

Mean canopy closure varied significantly among treatments with lower closure in all thinned groups relative to the control group (Table 2; Figure 4). As expected, there was a decreasing trend in canopy closure with increased thinning; yet, mean closure did not vary significantly among thinned groups (Table 2). Mean closure in all treated units fell within or below the threshold for low crown closure habitat (Figure 4)—as per Armleder et al. (1986).

Security Cover

Security cover varied significantly among treatments (Table 2). All treated groups provided significantly less security cover than control units (Table 2; Figure 5).

Table 2. Winter range indicators measured across four levels of tree thinning at Fiva Creek. Mean values for each treatment are reported with 95% confidence intervals* followed by ANOVA outputs ($F_{3,3}$ and p values) with p values < 0.05 bolded. Superscript "A's" and "B's" denote significant differences between treatment levels when letters are distinct (Tukey's HSD post-hoc test). Reference values are reported with citation information below.

Indicator	Reference values	Control	Clear-cut	Patchy Clumps	Thinned Forest	$F_{3,3}$	p-value
Mean Canopy Closure	35–65% ¹ 30–50% ²	60% ^A ± 9.5%	10% ^B ± 9.5%	13% ^B ± 9.5%	22% ^B ± 9.5%	64.92	< 0.01
Mean Visibility	N/A	26% ^A ± 19%	77% ^B ± 19%	60% ^{AB} ± 19%	75% ^B ± 19%	12.13	0.04
Mean Security Cover	90% ³	64% ^A ± 16%	18% ^B ± 16%	25% ^{AB} ± 16%	20% ^{AB} ± 16%	14.86	0.03
Mean Browse Cover	30–40% ⁴	4.94% ± 10%	3.28% ± 10%	6.81% ± 10%	7.50% ± 10%	1.26	0.427
Mean Cover of Preferred Browse	30–40% ⁴	1.36% ± 4.3%	0.50% ± 4.3%	3.18% ± 4.3%	1.53% ± 4.3%	1.91	0.305
Mean Twigs Browsed per <i>A. alnifolia</i>	< 50% ⁵ 50–65% ⁶ 60–65% ⁷	90% ± 8.0%	88% ± 1.3%	81% ± 1.6%	80% ± 17.5%	N/A	N/A
Mean Pellet Group Abundance/m ²	N/A	0.25 ^{AB} ± 0.14	0.18 ^A ± 0.14	0.35 ^B ± 0.14	0.21 ^A ± 0.14	17.43	0.02

* 95% confidence intervals based on least square means are reported for all indicators evaluated by linear mixed-models; traditional 95% confidence intervals are reported for mean browsing levels on *A. alnifolia*.

^{1,2} Landscape-level canopy closure recommended for winter range with moderate snowfall (Armleder et al. 1986, 1994; UWRTAT 2005). West Kootenay UWR canopy closure objective reported in Brade and Stevenson (2003).

³ Definition of security cover is > 90% concealment of a standing adult deer from 61 m or less (Thomas 1979); however, this is not a landscape level target. An ideal landscape level ratio of forage to security cover has been suggested as 60:40 in Oregon and Washington (Thomas 1979) yet targets for security cover on UWR have not been identified at the local scale (Brade and Stevenson 2003; UWRTAT 2005).

⁴ Target cover values for deciduous shrubs preferred by mule deer on UWR in the Prince George Forest District (Brade and Stevenson 2003).

^{5, 6, 7} 50% = level of multi-year browsing generally tolerated by browse plants (Gill et al. 1999). Wikeem and Wikeem (2005) advise that annual shrub use on B.C. rangelands is generally acceptable at levels of 50–65% based on Garrison (1953) while *A. alnifolia* may tolerate 60–65% based on Young and Payne (1948).

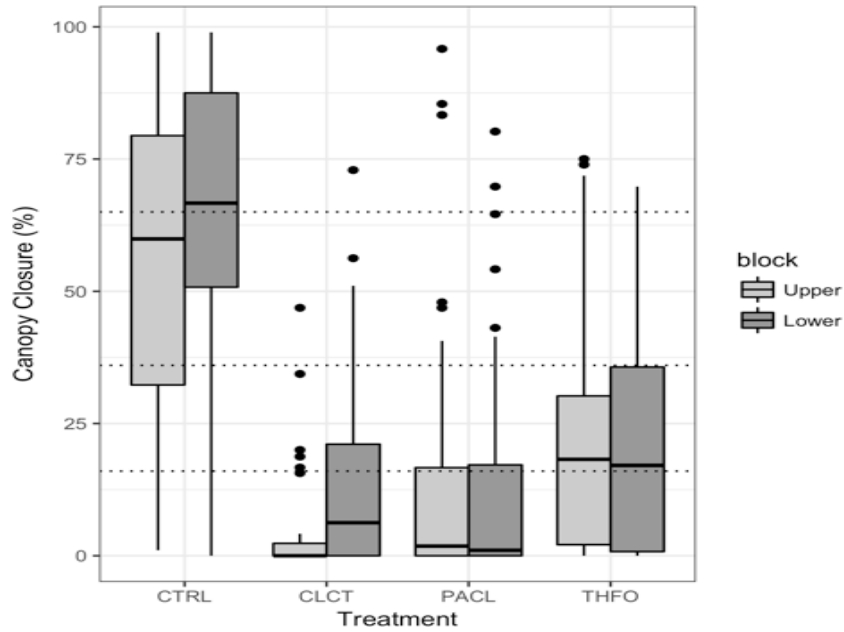


Figure 4. Boxplot indicating percent of sky hemisphere (viewed through a spherical concave densiometer) obscured by canopy closure within each experimental unit and grouped by treatment level ($n = 56$ in each unit except upper clear-cut where $n = 36$). Treatment levels—control, clear-cut, patchy clumps, and thinned forest—are abbreviated to CTRL, CLCT, PACL, and THFO, respectively. Dashed horizontal lines indicate boundaries of canopy cover categories taken from Armleder et al. 1986 (low = 16–35%, moderate = 36–65%, high > 65%). Separate shades indicate elevation blocks.

