INFLUENCE OF PRESCRIBED FIRE ON STONE'S SHEEP AND ROCKY MOUNTAIN ELK: FORAGE CHARACTERISTICS AND RESOURCE SEPARATION

by

Krista L. Sittler

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Name: Krista Sittler

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Title: INFLUENCE OF PRESCRIBED FIRE ON STONE'S SHEEP AND ROCKY MOUNTAIN ELK: FORAGE CHARACTERISTICS AND RESOURCE SEPARATION

Examining Committee:

Chair: Dr. Todd Whitcombe, Associate Professor
Mathematical, Computer, and Physical Sciences Program
University of Northern British Columbia

Supervisor: Dr. Katherine Parker, Professor
Natural Resources and Environmental Studies Program
University of Northern British Columbia

Committee Member: Dr. Roger Wheate, Associate Professor
Natural Resources and Environmental Studies Program
University of Northern British Columbia

Committee Member: Dr. Michael Gillingham, Professor
Natural Resources and Environmental Studies Program
University of Northern British Columbia

Committee Member: Doug Heard, MSc, Adjunct Professor
Ecosystem Science and Management Program
University of Northern British Columbia

External Examiner: Dr. Dale Seip, Wildlife Ecologist
British Columbia Ministry of Environment
Ecosystems Branch

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Abstract

For over 30 years prescribed fire has been used as a management tool to enhance ungulate habitat in northeastern British Columbia (BC), where up to 7,800 ha are burned annually. Yet relatively few studies have quantified the role of fire on both plant and animal response, and whether it enables competition between focal grazing species such as Stone's sheep (*Ovis dalli stonei*) and elk (*Cervus elaphus*). Seven prescribed burns (150–1,000 ha) were implemented in the spring of 2010 and 2011 in the Besa-Prophet area of northern BC. I examined the response of Stone's sheep and elk to seasonal changes in forage quantity and quality by elevation in treatment versus control areas. I monitored vegetation and fecal pellet transects at a fine scale and used Landsat imagery, survey flights and GPS telemetry at a landscape scale. By one year after burning, forage digestibility and rates of forage growth were higher on burned than unburned areas. At both scales Stone's sheep and elk always used burns more than control areas in winter. Stone's sheep and elk appeared to partition their use of the landscape through topography and land cover. Increased use of burned areas suggests that prescribed fire enhanced habitat value for grazing ungulates in the short-term. By altering animal distributions, however, the use of prescribed fire has the potential to change complex predator-prey interactions in northern BC.

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Chapter 1. Introduction

BACKGROUND

Prescribed burning in the Peace Region of northern British Columbia

Fire has been the dominant single natural-disturbance agent influencing the northern British Columbia (BC) landscape since the last ice age (Backmeyer et al. 1992). Successional stage of plant communities is often reset after fire. Over time, overlapping fires and their recovery create a mosaic of small younger patches embedded within a matrix of older forest (Turner et al. 1997, Johnson et al. 1998), thereby shaping the heterogeneity of the landscape in northern BC.

The BC Forest Service began fire suppression efforts in 1912. The suppression policy and advocacy concerned with stopping the spread of wildfire were successful and resulted in a large build-up of forest fuels, tree encroachment on grasslands and shrub lands, and changes in species composition (Backmeyer et al. 1992, Backer et al. 2004). In response to declining ungulate populations in the Peace Region (east of the continental divide in northeastern BC; Figure 1.1), the BC government initiated a prescribed-burn program in the early 1980's, aiming to reclaim lost wildlife habitat and enhance the quality and quantity of the forage for ungulates (AMEC Earth and Environmental Limited 2002).

Prescribed fire has a long history in northern BC (Backmeyer et al. 1992). Historically, First Nations have used fire for food production (Turner 1991, Gottesfeld 1994) and guide outfitters and ranchers have used spring burns as a means of enhancing range for livestock and wildlife (Backmeyer et al. 1992, AMEC Earth and Environmental Limited 2002). The Peace Region in northeastern BC is known for its abundance and diversity of ungulates and predators. The heterogeneous landscape that is home to this diverse assemblage of wildlife is due in part to topography and the mosaic of different successional

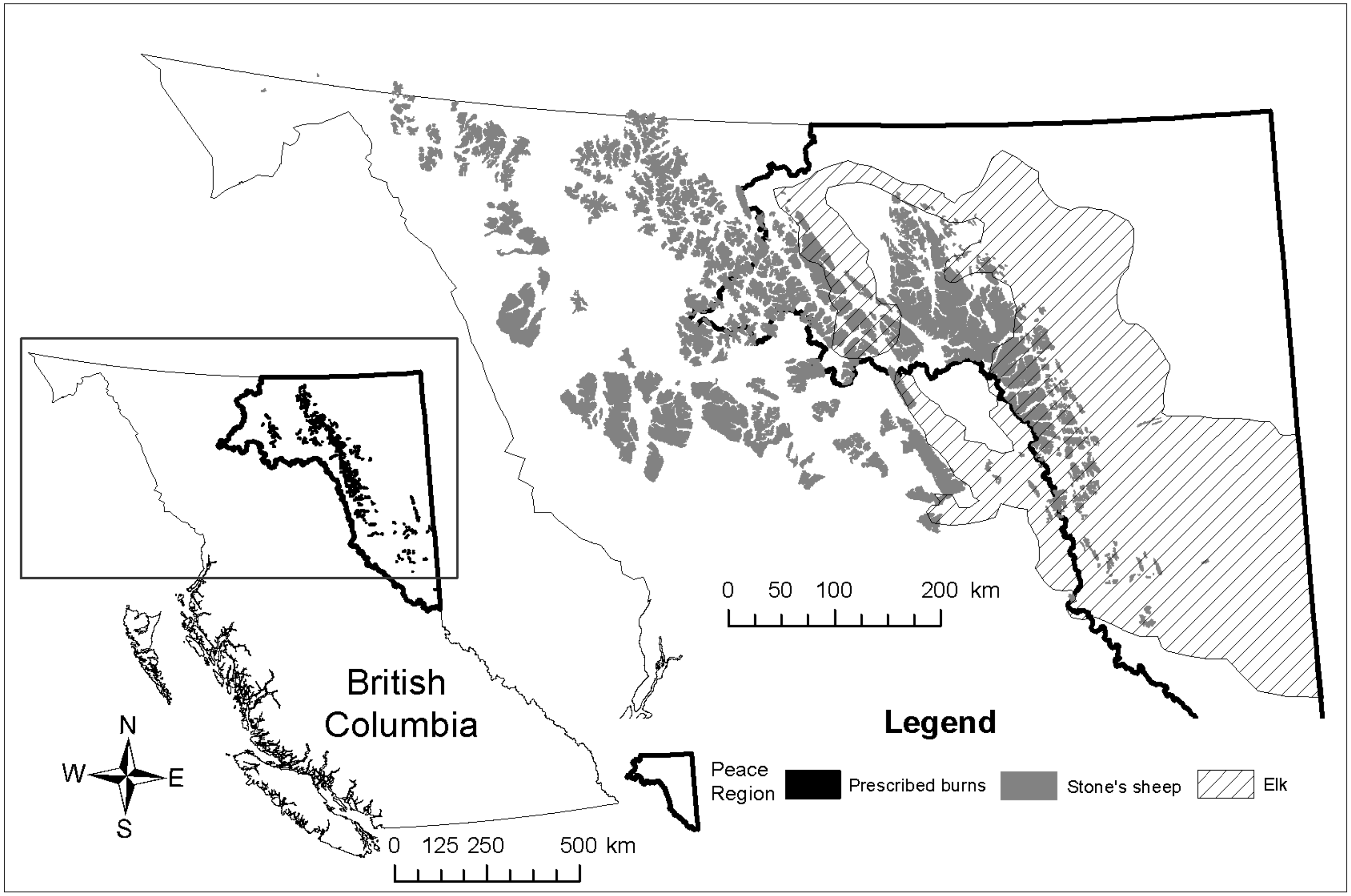

Figure 1.1. Distribution of Stone's sheep and elk in northern British Columbia and the footprint of prescribed burns (black polygons) from 1980–2013 in the Peace Region. Elk distribution is an approximation modified from Shackleton (2013).

stages created by natural wildfires and the use of prescribed fire. Guiding for big game is a major source of economic activity in the region. The prescribed-burn program is supported by non-profit conservation groups (e.g., Habitat Conservation Trust Foundation), local hunting organizations (e.g., Northeast Wildlife Fund) and guide outfitters (e.g., Northern Guide Outfitters) and is believed to be a credible and standard management practice by many northern residents. Up to 7,800 ha are intentionally burned each year in the Peace Region in an effort to enhance wildlife habitat, leading to the present landscape with 23% of all burns and 41% of the total area burned resulting from prescribed fire (Lousier et al. 2009). Compared to wildfires, prescribed burns are more restricted in their distribution (targeting areas of higher quality to ungulates), have a shorter return interval, and therefore occur at a higher frequency (Lousier et al. 2009).

Studies have shown that many large ungulates, such as moose (*Alces alces*; Gillingham and Parker 2008*a*, Nelson et al. 2008), elk (*Cervus elaphus*; Peck 1987, Sachro et al. 2005, Parker and Gillingham 2007, Van Dyke and Darragh 2007) and Stone’s sheep (*Ovis dalli stonei*; Seip and Bunnell 1985*a*, Walker 2005) select for post-fire vegetation. Yet, there have been few efforts to quantify the influence that fire has on the interactions between species. My research focused on the influence of burns on elk and Stone’s sheep. Major elk-wintering areas are associated with burns (Peck 1987, Parker and Gillingham 2007) and Stone’s sheep often use burned areas in late winter and early spring (Seip 1983, Walker 2005). As elk populations expand in northeastern BC (Shackleton 2013), there is concern that the management activities of prescribed burning may promote competition between elk and Stone's sheep.

Vegetation response to fire and forage for ungulates

Fire affects plant-community composition, and can lead to short-term increases in net primary productivity (Turner et al. 1997). Ungulates depend on plant communities for survival and up to 40–60% of each day is spent foraging (Wickstrom et al. 1984). Following a burn, many studies have found important, but often short-lived improvements in forage quantity (Singer and Harter 1996, Sachro et al. 2005, Van Dyke and Darragh 2007) and forage quality, as measured by crude protein, digestibility, and nutrient content of available forage (Hobbs and Spowart 1984, Van Dyke and Darragh 2007); others have found no difference in nutritional value, rather that changes in abundance and forage composition result in increased foraging efficiency (Seip 1983, Canon et al. 1987).

Nutritional condition can be a limiting factor in the rate of population growth for northern ungulates, which require energy and protein to meet their nutritional requirements (Cook et al. 2001, Parker et al. 2009). Because of this, management practices are often directed towards enhancing forage quality and availability through the use of prescribed fire (Backmeyer et al. 1992, AMEC Earth and Environmental Limited 2002). Stone's sheep and elk, as ruminants, have a highly developed and specialized digestive system. The micro-flora associated with the rumen allows them to digest some fiber in plant cell walls, which would be largely indigestible by other herbivores (Van Soest 1994). Nonetheless, forage intake rates by ungulates can be affected by the amount of fiber, which is not all digestible, and because what is digestible is degraded slowly even with microbial digestion (Barboza et al. 2009). Herbivores must digest plant cell walls to access available energy and protein. From a nutritional standpoint, if used correctly, fire is thought to be effective at increasing the short-term availability of higher quality forage for ungulates by increasing protein and decreasing fiber (Van Dyck and Darragh 2007, Greene 2010) and longer-term increases in forage quantity (Singer and Harter 1996, Sachro et al. 2005). Although fire is used extensively in northern BC to enhance wildlife habitat, there has been little quantification of the magnitude of change and the seasonal variation in forage production due to fire and herbivory.

Stone's sheep and elk

Stone's sheep are one of 2 subspecies of thinhorn sheep classified in the Caprinae subfamily of the family Bovidae (Valdez and Krausman 1999). Stone's sheep were named after American explorer Andrew J. Stone for bringing the first specimen from northern BC to the American Museum of Natural History (Stone and Allen 1900). These mountain-dwelling sheep reside in alpine regions of northern BC and southern Yukon and are found nowhere else in the world. The other subspecies, Dall's sheep (*Ovis dalli dalli*), is found primarily in Yukon, Northwest Territories and Alaska (Shackleton 1999). Where the ranges of these 2 species overlap, hybridization is common (Paquet and Demarchi 1999). Prior to 1998, Stone's sheep were a blue-listed species in BC (a species of special concern), but in 1998 populations were considered to be stable and the BC Conservation Data Center reclassified them as a species not at risk (yellow-listed). Stone's sheep are currently the most abundant wild sheep in BC. In 2008 numbers were estimated to be 10,000–14,000 (Gordon et al. 2008), constituting roughly 3/4 of the global population. In the early 2000's, however, resident hunter bag limits and guide outfitter quotas were reduced because population declines were observed in some areas of northern BC with lower than average number of rams observed (Demarchi and Hartwig 2004). Stone's sheep survival is thought to be limited by predation, severe winter weather, access management, anthropogenic disturbances, disease, and fire suppression resulting in a reduction in range quality due to forest encroachment (Bailey and Hurley 2000, Demarchi and Hartwig 2004).

Apart from predator removal, prescribed fire has been the primary tool for enhancing Stone's sheep populations in northern BC and it has been shown to be effective in reducing parasite loads and increasing horn size in rams (Seip and Bunnell 1985*b*). Stone's sheep are typically grazers and have been observed foraging on a wide range of alpine plants, with grasses (i.e., *Elymus innovatus* and *Poa* spp.), sedges (i.e., *Kobewai mysuroides*) and forbs constituting the majority of their diet (Luckhurst 1973), and occasionally on the leaves of some shrubs (Seip 1983). Post-burn habitats within traditional ranges of Stone's sheep provide favorable forage species, but the benefits to Stone's sheep may be less in areas with sympatric foragers.

Elk are the second largest member of the deer family (Cervidae) belonging to the subfamily Cervinae (Shackleton 1999). Elk were numerous and widely distributed throughout BC until a major population decline in the late 1800s (Spalding 1992). It is uncertain what caused the decline, but it was thought that elk were extirpated from most parts of northern BC. In 1917 the BC government began elk introductions throughout the province (Shackleton 1999). In 1984, 57 Manitoba elk from Elk Island National Park, Alberta were introduced into northeastern BC followed by 68 Rocky Mountain elk from the Kootenay region of southeastern BC into the same area the following year (Shackleton 1999). Since then elk have been expanding their range in northeastern BC and management activities associated with prescribed burning may be promoting this range expansion (Lousier et al. 2009). In 2011 there were an estimated 38,000–72,000 elk in BC (Shackleton 2013). Elk are found in a variety of habitats throughout their range. Foraging sites are often located in open habitats, but elk may be found in coniferous and deciduous forests of all ages as well as in wetter areas such as meadows, wetlands and estuaries (Shackleton 1999). Elk are generalist herbivores, optimally shifting their diet between grasses and shrubs to obtain the most nutrients from their diet. Primarily grazers, elk forage on grasses when available, although if grasses become less available due to utilization or deep snow, shrubs make up a larger portion of their winter diet (Singer 1979). The early seral habitats produced after burning provide excellent foraging opportunities for elk. Due to the generalist diet and ease of dispersal, elk in northern BC are expanding in response to anthropogenic disturbance (including burns), potentially into the small traditional ranges of Stone's sheep.