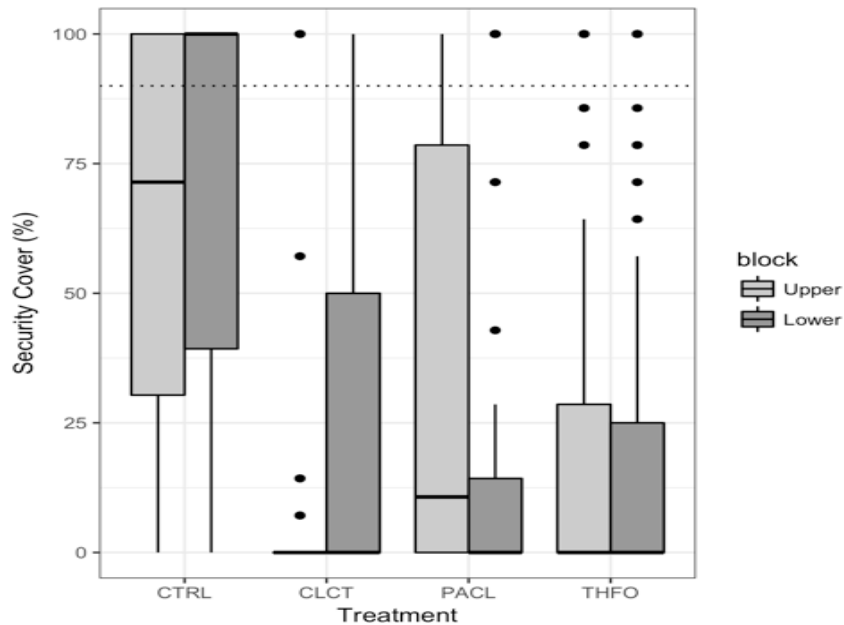


Figure 5. Boxplot indicating proportion of cover board (simulating a standing adult mule deer) obscured by vegetation (i.e., security cover) within each experimental unit and grouped by treatment level (from left to right, $n = 46, 55, 35, 53, 54, 52, 55$ and 55). Treatment levels—control, clear-cut, patchy clumps, and thinned forest—are abbreviated to CTRL, CLCT, PACL, and THFO, respectively. Dashed line indicates definition of mule deer security cover; i.e., conceals > 90% of a standing adult deer from 61 m or closer (Thomas 1979). Separate shades indicate elevation blocks.

Visibility

Mean visibility varied significantly among treatments (Table 2; Figure 6). Relative to the control group, mean visibility was significantly higher in the clear-cut and thinned groups (Table 2). Besides the upper spaced-patch unit where mean visibility was the lowest of all treated units (i.e., 48%), visibility estimates were similar across treated units (Figure 6). Figure 5 Mean visibility in control units ranged from 25–26%.

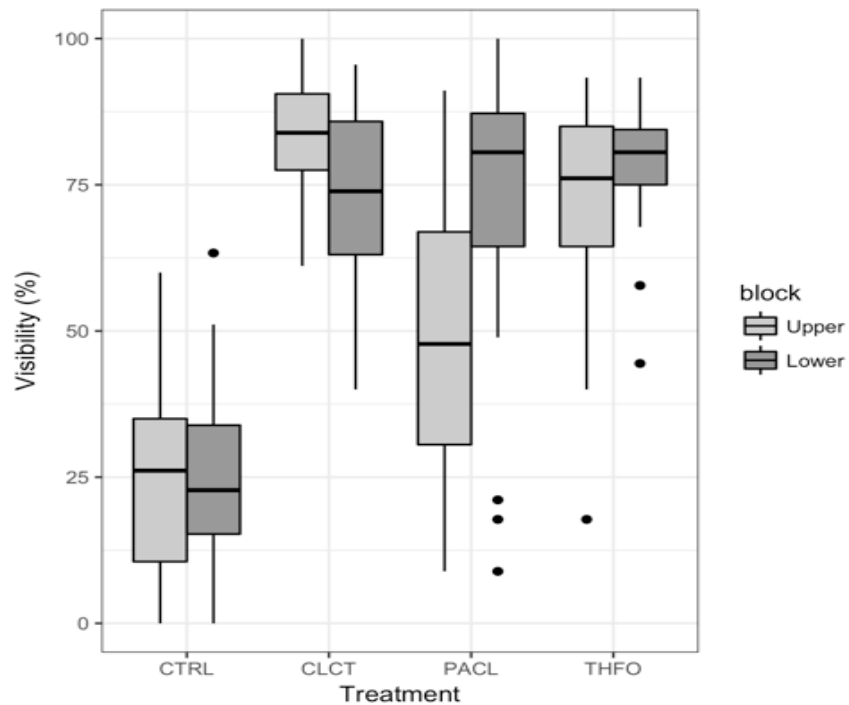


Figure 6. Boxplot indicating percent of 90° horizon visible up to 30 m within each experimental unit and grouped by treatment level (n = 28 for all units except upper clear-cut where n = 18). Treatment levels—control, clear-cut, patchy clumps, and thinned forest—are abbreviated to CTRL, CLCT, PACL, and THFO, respectively. Separate shades indicate elevation blocks.

Browse Availability

Eleven species of browse plants were encountered at Fiva Creek (Appendix C). Cover of all browse plants combined, as well as just preferred browse plants (see Appendix C for ranking), did not vary significantly across treatment groups (Table 2). Mean browse cover (total and preferred browse) was far below reference values in all treatments (Table 2). The lowest cover within each block occurred in clear-cut units (Figure 7 and Figure 8).