Resource partitioning and the potential for competitive interactions

Sympatric ungulates often share their environment through resource partitioning, thereby avoiding the potential for competition, or resulting from competitive displacement (Jenkins and Wright 1988, Johnson et al. 2000, Stewart et al. 2002). In winter, when the spatial distribution of ungulates is heavily influenced by vegetation type and snow depth (Singer 1979), resources are at their most limiting and the potential for competition may be high (Jenkins and Wright 1988, Stewart et al. 2010). Areas influenced by prescribed fire are typically south-aspect slopes and are usually the first to become snow free. Stone's sheep and elk in northern BC use these areas in late winter and early spring (Seip and Bunnell 1985*a*, Walker et al. 2007). Elk move up in elevation, while Stone's sheep come down in elevation, to use snow-free, early-mid seral communities and there is a need to quantify the extent to which 1 species might influence the other.

OBJECTIVES

I structured my thesis around 5 objectives aimed to better understand the relationships between fire, vegetation and ungulates.

1) To quantify plant response to prescribed fire, focusing on forage quantity and quality for grazing ungulates.

Prescribed fires can increase forage quality (protein and digestibility) in the short-term (Van Dyck and Darragh 2007, Greene et al. 2012) and have a longer-term increase in forage quantity (Singer and Harter 1996, Sachro et al. 2005). In northern BC, where the growing season is short, plant phenology plays an important role in the selection of foraging sites for Stone's sheep and elk (Seip 1983, Peck 1987, Walker 2005). As part of the Peace-Liard Prescribed Burn Program, 4 prescribed burns were implemented for this study in the spring of 2010. In this thesis, I quantified the seasonal changes by elevation in vegetation structure, composition, and quantity; and nutritional quality (protein and digestibility) on these 4 burns and 4 unburned areas, prior to burning, the year of the burn and 1 year after burning.

2) To distinguish the impacts of grazing from the impacts of fire on plant response.

At high population densities, selective herbivory by large ungulates can cause major changes in plant community composition and structure (Augustine and McNaughton 1998, Rooney 2001). “Pyric herbivory” is a theory that integrates fire and grazing as 2 disturbance agents, which are spatially and temporally dependent on each other, resulting in a shifting mosaic landscape that is critical to the ecological structure and function of many ecosystems (Fuhlendorf et al. 2008). Since the inception of the prescribed burn program, however, relatively few data are available from northern BC to isolate the influence that fire has on vegetation from the impacts of grazing. In my study, I placed permanent ungulate-proof range exclosures (8 × 8 m) on each of the 4 prescribed burns implemented in 2010, and 4 exclosures on adjacent unburned control areas. I sampled inside and outside each exclosure and quantified changes in forage biomass, cover, volume, and species diversity in summer and late winter the year of the burn and 1 year after burning.

3) To quantify the seasonal resource selection and use of burns by Stone's sheep and elk in relation to other available habitats.

Both Stone's sheep and elk are known to utilize burns seasonally, when available, in northern BC. Major wintering areas for elk are associated with burns in the Tuchodi River area of northern BC (Peck and Peek 1991). Stone's sheep also have been observed utilizing subalpine burned areas when snow levels have retreated (Seip and Bunnell 1985*a*, Walker et al. 2007). In my study, I used data from global position systems (GPS) collars on 11 female Stone's sheep (monitored over a 2-year period) and 22 female elk (11 each year, over a 2-year period) and used resource selection functions to model differences in the seasonal selection strategies of these 2 species, with emphasis on selection for different types of burns. In addition to the GPS collars, I conducted monthly survey flights encompassing 28 burns of different ages and sizes to better understand the use of burned areas by groups of Stone's sheep and elk (both sexes) on the landscape. At a finer scale, I used fecal-pellet counts to monitor use at vegetation sampling locations on burned and unburned areas.

4) To determine if resource partitioning occurs between Stone's sheep and elk.

Close coexistence among 2 or more ungulate species typically results in partitioning the use of some resources (Jenkins and Wright 1988, Stewart et al. 2010). The extent to which both Stone's sheep and elk utilize burns during different seasons (Objective 3), whether the ranges of these 2 species overlap, and whether that interaction might deter the use of burns by Stone's sheep has not been documented. I quantified seasonal movements and range overlap between Stone's sheep and elk in relation to burns using information from the GPS collars. I also examined whether the 2 species partitioned their use of the landscape through differences in seasonal use of topography and land-cover classes.

5) To provide recommendations for continued management of fire on the landscape to maximize the benefits for Stone's sheep and elk in northern BC.

A thorough synthesis of past fire history in northern BC was completed by Lousier et al. (2009) to identify knowledge gaps and develop a framework for a wildlife/fire research monitoring plan. As a first step, my research provides a baseline for assessing the effectiveness of the use of prescribed fire for enhancing ungulate habitat. In addition, I provide science-based recommendations for the continued use of prescribed fire, and future research priorities for management of Stone's sheep and elk in northern BC.

ORGANIZATION OF THE THESIS

I organized this thesis into 4 chapters. Chapter 1 (*Introduction*) provides context to the issues surrounding prescribed fire and its influence on Stone's sheep and elk. This chapter is followed by 2 separate data chapters to be submitted for journal publication and written in first person plural to acknowledge the contributions of my collaborators. Chapter 2 (*Response of vegetation to prescribed fire in the northern Rockies: Implications for Stone's sheep and elk*) addresses the short-term vegetation response to fire in relation to Stone's sheep and elk (Objectives 1 and 2). In Chapter 3 (*Resource separation on a landscape of prescribed burns: Stone's sheep and elk in the northern Rockies*), I examine the influence of prescribed fire on the seasonal resource-selection strategies and habitat-use patterns of female Stone's sheep and elk (Objectives 3 and 4). In the final chapter (Chapter 4; *Research summary and management recommendations*), I provide a synthesis of the results of my research and propose additional considerations for the continued use of prescribed fire for the purpose of benefiting both Stone's sheep and elk (Objective 5).

Chapter 2. Response of vegetation to prescribed fire in the northern Rockies: Implications for Stone's sheep and elk

ABSTRACT

Prescribed fire typically increases the quality and quantity of forage for grazing ungulates. In the early 1980's a prescribed-burn program was initiated in northeast British Columbia in response to declining ungulate populations. We evaluated the effectiveness of this burning on 2 focal grazers, Stone's sheep (*Ovis dalli stonei*) and elk (*Cervus elaphus*), for which the burns are targeted. We implemented 4 prescribed fires and monitored the short-term vegetation (quantity and quality) and ungulate (Stone's sheep and elk) responses. We took measurements prior to burning, the year of burning, and 1 year after burning in treatment areas and adjacent unburned control areas in both winter and summer at 2 different scales. At the fine scale, we used vegetation transects and pellet counts; at the landscape scale, we used Landsat imagery for vegetation and aerial survey flights for animals. To assess grazing pressure, we installed 8 large range exclosures, 1 on each burn and unburned control area. With the reduction in shrubs following prescribed fire, burned communities increased herbaceous cover. Species diversity was reduced by burning, but it increased to almost that of unburned areas by 1 year after burning. Vegetation biomass increased to pre-burn levels by 1 year after burning; the rate of forage growth also was higher on burned areas than unburned control areas. Crude protein levels across sites increased 1–3% in the year of the burn compared to pre-burn levels. Forage digestibility on burned areas 1 year after burning was 4–5% higher than on control areas. Stone's sheep and elk always used burns more than controls in winter, at both scales. The grazing observed in this study did not impact forage quantity on burned or unburned sites. Elk used areas with more forage; Stone's sheep appeared to respond to forage quality at the fine scale. Prescribed burning is an

effective management tool for enhancing winter and summer range for grazing ungulates for at least 1 year after burning. We recommend long-term monitoring to track changes in grazing pressure in response to increased use of burned areas and to determine the length of time burned areas in the northern Rockies remain beneficial to both Stone's sheep and elk.

INTRODUCTION

Forage quantity, quality or both can limit population growth for large herbivores (Cook et al. 2001, Parker et al. 2009), which typically spend 40–60% of their day foraging (Wickstrom et al. 1984). Additional constraints on northern ungulate populations include predation (Milakovic 2008) and severe winters (Daily and Hobbs 1989, Shackleton 1999). When the management objective is to increase productivity of an ungulate population, management practices are often directed towards enhancing forage quality and availability by restructuring vegetation communities. A common approach used to achieve this goal is prescribed fire (Hobbs and Spowart 1984, Peck and Peek 1991, Ruckstuhl et al. 2000). Prescribed fires reset the successional stage of plant communities and can lead to increases in net primary productivity of forage plants (Turner et al. 1997). Vegetation response to fire varies by species (Keeley et al. 2005), timing (Owensby and Anderson 1967), and severity of the fire (de Groot et al. 2004). Following burns, some studies have found significant, but often short-lived increases in forage quality as measured by crude protein and digestibility of available forage (Van Dyck and Darragh 2007, Greene 2010) and longer-term increases in forage quantity (Singer and Harter 1996, Sachro et al. 2005, Van Dyke and Darragh 2007). Other researchers have reported no difference in nutritional value, but rather changes in forage abundance and composition after fire that increased foraging efficiency by grazing ungulates (Hobbs and Spowart 1984, Seip and Bunnell 1985*b*, Canon et al. 1987).

British Columbia (BC) has a long history of prescribed fire. First Nations used prescribed fires primarily for food production, recognizing the benefits to wildlife habitat (Turner 1991, Gottesfeld 1994); early settlers used and guide outfitters still use spring burns to enhance range for their livestock and horses. In northeastern BC, a prescribed-burn program (Peace-Liard Prescribed Burn Program) was initiated in the early 1980's by BC government wildlife biologists in response to declining ungulate populations (AMEC 2002). Originally it began as an elk (*Cervus elaphus*) enhancement project, but later expanded to moose (*Alces alces*), Stone's sheep (*Ovis dalli stonei*) and mountain goats (*Oreamnos americanus*). Up to 7,800 ha are intentionally burned each spring, typically targeting south- and west-aspect slopes in an effort to create, maintain and enhance habitat for large game species (Lousier et al. 2009). Although the use of prescribed fire is not welcomed unanimously among managers and is thought to negatively impact some species (Wambolt et al. 2001), this burn program is assumed to be successful by most northern residents because it is effective at increasing productivity of some ungulate populations (Lousier et al. 2009). Several studies have documented seasonal use of burns by ungulates in other areas farther south (Zimmerman 2004, Sachro et al. 2005, Van Dyck and Darragh 2007), but in northern BC there have been very few efforts to document the effects of prescribed burning on wildlife (Seip 1983, Peck 1987). No studies have quantified both vegetation and ungulate responses to prescribed fire using a multi-scale approach.

Elk and Stone's sheep are the 2 focal grazers in northern BC for which prescribed fires are currently implemented. Elk are regarded as adaptive foragers (Houston 1982), typically selecting grasses when available (approximately 80% of the time; Morgantini and Hudson 1989, Cook 2002), but optimally shifting between grasses and shrubs when grasses are less available (Singer 1979, Hanley 1982). Burned areas may provide excellent foraging opportunities for seasonal use by elk (Van Dyck and Darragh 2007, Gillingham and Parker 2008*a*). Due to their generalist diet and ease of dispersal, elk have now expanded their range in northern BC (Shackleton 2013). Prescribed fires may be facilitating this expansion (Shackleton 1999); as elk move on burned slopes into the small traditional ranges of Stone's sheep, there is concern regarding potential niche overlap leading to adverse affects on Stone's sheep.

Stone's sheep are native only to northern BC and the southern Yukon and are found nowhere else in the world (Shackleton 1999, Demarchi and Hartwig 2004). They forage on a wide range of alpine plants, with grasses (i.e., *Elymus innovatus* and *Poa* spp.) and sedges (i.e., *Konewai mysuroides*) constituting a major part of their diet (Luckhurst 1973), and occasionally on the leaves of some shrubs (Seip 1983). Stone's sheep show strong site fidelity and philopatry to seasonal ranges (Geist 1971, Hengeveld and Cubberly 2011). If prescribed burns are present, Stone's sheep may utilize them seasonally (most frequently in late winter and early spring), moving down from higher elevation to take advantage of these early seral habitats (Seip and Bunnell 1985*a*, Walker et al. 2007).

Selective herbivory by large mammals at high population densities results in changes to composition and structure of plant communities (Augustine and McNaughton 1998, Rooney 2001). Fire and grazing typically do not function independently, rather as 2 disturbance agents that are spatially and temporally dependent on each other (Fuhlendorf et al. 2008). In grassland ecosystems, grazing is promoted by spatially discrete fires and foraging bouts lead to increases in patch-level heterogeneity (Fuhlendorf and Engle 2004). As elk populations expand their range in the mountainous regions of northern BC in response to the availability of early seral vegetation, the increased herbivory coupled with utilization of burned areas is likely impacting vegetation structure. Relatively few data are available that isolate the influence that fire has on vegetation from the impacts of herbivory. Luckhurst (1973) documented plant community associations of Stone's sheep using exclosures in the absence of fire and Seip (1983) compared quality and quantity of forage available between burned (older burns up to 9 years old) and unburned ranges in the presence of herbivory.

Understanding how grazing and fire influence the structure and composition of vegetation is important for the continued use of prescribed burning as an active management tool for focal ungulates.

In this study we evaluated the effectiveness of the prescribed-burn program in enhancing ungulate range to gain a more thorough understanding of the interactions among fire, forage and herbivory. We monitored both the vegetation (quantity and quality) and animal (elk and Stone's sheep) response to 4 different prescribed burns by taking measurements prior to burning, the year of the burn and 1 year after the burn in both winter and summer at 2 different scales. At the fine scale, we used vegetation transects and pellet counts; at the landscape scale, we used Landsat imagery for vegetation and fixed-winged survey flights for animals. Our 3 main objectives were: 1) to monitor the short-term vegetation response to prescribed fire by quantifying changes in forage quantity and quality after burning; 2) to monitor use of prescribed burns by Stone's sheep and elk; and 3) to assess whether grazing impacted vegetation quantity and composition. We predicted higher use of burned areas by elk and Stone's sheep in response to increased forage quality and quantity and no changes in use of unburned areas. We expected these increases in forage metrics and animal response would be apparent in both summer and winter. This quantification of plant and animal response is part of a larger effort to assess how Stone's sheep and elk share a heterogeneous landscape, provided by topography and prescribed burning.

STUDY AREA

The Muskwa-Kechika Management Area of northern BC stretches from near the BC-Yukon border south towards Williston Lake, encompassing approximately 6.4 million ha. It is divided into various conservation and management zones, ranging from areas protected as parks to areas that allow some level of resource development. This study was concentrated in the Besa-Prophet area, specifically within the Besa-Prophet Pre-Tenure Planning Area (Figure 2.1), which is a management zone designed to guide environmentally responsible development of future oil and gas exploration and extraction (British Columbia Ministry of Sustainable Resources 2004). The pre-tenure planning area covers 204,679 ha in the foothills of the Rocky Mountains, between 57°50'–57°20' N latitude and 123°45'–123°10' W longitude.

Elevations in the Besa-Prophet area range from ~700–2200 m, with tree line occurring between 1450–1600 m (Lay 2005). There are 3 biogeoclimatic zones: Boreal White and Black Spruce (BWBS), Spruce-Willow-Birch (SWB), and Boreal Altai Fescue Alpine (BAFA), with a natural fire return interval of 100 to 200 years (Table 2.1). Repeatedly burned south-facing slopes were dominated by fuzzy-spiked wildrye (*Elymus innovatus),* fireweed *(Epilobium angustifolium*), tall bluebells (*Mertensia paniculata*) and alpine sweet-vetch (*Hedysarum alpinium*); as the burned slopes aged, aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*) and willows (*Salix* spp.) dominated the shrub layers (Lay 2005). Previously burned west-facing slopes were typically dominated by scrub birch (*Betula glandulosa*), willows, and shrubby cinquefoil (*Potentilla fruticosa*) and dwarf shrubs such as lingonberry (*Vaccinium vitis-idea*) and bearberry (*Arctostaphylus uva-ursi*) formed mats on the ground.