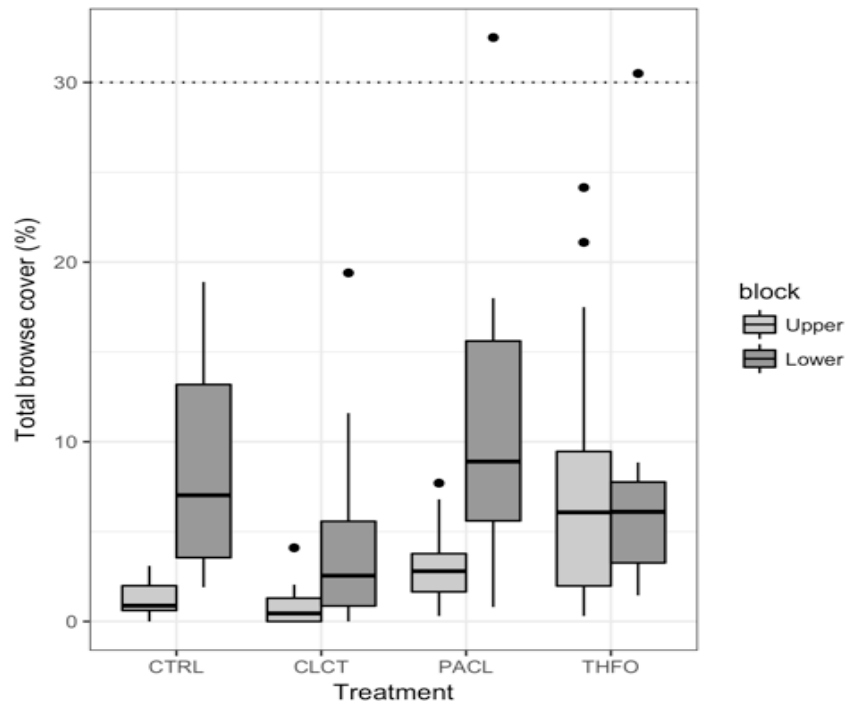


Figure 7. Boxplot indicating percent of 25 m² plot covered by browse species within each experimental unit and grouped by treatment level (n = 14 in all except upper clear-cut where n = 9). Treatment levels—control, clear-cut, patchy clumps, and thinned forest—are abbreviated to CTRL, CLCT, PACL, and THFO, respectively. Dashed line indicates minimum target for deciduous browse cover used for UWR in the Prince George Forest District (Brade and Stevenson 2003). Separate shades indicate elevation blocks.

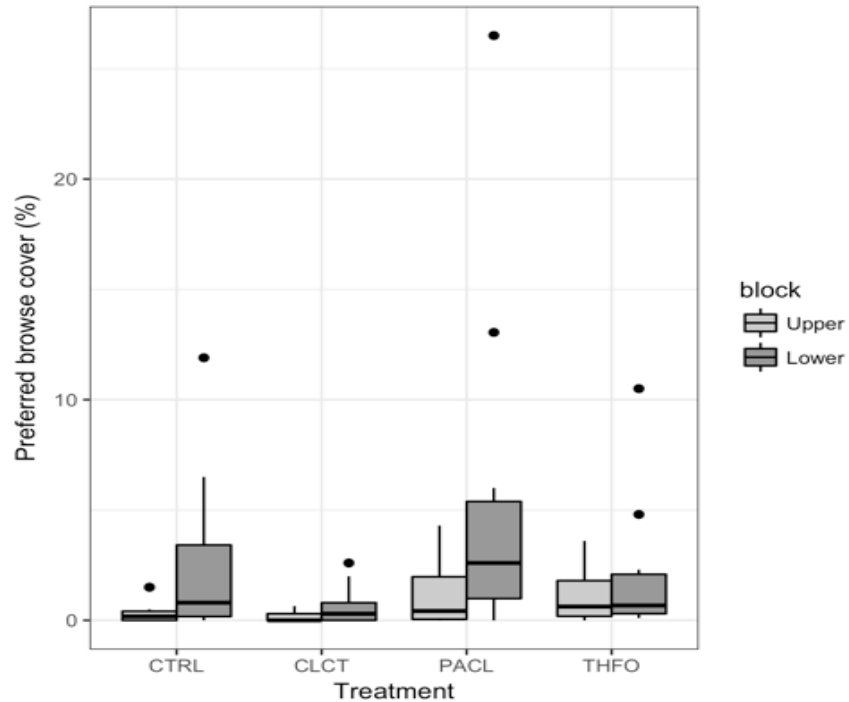


Figure 8. Boxplot indicating percent of 25 m² plot covered by preferred browse species (Appendix C) within each experimental unit and grouped by treatment level (n = 14 in all except upper clear-cut where n = 9). Treatment levels—control, clear-cut, patchy clumps, and thinned forest—are abbreviated to CTRL, CLCT, PACL, and THFO, respectively. Preferred browse cover in all plots was well below the minimum target of 30% used for deciduous browse cover on UWR in the Prince George Forest District (Brade and Stevenson 2003). Separate shades indicate elevation blocks.

Browsing Pressure

In total, 115 specimen of *A. alnifolia* were assessed (control = 31, clear-cut = 22, spaced patch = 29, thinned forest = 33). The average percent of twigs browsed on *A. alnifolia* was > 80% in all treatments (Table 2) and heavily hedged shrubs were common (Appendix D).

Pellet Groups

Abundance of pellet groups ranged from 0–15 groups/plot or 0–1.2 groups/m² (Figure 9). Pellet group abundance varied significantly among treatments (Table 2). Although mean pellet abundance in the control group was not significantly different from the other treatments, the patchy clump group exhibited significantly higher mean pellet abundance than the clear-cut and thinned forest groups (Table 2). Mean pellet abundance was lowest in the clear-cut group (Table 2).

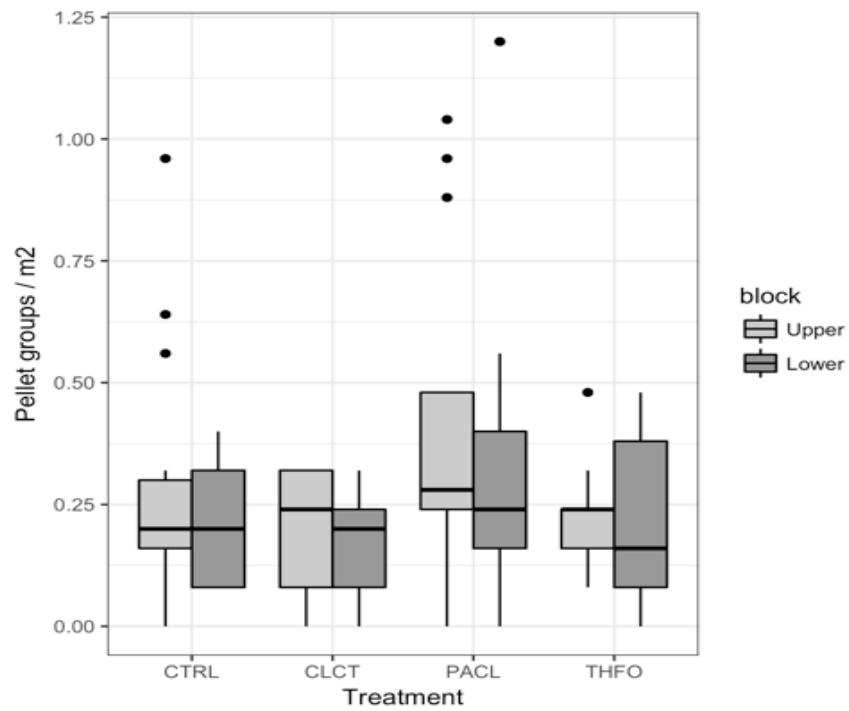


Figure 9. Boxplot indicating pellet groups/m² within each experimental unit and grouped by treatment level (n = 14 in all except upper clear-cut where n = 9). Treatment levels—control, clear-cut, patchy clumps, and thinned forest—are abbreviated to CTRL, CLCT, PACL, and THFO, respectively. Separate shades indicate elevation blocks.