The Besa-Prophet area supports one of the most diverse large mammal predator-prey systems in North America. Large mammals found in the area include mountain goats, moose, elk, Stone's sheep, introduced plains bison (*Bison bison*), black bears (*Ursus americanus*), grizzly bears (*Ursus arctos*), wolves (*Canis lupus*), wolverines (*Gulo gulo*), lynx (*Lynx canadensis*), and the occasional mule deer (*Odocoileus hemionus*) and white-tailed deer (*Odocoileus virginianus*). Although the Besa-Prophet area has severe, cold

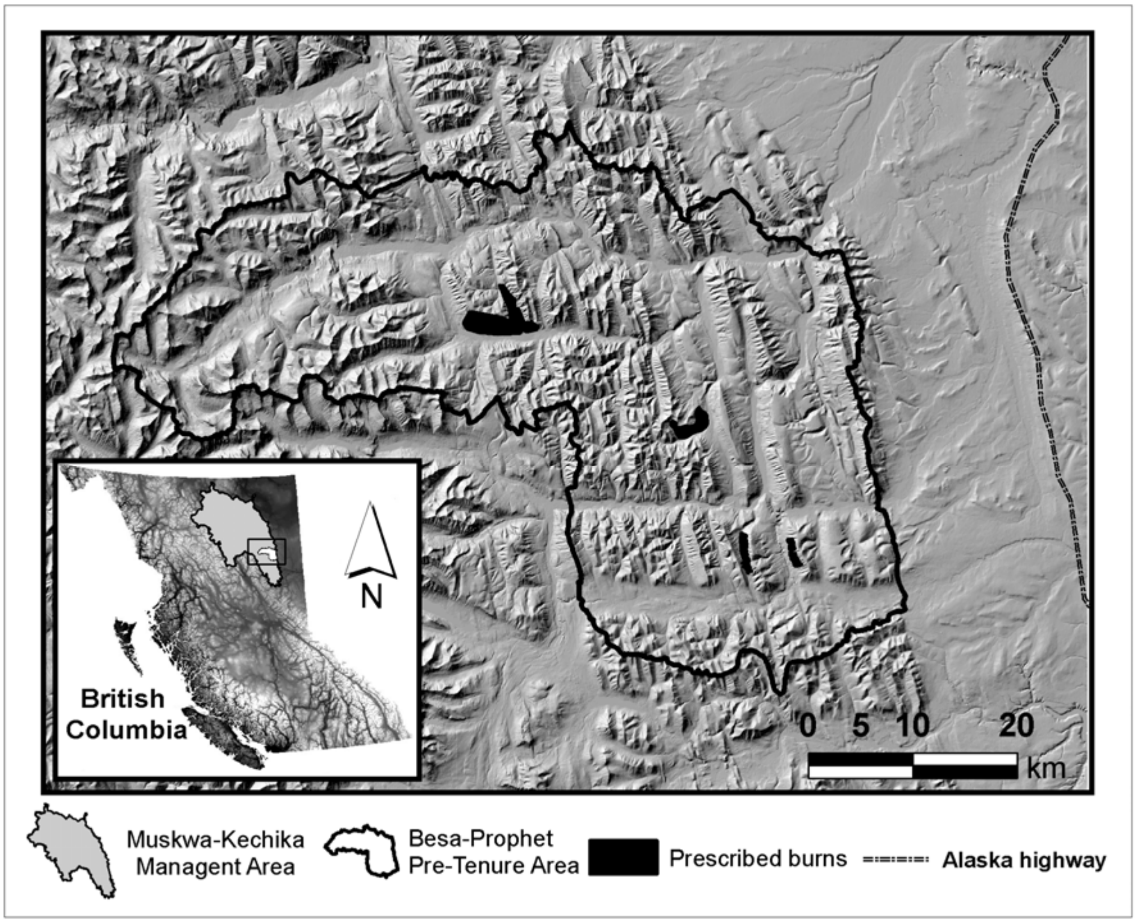

Figure 2.1. Location of 4 prescribed burns (black polygons) in relation to topography within the Besa-Prophet area of northern British Columbia. The Besa-Prophet Pre-Tenure Planning Area is outlined in black within the Muskwa-Kechika Management Area (in grey) and a map of British Columbia is shown in the bottom-left corner.

Table 2.1. The 3 Biogeoclimatic Ecosystem Classification (BEC) zones and their natural fire-return intervals found in the Besa-Prophet area in northern British Columbia.

BEC Zone	Elevation Range[a]	Fire Return Interval [b]	Dominant Vegetation [c]
Boreal White and Black Spruce (BWBS)	700–1,300 m	100–125 years	white spruce (*Picea glauca*), black spruce (*P. mariana*)
Spruce-Willow-Birch (SWB)	900–1,500 m	~ 200 years	subalpine fir (*Abies lasiocarpa*), scrub birch (*Betula glandulosa*), willow shrubs (*Salix* spp.)
Boreal Altai Fescue Alpine (BAFA)	1,600–2,200 m	N/A	some fescues and grasses, herbs, mosses, and bare rocks or covered with lichens

[a] Lay 2005
[b] British Columbia Ministry of Forests 1995
[c] Meidinger and Pojar 1991

winters (Delong et al. 1991), the south-facing slopes and low snow pack on exposed alpine and subalpine ridges provide access to forage for many ungulates (Walker 2005, Gillingham and Parker 2008*a*). Spring can come late and fall early. With longer daylight hours, however, the growing season is short but intense compared to areas farther south.

METHODS

Prescribed burns

Prescribed burns were implemented in the spring of 2010 (between 15 May and 1 June) at 4 sites: Luckhurst, a site on the west side of Luckhurst Mountain in the southeast corner of the Besa-Prophet Pre-Tenure Planning Area; Nevis, a west-facing site on the slope above Nevis Creek located on the mountain just east of Luckhurst; Richards, a south-facing slope in the Richards Creek drainage in the northern portion of the pre-tenure area; and Townsley, another south-facing slope located near the center of the pre-tenure area in the Townsley Creek drainage. The burns were implemented by BC government wildlife biologists as part of the Peace-Liard Prescribed Burn Program using a delayed-aerial-ignition device system (Rothermel 1984). This method allows for multiple ignition sites and the resultant landscape is a mosaic of unburned patches within a larger burned area. All sites except Luckhurst had been burned previously (although the new Luckhurst burn area extended the area of previous burns). The 2010 burns ranged in size from 150–1,000 ha (Table 2.2). The burn on Luckhurst occurred 2 weeks later than the other sites because of high snow accumulation on the site.

Fine-scale vegetation monitoring

Prior to implementing the 2010 prescribed fires, we selected 4 unburned (control) areas to be as similar as possible to burned (treatment) areas in pre-burn vegetation, elevation, aspect and slope. We identified potential areas using Geographic Information

Table 2.2. Descriptions and site history of 4 prescribed burns implemented in the Besa-Prophet area in northern British Columbia in 2010. Four unburned control areas were located on similar aspects near prescribed burns.

Site	**Area (ha)**	**Aspect**	**Date Burned**	**Years Burned**
Luckhurst†	150	West	01 June 2010	1984, 1987, 2001, 2010
Nevis	300	West	16 May 2010	1984, 1987, 2001, 2010
Richards	1,000	South	15 May 2010	1981, 1985, 1987, 1991, 2002, 2010
Townsley	370	South	16 May 2010	1987, 2010

† The 2010 burn on Luckhurst was a new area adjacent to previous burns.

Systems (GIS) in ArcMap (ESRI 2011. ArcGIS Desktop: Release 10. Environmental Systems Research Institute. Redlands, CA) and then confirmed similarities visually from a helicopter. To control for the effect of elevation on vegetation response to fire, each burned and unburned area was stratified by an elevational gradient.