4 Discussion

4.1 Evidence of Constrained Browse Growth

As thinning and burning treatments are increasingly prescribed for enhancing browse on UWR (e.g., Gill et al. 1999; Brade and Stevenson 2003; UWRTAT 2005; Long et al. 2008; Bergman et al. 2014), the most important finding from this investigation was the insignificant effect of thinning with follow-up burning on meeting this core objective nine years after treatment. Specifically, mean coverage of preferred browse in treated groups ranged from 0.5–3.2% and showed no significant difference from the control mean of 1.3%. Supporting these observations, Hebert and Halko (2001) described similarly low coverage of highly palatable browse on southern aspects of UWR in the Boundary Forest District (i.e., 1.9%). While mean cover of browse was greater in patchy clump units relative to control units, an increase in cover of < 3% is likely of little biological significance. Further, browse cover in all treatments remained well below the reference values of 30–40% used for UWR in the Prince George Forest District (Brade and Stevenson 2003). Thus, it is apparent that browse production at Fiva Creek has been limited by one or more unaddressed filters.

I suggest three factors have likely influenced the productivity of browse plants at Fiva Creek: continued heavy browsing, seed bank limitations, and dry growing conditions. Extensive browsing over multiple years can damage and kill woody plants—reducing forage supplies and shifting the composition of plant communities to less palatable species (Gill et al. 1999; deVos et al. 2003). Considering the poor, over-browsed, condition of forage plants observed at Fiva Creek prior to treatment (Hebert and Halko 2001; Przeczek and Winter 2002) and the heavy levels of browsing reported here (i.e., > 80% which exceeds recommended levels (Table 2)), browsing pressure

likely has remained high over the interval between treatment and assessment. Thus, continued heavy browsing pressure appears to be an important limiting factor for browse regeneration at Fiva Creek. Stunted and severely hedged growth forms of browse plants were commonly observed while plants > 2 m were almost completely absent (Appendix D). This suggests browsing levels at Fiva Creek have effectively arrested growth beyond the browsing zone for several years (e.g., Keigley et al. 2003). The evidence of intense browsing pressure that I observed further suggests food-resource limitation for ungulates is locally prevalent. This supports Mowat and Kuzyk's (2009) hypothesis that mule deer are food limited on winter range in the West Kootenays and highlights the need for restoration methods that reliably enhance browse on UWR in light of heavy browsing pressure.

Heavy browsing pressure not only can result in a depauperate understorey of forage plants but can produce legacy effects through the depletion of the local seed bank (Goetsch et al. 2011). This may further explain why the shrub response at Fiva Creek was below expectations. Fire-adapted shrubs like *A. alnifolia* and *Ceanothus* spp. (all utilized as preferred winter forage by mule deer (Appendix C)) were expected to have a high potential for regeneration and germination after broadcast burning (Przeczek and Winter 2002; Davies 2007); however, it may be that the cumulative effect of heavy browsing prior to treatment had reduced the capacity of the site to regenerate due to legacy effects from browse-related senescence and reduced seed availability (e.g., Goetsch et al. 2011). In contrast, it is possible that vigorous growth of browse plants followed restoration treatments, but due to heavy browsing or other unknown factors, browse cover was diminished prior to assessment. Hebert and Halko (2001) described areas with sparse cover of browse at Fiva Creek prior to treatment; these areas likely had low potential for regeneration because of limited seed resources and

plant dispersal capabilities. However, I can only speculate about these limitations because there was no pre-treatment or follow-up assessments of browse abundance conducted at Fiva Creek prior to this investigation. While answering why browse enhancement failed is beyond the scope of the present investigation, a greater initial emphasis on experimental design would have helped elucidate the underlying limiting factors.

Other studies have reported a lack of treatment effect from thinning or burning on mule deer occurrence, population productivity, and browse cover (e.g., Long et al. 2008; Bergman et al. 2014, 2015; Kramer et al. 2015), but successful outcomes have also been described. Bergman et al. (2014) demonstrated a significant improvement in over-winter survival of mule deer fawns on restored winter range in Colorado. Treatments included mechanical clearing (hydro-ax or roller-chop), follow-up seeding of preferred browse, and chemical control of weeds. However, mechanical treatment alone had little effect on fawn overwinter survival—highlighting the potential importance of follow-up treatments (Bergman et al. 2014).

Without an adequately stocked seed bank or sufficient moisture, thinning alone is unlikely to generate a desired understorey response (UWRTAT 2005; Lang and Halpern 2007; Bergman et al. 2014; Kramer et al. 2015). This limitation is likely also true for combined thinning and burning treatments. Therefore, whether follow-up treatments are necessary is likely a site-specific function of the available seed bank and moisture regime (Bergman et al. 2014). In conjunction with continued heavy browsing and potential seedbank limitations, it is possible that low moisture conditions—characteristic of IDF dm1 forests (Braumandl and Curran 2002)—might also have limited the potential for regeneration of browse at Fiva Creek. The ability of arid environments to produce forage is highly sensitive to moisture availability (Pierce et al. 2012). Kramer et al. (2015)

observed a lack of forage response following thinning treatments in New Mexico and considered ongoing drought conditions a key limiting factor. Drought conditions over several years can even reduce the nutritional carrying capacity of the environment (Pierce et al. 2012). Pierce et al. (2012) observed this effect in the Round Valley (California) population of mule deer where widespread starvation coincided with persistent drought. With projections of increased occurrence of summer drought in B.C. (British Columbia 2018), the effect of moisture limitation on browse production and survival is likely to increase.

The influence of elevation block on browse cover provides limited support for the potential effects of moisture limitation. Lower elevation sites yielded higher browse cover, and the random factor of elevation block explained about 50% of the variation in both total and preferred browse at the site. Considering the influence of slope and landscape position on available moisture, positioning treatments at different slope positions would likely influence restoration outcomes. However, this experiment was not designed to assess the factor of elevation; rather, it was included as a random blocking factor to account for environmental variation. Further investigations could improve restoration effectiveness by identifying key principals for site selection.

Considering the potential limiting factors outlined above (i.e., browsing pressure, seed bank limitations, and available moisture), it would be valuable to determine the relative roles of each at Fiva Creek. This could be experimentally evaluated using ungulate exclusion, follow-up planting or seeding (or an assessment of the available seed bank), and watering trials. Identifying the filters limiting browse production would inform how to improve this restoration project's effectiveness. Further, such information could prove useful for analogous efforts to enhance UWR (in similar ecosystems). However, analogous efforts will likely be more effective if potential limiting factors are

first identified from pilot-studies at the specific site in consideration (i.e., before implementing large-scale treatments).

4.1.1 Potential Competition with White-tailed Deer

It would be beneficial to identify the level of forage competition at Fiva Creek as there is evidence of high white-tailed deer abundance in the region. The Kootenays likely contain the highest densities of white-tailed deer in B.C. (Mowat and Kuzyk 2009). Moreover, Hebert and Halko (2001) reported primarily white-tailed deer and few mule deer during January surveys near Fiva Creek; and while I observed no deer at Fiva Creek during summer sampling, I discovered two antlers which both originated from white-tailed deer. Together, these observations suggest white-tailed deer likely compete for food resources with mule deer at Fiva Creek.

Competition with white-tailed deer for limited food resources will likely reduce the effectiveness of forage-based restoration efforts for mule deer unless browse is dramatically increased. Further, high levels of inter-species competition for forage could lead practitioners to falsely declare restoration success when browse levels are enhanced yet not sufficiently available to the target species. Estimating the level of winter browsing by each species would better inform evaluations of success over simpler metrics like percent cover of browse because the latter is potentially confounded in the presence of competition.

Fortunately, the intensity and precise locations of competition between browsing ungulates can be measured reliably using environmental DNA (eDNA) sampling of browsed plants (Nichols et al. 2012). Nichols et al. (2012) reported that about 50% of browsed twig samples contain enough traces of eDNA to reliably identify ungulate species up to 12 weeks after browsing; even 24 weeks after browsing, 12.5% of samples

provided sufficient eDNA for species identification. A major limitation of the present investigation is that browse availability and cover cannot be translated into mule deer population performance (Bergman 2013). However, measuring species-specific browsing using eDNA could provide a direct method to evaluate whether restoration objectives are reaching the target species. Similarly, analyzing eDNA from pellet samples at Fiva Creek could disentangle the relative abundance of these two species.

4.2 Further Treatment Effects on Quality of UWR

4.2.1 Snow Interception

Snow interception from the forest canopy is a crucial function of UWR in northern regions (e.g., Armleder et al. 1986, 1994; Poole and Mowat 2005; UWRTAT 2005). Yet, the level of thinning at Fiva Creek did not preserve this functional capacity. In a study of mule deer in B.C.'s Interior-Douglas-Fir BEC zone, Armleder et al. (1994) reported that forest canopies between 36–65% crown closure were used more often than expected by relative availability. UWRTAT (2005) built upon this work and incorporated snow loading data and the specific abilities of mule deer to create general guidelines for managing UWR across BEC subzones. For forests within the IDF dm1 BEC subzone, and particularly when snow loading is moderate (see Table 1), UWRTAT recommends maintaining 36–65% canopy closure. Snow data from the closest weather stations to Fiva Creek (that also occur within IDF dm1) suggest moderate snow loading is an appropriate level to expect at the study site (Appendix A). Because all thinned groups at Fiva Creek exhibited mean crown closure ranging from 10–22% (i.e., low crown closure; Armleder et al. 1986, 1994), the function of snow interception was likely not preserved in any treated units over this 400+ ha site. The implications from this level of thinning are reflected in the work of Armleder et al. (1994): low crown closure forests (in the IDF BEC

zone) received less winter use by mule deer than expected based on availability—under all classes of snow depths (Table 1).

Furthermore, heavy thinning removes an important forage item: litterfall (e.g., Waterhouse et al. 1991; Armleder et al. 1986; 1994). In a study of winter diet which included sampling at Fiva Creek, Hebert and Halko (2001) observed Douglas-fir was the most common species in mule deer pellets—contributing about 50% to deer diets while all shrubs combined contributed between 17–34%. While the lower contribution of shrubs likely reflects lower relative availability rather than preference, the importance of litterfall to mule deer in the West Kootenay region is apparent from this work. Therefore, not only has the snow-intercepting function of the canopy been compromised, but the availability of an important food source has also been reduced—exacerbating the lack of effect on enhancing understorey browse.

While thinning was intended to open the canopy to facilitate shrub growth, it is necessary to balance forage availability and snow interception (Armleder et al. 1986; Poole and Mowat 2005). Thinning at Fiva Creek covered an expanse of roughly 421 ha and incorporated few patches with high canopy closure within the broad treatment area (Figure 2). This scale of effectively homogenous thinning to low canopy cover, with correspondingly low ability for snow interception, likely does not reflect an optimal balance. Rather, a patchy distribution of openings within a functional snow-intercepting forest (in this case, a forest with moderate canopy closure) would be preferable (e.g., Armleder and Dawson 1992). Thus, excessive clearing for the predicted snow levels at Fiva Creek appears to have occurred in all treated units. Allen et al. (2002) describe concerns regarding projects where merchantable timber harvest is conducted as part of restoration: e.g., Fiva Creek. In such cases, there is a risk that economic imperatives can dominate restoration decisions. These imperatives may stem from legitimate and

desirable goals to sustain rural economies or reduce project costs (Allen et al. 2002); however, projects can only qualify as ecological restoration when they are grounded in ecological principles (Allen et al. 2002; Miller and Hobbs 2007). The planning and layout of treatments should directly reflect the needs of target species and not economic efficiencies. To achieve restoration goals for mule deer on UWR (i.e., minimize the energetic cost of occupation) it will likely be critical to provide widely distributed patches of forests (for snow interception, litterfall, security and thermal cover) and openings (for enhanced forage quality and production) (Thomas 1979; Armleder et al. 1986; Armleder and Dawson 1992; Gilbert et al. 2017).