In early May 2010, as soon as the snow melted and prior to burning, we established 3 permanent 50-m transects within each burned and unburned area at high, mid, and low elevations. We noted the general vegetation community, elevation, aspect, and slope for each transect (Appendix A). We used line-intercept to measure absolute cover of herbaceous plants (grasses and forbs), bare ground (rocks and bare soil), shrubs by species along the 3 permanent transects in each area (Bonham 1989). We placed 3 sampling plots (1 × 1 m) along each transect at 0 m, 25 m, and 50 m. We measured the height and estimated percent cover of all species using Daubenmire cover classes (Daubenmire 1959, Stohlgren 2007). Height was measured for up to 10 individuals from each species and averaged. We calculated forage volume by summing up the products of the average height of each species and its percent cover (Johnson 2000). In subsequent summer sampling, we quantified species diversity using Simpson's Diversity Index (Krebs 1999) and we defined species richness as the number of species found in all 3 plots along each transect. We clipped all vegetation (except large shrubs and trees) to the ground, within a 0.25-m^2 quadrat on an outside corner of each 1-m^2 plot, for estimates of biomass and nutritional quality. We sorted the clipped samples into the following classes: graminoids/forbs, dwarf shrubs (by species), and shrubs (by species) for air drying in paper bags. We then dried all samples using a forced-air oven at 50°C for 4 days (Parker et al. 1999) and weighed sample biomass to the nearest 0.01 g. We defined forage as a mix of graminoids and forbs that are known to be available and typically consumed by elk and Stone's sheep (Appendix B).

To distinguish between the impacts of herbivory and the impacts of fire on vegetation communities, we placed 1 permanent range exclosure at mid elevation on each burned area and its associated control (Stohlgren 2007) in June 2010. We built the frame of the exclosures with 5-cm square, hollow steel tubing and welded agricultural woven wire for the fencing. The 8 × 8-m exclosures were 2 m high and weighed ~545 kg. We used an A-STAR B2 helicopter to move the exclosures and because of the extreme slopes on many of the sites (>35^{o}), we placed them with 1 corner facing up mountain to help prevent excess snow build-up in winter.

We sampled vegetation inside and outside the permanent exclosures starting in mid-late July 2010. We refrained from sampling within 0.5 m of the fencing to control for potential edge effects of the fencing on vegetation. We placed 3 parallel line-intercept transects (7 m long) at 1.5 m, 3.5 m and 5.5 m (from the top edge of the fencing) to measure percent cover following the methods above. We placed 3 plots (1 × 1 m) on each transect to sample as above for species cover, height and biomass. Five m away from each exclosure, we established a paired same-sized, non-enclosed area and sampled on transects following the same sampling scheme as for the exclosure.

We monitored vegetation on the transects and exclosures in mid-late July 2010 and 2011, representing maximum summer biomass and nutritional value the year of and 1 year following the prescribed burns, and in early May 2011 and 2012, representing late winter nutritional quantity and quality the year of and 1 year after the prescribed burns. With each subsequent sampling period, we moved each sampling plot over 1 m along each transect to avoid sampling in a previously clipped quadrat. In May 2012, we also measured vegetation height every 10 m along the 50-m transects to quantify differences in visibility between burned and unburned areas.

Nutritional quality

We determined nutritional quality of forage after fire from subsamples of the vegetation clipped at each burned area and compared it to unburned areas. We ground the dried forage clippings from each quadrat in a Wiley Mini-Mill (Arthur Thompson Company, Philadelphia, PA) with a 1-mm screen. We submitted subsamples for quantification of elemental nitrogen (Ministry of Environment Analytical Chemistry Services Lab, Victoria, BC) and estimated percent crude protein (CP) as the total nitrogen (g N/g forage) multiplied by 6.25 (Robbins 1993). We used sequential detergent analysis (without sodium sulfite) to quantify neutral detergent fiber (NDF) and acid detergent fiber (ADF) using an Ankom^{200} Fiber Analyzer (ANKOM Technology, Macedon, NY) and assayed lignin and ash content (Van Soest 1994). We estimated digestible dry matter (g/100g; hereafter referred to as digestibility) as in Hanley et al. (1992), without silica or tannins, and multiplied it by forage biomass per quadrat to obtain available digestible dry matter (g DDM). We determined available digestible protein per unit area (g DP) by multiplying digestible protein (g/100g; Hanley et al. 1992) by forage biomass.

Burn severity and landscape-level vegetation response to fire

During the pre-burn vegetation monitoring in May 2010, we placed 3 depth-of-burn pins in the ground at 1-m intervals perpendicular to each transect (i.e., 1 on, 1 above and 1 below the transect) on areas that were scheduled for prescribed burns. Depth-of-burn pins are used to measure the depth of vegetation and soil consumed by fire and to provide a relative index of burn severity (Stock 1987). Severity is the magnitude or degree of environmental change (e.g., loss of vegetation biomass and soil) caused by fire (Pickett and White 1985, Keeley 2009). We revisited burned areas within a week of the burn to measure the depth of each burn and retrieve the burn pins. Several pins were pulled out of the ground presumably by elk, especially at the lower elevations of the Townsley area, where the transect was close to an animal trail. The Nevis area did not burn well where the depth-of-burn pins were placed and measurements were taken on only 2 of 44 potential depth-of-burn pins.

We used multi-spectral images from Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper (+ETM) to determine the broad-scale vegetation response to fire. We downloaded scenes at maximum green-up in July–Aug of 2010 (year of the burn) and 2012 (2 years after the burn); reasonable cloud-free images were not available for any site in 2011. We used the normalized difference vegetation index (NDVI) to monitor changes in vegetation biomass (net primary productivity) in response to prescribed burning through time (Tucker and Sellers 1986, Purevdorj et al. 1998, Hope et al. 2007). NDVI was not assessed at the Townsley area in July 2012 because no cloud-free imagery was available.

We used the delta-normalized burn ratio (dNBR) to determine landscape-level burn severity and to measure the extent of the fires (Appendix C). dNBR is correlated with the amount of pre-burn photosynthetic activity and provides an indication of how much vegetation was killed/consumed by the fire (Miller and Thode 2007). The dNBR is derived by subtracting a post-fire from a pre-fire multi-spectral NBR Landsat TM/+ETM image. Post-fire images were within 3 weeks of the prescribed burns.

In 2003, the scan-line corrector (SLC) on Landsat 7 failed (National Aeronautics and Space Administration 2013). Although the satellite continues to function normally with the SLC off, there are narrow black stripes with no data across the images. We removed data from between the black stripes using the EASI Modeler in a raster GIS program (PCI, Geomatics version 10.1, Richmond Hill, ON) and only used NDVI and dNBR data in between the stripes. Burn extents were estimated for areas with malfunctioned data by using a GPS track from a helicopter that flew the border of the burn. Landsat 5 has a working SLC, so when available we preferred images from this satellite.

Animal response to prescribed burns

We monitored fine-scale animal use of burns with pellet-count transects (Neff 1968) at the same time as vegetation sampling. We established belt transects (100 m × 4 m) in both burned and unburned areas. The first 50 m of the belt transects were on the vegetation monitoring transects and then we extended the belt transects an additional 50 m. We recorded the species of each ungulate pellet group (5 pellets or more) and cleared all pellet groups from the transects to avoid double counting in subsequent sampling. We also recorded any additional scat/sign from other animals found within the belts.

To better understand the temporal and spatial use of the burned and control areas by groups of elk and Stone's sheep in the Besa-Prophet area, we began monthly fixed-winged (Cessna 172) survey flights in June 2011. We flew animal-distribution flights every month until May 2012, except November and December 2011 (due to weather and pilot issues) over each treatment and control area. For all animals observed, we recorded group size, elevation (high, mid, low) and whether they were in 1 of the 4 burned or 4 unburned control areas.

STATISTICAL ANALYSIS

We used transects as the sampling unit for all our analyses of vegetation and pellet counts. Data collected in the 3 plots along each transect were averaged before analysis. Burn severity was averaged from 3 depth-of-burn pins within 1 m of each other at 5 points along each transect. Data were transformed as needed to meet the assumptions of normality and equality of variances. All means in the text are presented as raw means ± standard error (SE) unless otherwise noted. All statistical analyses were performed in Stata 12.0 (StataCorp 2012. Release 12. College Station, TX). Level of significance for all tests was set to $\alpha = 0.05$.