4.2.2 Visibility, Security and Thermal Cover

The multifaceted functions of understorey plants for mule deer means that a failure to enhance forage likely has additional costs on UWR value. For instance, all thinned groups exhibited low levels of mean security cover (range: 18–25%) with infrequent observations of > 90% concealment (i.e., the criteria for security cover as per Thomas 1979). In contrast, mean security cover in control areas was 64% with several observations of > 90% concealment (Figure 5). While treated units exhibited greater visibility (Figure 6), the general lack of security cover and associated greater distance to cover likely has offset any visibility improvements. Additionally, considering the roles of vegetation and forest canopy in providing thermal refugia (e.g., Thomas 1979; deVos et al. 2003), thinned groups exhibited a far lower capacity for attenuating heat loss as evidenced by low canopy closure and security cover. Thus, a notable consequence from the lack of browse production in treated groups appears to be diminished security and thermal cover. Identifying the functional roles of these habitat attributes at the scale of individual deer would be beneficial to inform approaches to UWR restoration (Brade and Stevenson 2003; UWRTAT 2005).

4.3 The Best Level of Treatment?

There is limited evidence to suggest that the patchy clump treatment may offer advantages over the other thinning levels assessed. Among treated groups, mean security cover was greatest in the patchy group, and among all treatments, mean pellet occurrence and preferred browse cover were highest in this group. However, there was no consistent pattern across replicates. Additionally, the inability to distinguish white-tailed deer pellets from the target species reduces the inferential value of pellets as an indicator of mule deer selection. If both species have similar microsite preferences, pellets might still provide some indication of habitat value for mule deer; yet, deer behavioural plasticity (Gilbert 2017) and considerable within-species variation of life-history strategies (e.g., Nicholson et al. 1997) challenge whether such a fine scale assumption is appropriate. Nevertheless, patchy clumps may offer benefits by retaining whole patches of forest and increasing available edge habitat. Mule deer are commonly associated with this ecotone as increased access to forage is provided in close proximity to security cover and resting areas (e.g., Reynolds 1966a as cited in Thomas 1979). However, the relative availability of clearings to forest patches is an important consideration on UWR. In contrast to the patchy clump treatment utilized at Fiva Creek where the area of openings far exceeded forest patches, I suggest this ratio should be reversed and that forest patches should have larger sizes (e.g., 2 ha; Thomas 1979) to meet snow interception, security, and thermal cover functions.

While the results for the patchy treatment suggest there may be ways to enhance UWR with a modified form of the treatment, the results for clear-cut treatments indicate this method was generally detrimental to UWR quality at Fiva Creek. In B.C.'s interior, clear-cuts are generally avoided by mule deer in the winter (e.g., Armleder et al. 1994; Serrouya and D'eon 2008). My results support this observation as mean pellet group

abundance was lowest in this treatment group—although the season of deposition cannot be ascertained from this study. Further, browse cover was consistently minimized in clear-cut units within each elevation block. This is an important observation because clear-cut treatments were intended to maximize shrub growth (Przeczek and Winter 2002). Why would productivity in the clear-cut have been so low? It is possible that the exposed conditions of clear-cut treatments exacerbated moisture limitations or that the increased levels of disturbance associated with implementing clear-cutting negatively affected the soil. Regardless, this treatment exhibited the most-limited growing conditions; it also exhibited many examples of invasive plant establishment. Controlling plant invasions in clear-cut areas will likely be an important step in restoring the trajectory of Fiva Creek back towards productive UWR.

4.4 Limitations of Investigation

The conclusions drawn from this investigation must be tempered with the knowledge that my approach has considerable limitations. For instance, I made the assumption that a coarse comparison roughly 10 years post-treatment would reflect treatment effects. There were no baseline data on browse cover available—data that could verify whether experimental units had roughly equal potential for regeneration or whether differential browse cover prior to treatment might have influenced regeneration. Similarly, the effects of fire across the site were likely variable, but there were no data available to examine this potentially confounding factor (e.g., specific burn locations, intensity, and spread). And of course, the single site examined in this investigation precludes these results from being extrapolated beyond Fiva Creek—at least without cautious recognition of this limitation. A stronger experimental approach, such as a factorial assessment of thin and burn treatments (ideally replicated across multiple

sites), could have provided greater insight into the independent and combined effects of these restoration treatments.

Despite these limitations, this investigation still provides valuable knowledge. For example, it is clear browse enhancement was unsuccessful at Fiva Creek. Similarly, in light of projected snow levels, it is apparent that excessive thinning occurred at Fiva Creek. Thus, my investigation has demonstrated a need for more reliable UWR restoration methods by revealing the potentially detrimental outcomes that can occur from commonly recommended treatments.

4.5 Recommendations

4.5.1 Restoration Recommendations for Fiva Creek

- Prepare a restoration plan that incorporates follow-up experimental treatments of browse exclosures, planting and/or seeding (or alternatively, a seed bank assessment), and watering to elucidate limiting factors at the site;
- Consider identifying species-specific levels of winter browsing using eDNA (e.g., Nichols et al. 2012) to determine the level of forage competition at Fiva Creek and thus the availability of browse to mule deer. Alternatively, pellet eDNA could be sampled or wildlife cameras could be installed to provide information on the relative abundances of white-tailed versus mule deer on site;
- Control and monitor non-native plants beginning to colonize the site (e.g., upper clear-cut); and
- Consider full deactivation and reclamation of roads across the site (e.g., Hayden et al. 2008).

4.5.2 Recommendations to Improve Future Projects

- Conduct pilot studies to identify potential limiting factors and provide baseline data before implementing treatments;
- Devise specific metrics of success and sampling procedures based on target species needs (Miller and Hobbs 2007). For instance, a metric that directly translates to deer population performance, such as fawn over-winter survival, would be much better than browse cover (Bergman 2013);
- Utilize an experimental approach where treatments are replicated across multiple sites to evaluate hypotheses and increase the reliability of inferences;
- Plan for follow-up seeding/planting of preferred browse plants unless there is evidence of an abundantly stocked seed bank (Bergman et al. 2014);
- Plan for follow-up control of invasive plants (Bergman et al. 2014);
- Plan for follow-up monitoring;
- Communicate restoration results;
- Follow UWRTAT (2005) recommendations for canopy retention levels; and
- Ensure harvesting activities occur during periods of minimal impact to understorey and soil features (e.g., winter harvest).

5 Conclusion

Thin and burn treatments not only failed to achieve restoration objectives at Fiva Creek but they have likely diminished the overall quality of the site as UWR. These results exemplify why restoration efforts must be carefully formulated to meet the needs of target species (Miller and Hobbs 2007) and further provide a cautionary example of the consequences that arise when key constraining factors are not sufficiently addressed. The primary goal of restoration at Fiva Creek was to enhance understory browse; yet, treatment showed no effect and browse cover remained well below reference values (e.g., Brade and Stevenson 2003). Consequently, food resources remain sparse and heavily browsed at Fiva Creek. Moreover, the functional capacity of the canopy to intercept snow was reduced below recommended levels (UWRTAT 2005)—an effect that will last for decades. To improve UWR conditions on site and mitigate unintended treatment outcomes, follow-up restoration should be implemented. However, further investigations are needed to develop effective UWR restoration methods. Approaches that emphasize experimental design and long-term monitoring will not only provide greater insight into why treatments succeed or fail—they will improve the reliability of ecological restoration as a conservation and management tool. While winter foraging areas have been historically underrepresented in ungulate management policy in B.C. (Serrouya and D’eon 2008), it will become increasingly important that methods applied to enhance these areas are effective moving forward.

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Appendix A

Approximating optimal canopy closure for Fiva Creek

UWRTAT (2005) describes the broad relationships between BEC subzones and snow conditions. Based on snow loading data within B.C., they recommend the maintenance of moderate canopy closure (i.e., 36 – 65%; Armleder et al. 1986, 1994) for forests within the IDF dm1 BEC subzone. This level of canopy closure is considered appropriate for “[snow] depths sufficient to inhibit movements for periods of days to weeks most winters” (i.e., 25 cm) and snow depths that reach the critical depth of 50 cm for several days or less (UWRTAT 2005). Snow data from the nearest weather stations to Fiva Creek in IDF dm1 suggest the site fits the criteria for moderate snow loading (Table A); however, site-specific snow data would better inform canopy cover targets. Of course, homogenous cover across the forest landscape is suboptimal; instead, a mosaic of microsites providing small openings for food and moderate canopy cover for shelter would be preferable (Armleder and Dawson 1992; Gilbert et al. 2017).

Table A. Mean annual snowfall and mean maximum snow depth for IDF dm1 BEC subzone as reported by UWRTAT (2005).

Mean Annual Snowfall ¹	Range of Annual Snowfall	Mean Maximum Depth ²
184 cm	138 - 230 cm	48cm

¹ Annual snowfall data were taken from two Atmospheric Environment Service stations in the Nelson Forest Region

² Maximum depth data from 1966-1999 at the Trapping creek-lower snow station, Kettle Valley (elevation = 930 m).

Appendix B

Residual plot outputs for each response variable (unit means) assessed using linear mixed-effects ANOVA tests:

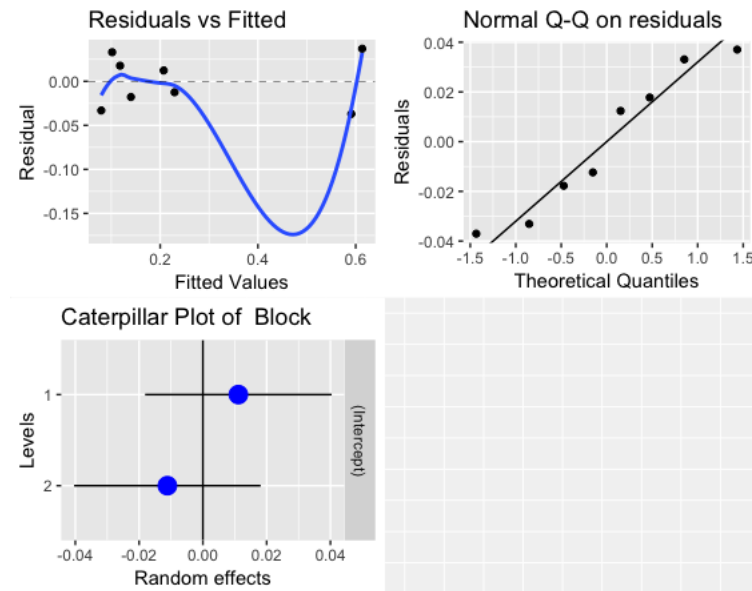


Figure B1. Residual plots of canopy closure unit means.

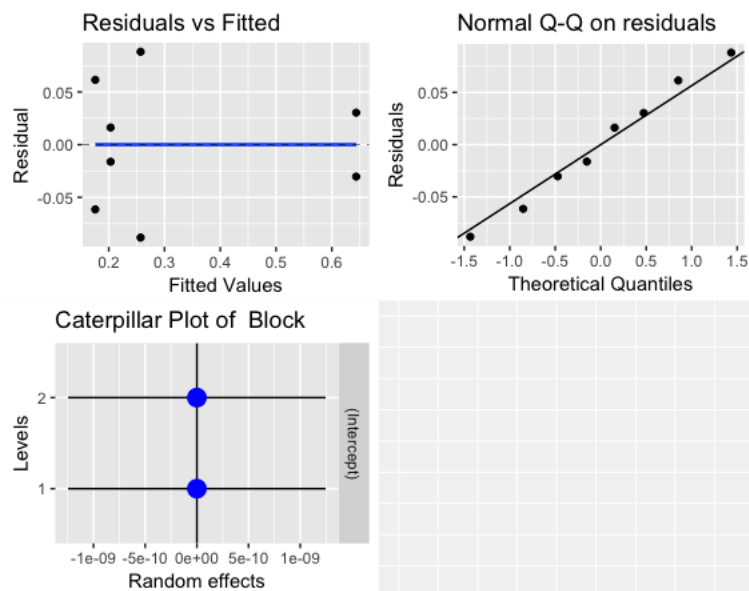


Figure B2. Residual plots of security cover unit means.

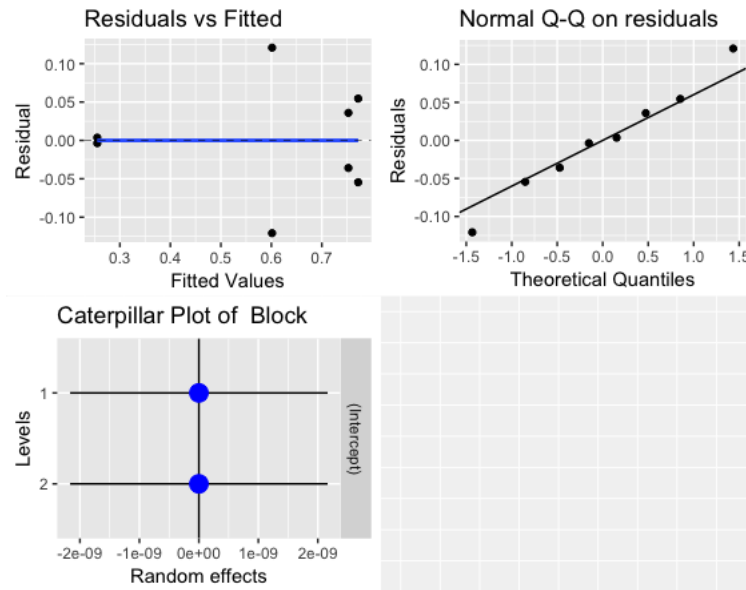


Figure B3. Residual plots of visibility unit means.