Burn severity

The areas where burn pins had been placed on Nevis prior to the prescribed burn did not burn and, therefore, the Nevis site was dropped for the analysis of burn severity. To examine burn severity across sites (Luckhurst, Richards, Townsley), we tested the depth of burn using an analysis of covariance (ANCOVA) with elevation of each burn pin as the covariate. We tested the assumption of parallelism among treatments by initially including the interaction term of site × elevation in the model. We used descriptive statistics to examine trends over time in dNBR and NDVI obtained from Landsat imagery using PCI (Geomatics version 10.1, Richmond Hill, ON).

Vegetation quantity and quality

To examine the influence of prescribed burning on vegetation quantity (i.e., forage biomass, forage volume, forage cover, shrub cover) and on forage quality (CP, g DP, digestibility, g DDM), we used mixed-effects regression models (xtmixed; Rabe-Hesketh and Skrondal 2008) testing the effects of burning versus unburned controls, elevation (high, mid, low) and site (Luckhurst, Nevis, Richards, Townsley). We used reference coding to include all 3 independent categorical variables in a regression framework. Year was included in the model to account for the repeated nature of all measurements, and individual transects were nested within site. Because xtmixed models did not provide a traditional measure of model significance, we assumed that a factor in the model was significant if any level of that factor differed significantly from the reference level. To control for experiment-wide type I error, we examined any significant factors with 95% Bonferroni confidence intervals applied to the adjusted means (i.e., means for each level of each factor that have been adjusted for all other factors in the model) to assess differences among factors with more than 2 levels. Because vegetation structure and composition differed seasonally, we tested post-burn effects in summer and winter separately (summer: year of burn–July 2010, 1 year after burning–July 2011; winter: year of the burn–May 2011, 1 year after burning–May 2012).

Rate of forage growth

To assess the relative magnitude of post-burn forage growth compared to forage growth on unburned areas, we used a multi-way analysis of variance (ANOVA) with a difference variable calculated from the seasonal change in biomass (i.e., July 2011–July 2010, May 2012–May 2011). We included treatment (burned, unburned), elevation (high, mid, low) and site (Luckhurst, Nevis, Richards, Townsley) in the analysis. Bonferroni 95% confidence intervals were applied to the adjusted means where appropriate.

Vegetation composition

We examined the changes in vegetation composition (diversity and richness) after burning for summer only, using the same approach to forage quantity and quality (i.e., a mixed-effects regression). For species richness, however, we used a mixed-effects regression model with a Poisson distribution (Stata: xtmepoisson) because the data were count data. Again, we examined 95% Bonferroni confidence intervals to assess differences among levels for factors with more than 2 levels (i.e., elevation and site).

Vegetation height

We tested whether vegetation height 1 winter after burning varied with treatment (burned, unburned), elevation (high, mid, low) or site (Luckhurst, Nevis, Richards, Towsley) using a multi-way ANOVA. Differences within factors that were significant in the ANOVA and had more than 2 levels were determined using 95% Bonferroni confidence intervals applied to the adjusted means.

Winter vegetation in pre-burn versus post-burn areas

To examine how forage value (quantity and quality) in winter changed yearly from pre-burn to post-burn conditions, we ran the xtmixed model with winter data (biomass, volume, forage cover, shrub cover, CP, g DP, digestibility, g DDM) from burned areas only for pre-burn (2010), the year of the burn (2011), and 1 year after the burn (2012) with the same factors (site, elevation, year). Because the areas sampled during the pre-burn vegetation monitoring on Nevis did not burn, the vegetation transects were moved to the adjacent actual burn. Consequently, Nevis was dropped from all analyses relating to pre-burn data.

Pellet counts

To quantify past use by Stone's sheep and elk, we used the pellet counts on control and treatment areas prior to burning. We used a generalized linear model with a Poisson distribution to test the effects of site, elevation and treatment for each species. We examined the adjusted means for each factor and used the 95% Bonferroni confidence intervals as appropriate. Data for elk and Stone’s sheep were run separately. To quantify the post-burn use of areas by Stone's sheep and elk, we tested the number of pellet groups counted on burned versus unburned areas, by elevation and site using the xtmepoisson model following the same approach as for species richness. We ran 1 model for each species in both summer and winter.

Distribution flights

To assess whether numbers of Stone's sheep and elk recorded during the fixed-winged flights varied by elevation, season (summer: May–Aug; winter: Jan–Apr), site, or treatment (burning versus unburned), we used a generalized linear model with a Poisson distribution. We examined the adjusted means for each factor and used the 95% Bonferroni confidence intervals to determine the difference among levels of each factor (with more than 2 levels) that was significant in the regression. The 2 fall months (October, September) were dropped from the analysis for a balanced statistical design and to be comparable with vegetation and pellet analyses.

Grazing

To test if grazing influenced forage quantity (biomass, volume, cover) and diversity (in summer only), we used the same mixed-model regression approach as above with treatment and site, but replaced elevation with grazed (non-exclosures) versus ungrazed (exclosures). We tested summer and winter separately. We examined the adjusted means, and used 95% Bonferroni confidence intervals applied to the adjusted means to assess differences among levels of significant factors.

RESULTS

Prescribed fires and burn severity

Approximately 1,820 ha were burned in 2010 at the 4 different sites in the study area. There was a marginal significant effect of site on burn severity ($F_{2, 40} = 3.25$, $P = 0.049$) and although Luckhurst had a higher average depth of burn (Table 2.3), none of the individual site means were statistically different from each other. At the landscape level, dNBR was high at Luckhurst, followed by Townsley, Richards and then Nevis (Table 2.3).

Vegetation quantity

Forage biomass varied by season, site, and elevation; and the influence of fire was scale-dependent. At the scale of the 50-m transect, the total amount of forage produced (i.e., biomass) after prescribed burning did not differ 1 year after burning from the unburned control areas in either season (both $z \leq 1.81$, $P \geq 0.70$; Tables 2.4, 2.5 and Tables D.1–D.5), but more forage grew back in summer on burned areas than on control areas ($F_{1,23} = 6.89$, $P = 0.017$). On burned areas only, there was less forage biomass in winter the year of the burn compared to pre-burn conditions, but forage biomass rebounded to pre-burn levels by 1

Table 2.3. Average burn severity (measured at 2 spatial scales in May–June 2010) and the resulting landscape-level vegetation biomass (July 2010, 2012) following prescribed burning in May 2010 at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area in northern British Columbia. Burn severity was measured as averaged depth of burn (DOB) using pins along transects and as delta-normalized burn ratio (dNBR) derived from Landsat imagery. Vegetation biomass at the landscape scale was derived from Landsat imagery using the normalized difference vegetation index (NDVI).

Site	DOB ± SE (cm)	dNBR ± SD[††]	NDVI ± SD (July 2010)		NDVI ± SD (July 2012)	
			Burn	Control	Burn	Control
Luckhurst	6.2 ± 0.57	0.71 ± 0.17	0.24 ± 0.07	0.45 ± 0.04	0.33 ± 0.08	0.41 ± 0.06
Nevis	0.2 ± 0.12	0.51 ± 0.18	0.34 ± 0.06	0.43 ± 0.07	0.32 ± 0.08	0.40 ± 0.08
Richards	4.9 ± 0.35	0.52 ± 0.11	0.24 ± 0.07	0.33 ± 0.09	0.36 ± 0.09	0.34 ± 0.07
Townsley[†]	3.2 ± 0.41	0.67 ± 0.10	0.27 ± 0.09	0.33 ± 0.07	0.34 ± 0.07	

[†] No Landsat imagery was available in July 2012 for this site.
[††] SD was used to show variation among all of the pixels within each burned area.