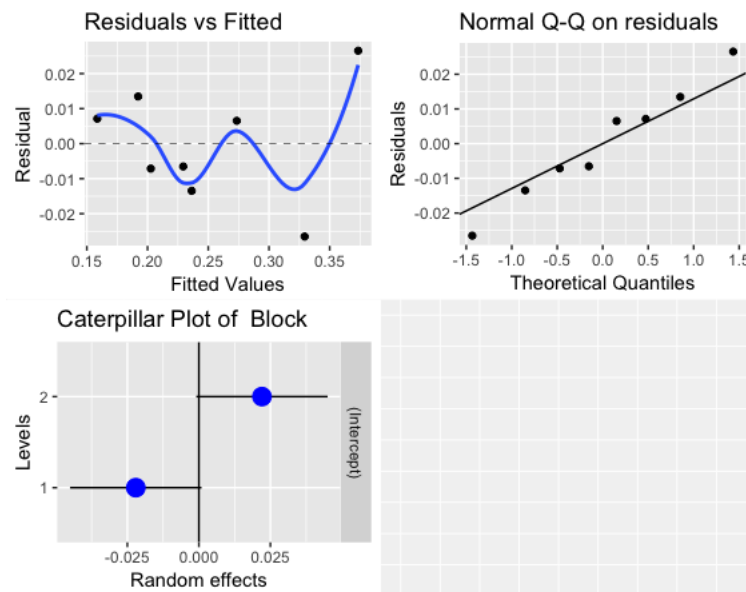


Figure B4. Residual plots of pellet abundance unit means.

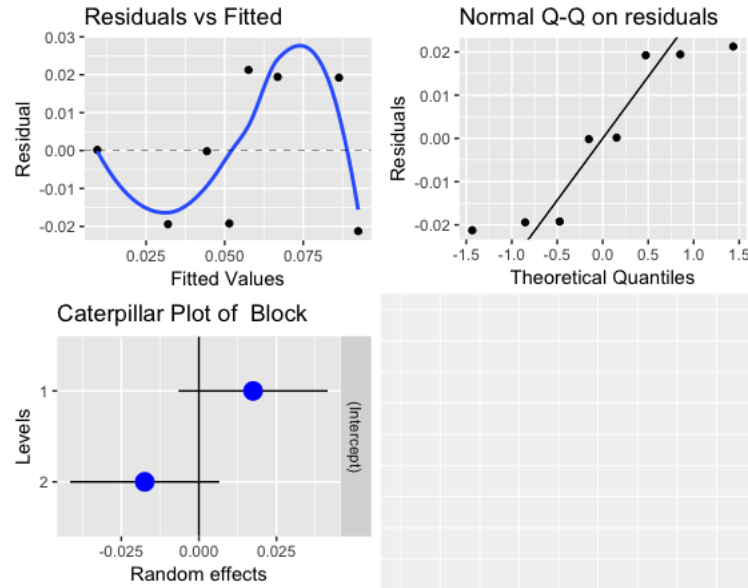


Figure B5. Residual plots of total browse unit means.

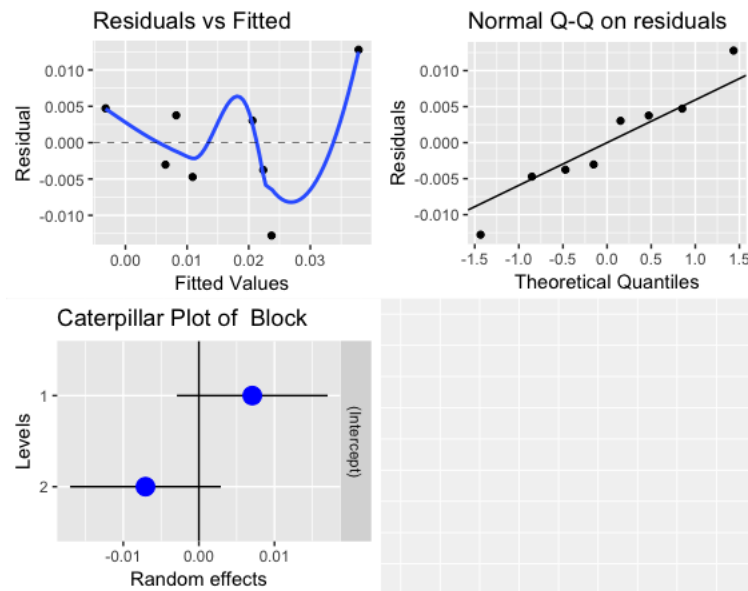


Figure B6. Residual plots of preferred browse unit means.

Appendix C

Table C. Mule deer browse plants encountered at Fiva Creek. Species with preference listed as high or moderate were included in preferred browse cover assessments, while all species in the table were included when estimating total browse cover.

Latin name	Common name	Mule deer preference ¹
<i>Acer glabrum</i>	Douglas maple	High
<i>Amelanchier alnifolia</i>	Saskatoon	High
<i>Ceanothus sanguineus</i>	Red-stem ceanothus	High
<i>Ceanothus velutinus</i>	Snowbrush	High
<i>Salix</i> spp.	Willow	High
<i>Berberis aquifolium</i>	Tall Oregon-grape	Moderate
<i>Rosa acicularis</i>	Prickly rose	Moderate
<i>Physocarpus malvaceus</i>	Mallow ninebark	Infrequent
<i>Sherpherdia canadensis</i>	Soopalallie	Infrequent
<i>Spirea betulifolia</i>	Birchleaf Spirea	Infrequent
<i>Symphoricarpos occidentalis</i>	Snowberry	Infrequent

¹ Preference indicated in Blower (1982) and Hebert and Halko (2001).

Appendix D

Examples of *Amelanchier alnifolia* specimen at Fiva Creek exhibiting stunted growth due to intense browsing pressure (photos: S. Foster). Note hedged stem clusters indicating arrested growth form (Keigley et al. 2003).