Table 2.4. Adjusted means for the effects of treatment (prescribed burn, unburned control), site, elevation and year on summer vegetation and animal-use parameters using mixed-effects regression models for vegetation quantity (forage biomass (g/0.25 m^2), forage volume (cm^3), forage cover (% herb cover), % shrub cover); vegetation composition (Simpson's diversity index, species richness); forage quality (crude protein (CP, %), available digestible protein (g DP, g/0.25m^2), digestibility (g/100 g), available digestible dry matter (g DDM, g/0.25m^2); and Stone's sheep and elk pellet counts (number/400m^2). Adjusted means sharing the same superscript for the same parameter were not different based on overlapping 95% Bonferroni confidence intervals around those adjusted means; the treatment effects of burn and control were assessed directly from the model output.

Parameter†	Treatment		Site				Elevation			Year	
	Burn	Control	Luckhurst	Nevis	Richards	Townsley	High	Mid	Low	2010	2011
Biomass	18.53^{a}	12.66^{a}	3.67^{c}	8.95^{c}	31.04^{d}	27.53^{d}	10.40^{g}	15.80^{gh}	21.12^{h}	13.14^{j}	17.95^{k}
Volume	53373.2^{a}	50389.9^{a}	20185.3^{c}	29969.4^{c}	87994.8^{d}	69376.8^{d}	34140.4^{g}	54227.5^{gh}	67276.8^{h}	38625.4^{j}	65137.8^{k}
Herb cover	86.0^{a}	98.1^{b}	41.8^{c}	96.0^{d}	97.2^{d}	99.5^{d}	65.7^{g}	98.0^{h}	98.4^{h}	90.2^{j}	97.2^{k}
Shrub cover	17.6^{a}	45.6^{b}	29.7^{cd}	52.4^{c}	12.1^{d}	32.7^{cd}	25.2^{g}	30.7^{g}	34.3^{g}	26.8^{j}	33.3^{j}
Diversity	0.79^{a}	0.85^{b}	0.80^{c}	0.84^{c}	0.78^{c}	0.85^{c}	0.80^{g}	0.83^{g}	0.82^{g}	0.79^{j}	0.84^{k}
Richness	2.46^{a}	2.74^{b}	2.35^{c}	2.69^{de}	2.51^{d}	2.85^{e}	2.50^{g}	2.66^{g}	2.64^{g}	2.55^{j}	2.65^{k}
CP	15.26^{a}	13.70^{b}	15.82^{c}	13.25^{d}	14.70^{cd}	14.15^{cd}	14.70^{g}	14.07^{g}	14.67^{g}	14.79^{j}	14.17^{j}
g DP	185.90^{a}	116.29^{b}	40.46^{c}	76.49^{c}	314.46^{d}	255.92^{d}	99.32^{g}	155.20^{gh}	201.74^{h}	130.94^{j}	168.37^{k}
Digestibility	62.14^{a}	59.38^{b}	59.99^{c}	62.24^{c}	59.31^{c}	61.49^{c}	60.76^{g}	60.36^{g}	61.16^{g}	62.19^{j}	59.33^{k}
g DDM	1155.7^{a}	844.2^{a}	240.8^{c}	714.9^{c}	1825.2^{d}	1690.9^{d}	744.6^{g}	973.8^{g}	1301.8^{g}	846.6^{j}	1152.8^{k}
Elk††	0.27^{a}	-0.48^{a}	-0.20^{cd}	-1.56^{c}	0.75^{d}	0.57^{d}	0.43^{g}	-0.58^{g}	-0.17^{g}	-0.34^{j}	0.12^{k}
Stone's sheep	-0.09^{a}	-1.69^{b}	0.42^{c}	-0.79^{cd}	-2.50^{d}	-0.68^{cd}	0.26^{g}	-0.84^{gh}	-2.08^{h}	-1.72^{j}	-0.05^{k}

† Mixed-effects regression model used for vegetation quantity and quality (biomass, volume, herb cover, shrub cover, diversity, CP, g DP, digestibility, g DDM) and mixed effects regression model with a Poisson distribution used for count data (richness, elk and Stone' sheep pellet counts).

†† Negative values occur if use was low or none after being adjusted for treatment, site, elevation and year, in analyzed using a Poisson distribution.

Table 2.5. Adjusted means for the effects of treatment (prescribed burn, unburned control), site, elevation and year on winter vegetation and animal-use parameters using mixed-effects regression models for vegetation quantity (forage biomass (g/0.25 m^2), forage volume (cm^3), forage cover (% herb cover), % shrub cover); vegetation composition (Simpson's diversity index, species richness); forage quality (crude protein (CP, %), available digestible protein (g DP, g/0.25m^2), digestibility (g/100 g), available digestible dry matter (g DDM, g/0.25m^2); and Stone's sheep and elk pellet counts (number/400m^2). Adjusted means sharing the same superscript for the same parameter were not different based on overlapping 95% Bonferroni confidence intervals around those adjusted means; the treatment effects of burn and control were assessed directly from the model output.

Parameter†	Treatment		Site				Elevation			Year	
	Burn	Control	Luckhurst	Nevis	Richards	Townsley	High	Mid	Low	2010	2011
Biomass	10.53^{a}	7.97^{a}	2.14^{c}	5.03^{c}	20.07^{d}	15.60^{d}	4.62^{g}	11.10^{h}	13.11^{h}	7.12^{j}	11.56^{k}
Volume	13296.2^{a}	15126.7^{a}	2641.9^{c}	8715.9^{c}	28137.4^{d}	26928.4^{d}	7842.0^{g}	17205.1^{h}	18968.6^{h}	11101.0^{j}	17672.7^{k}
Herb cover	65.8^{a}	75.5^{a}	35.5^{c}	65.1^{cd}	90.3^{d}	91.6^{d}	44.8^{g}	80.1^{h}	86.9^{h}	68.1^{j}	73.1^{k}
Shrub cover	45.5^{a}	66.5^{b}	58.8^{c}	73.2^{c}	29.5^{d}	60.6^{c}	50.5^{g}	60.0^{g}	58.8^{g}	53.9^{j}	58.9^{k}
CP	9.14^{a}	5.95^{b}	13.56^{c}	5.70^{d}	5.75^{d}	5.18^{d}	8.40^{g}	6.98^{g}	7.26^{g}	8.84^{j}	6.26^{k}
g DP	16.93^{a}	10.41^{a}	7.29^{c}	3.50^{c}	31.40^{d}	12.50^{cd}	12.21^{g}	10.20^{g}	18.60^{g}	14.66^{j}	12.68^{j}
Digestibility	51.83^{a}	49.90^{b}	54.18^{c}	49.50^{d}	51.23^{cd}	48.55^{d}	52.77^{g}	50.48^{gh}	49.35^{h}	47.06^{j}	54.67^{k}
g DDM	595.06^{a}	437.56^{a}	194.91^{c}	275.42^{c}	1036.14^{d}	777.14^{d}	289.47^{h}	605.76^{h}	693.87^{g}	353.45^{j}	702.85^{k}
Elk ††	1.68^{a}	0.92^{b}	0.50^{c}	0.02^{c}	2.42^{d}	2.27^{d}	1.63^{g}	0.93^{g}	1.34^{g}	1.71^{j}	0.89^{k}
Stone's sheep	0.76^{a}	-0.67^{b}	1.25^{c}	1.29^{c}	-3.00^{d}	0.62^{c}	1.67^{g}	-0.08^{h}	-1.47^{h}	0.12^{j}	-0.03^{k}

† Mixed-effects regression model used for vegetation quantity and quality (biomass, volume, herb cover, shrub cover, CP, g DP, digestibility, g DDM) and mixed effects regression model with a Poisson distribution used for count data (elk and Stone' sheep pellet counts).

†† Negative values occur if use was low or none after being adjusted for treatment, site, elevation and year, in analyzed using a Poisson distribution.

year after the burn (Table 2.6). Because sites were either south-facing (i.e., Richards and Townsley) or west-facing (i.e., Luckhurst and Nevis), we examined the total biomass production by aspect. Forage biomass on the 2 south-facing sites did not differ from each other in either season (Tables 2.4, 2.5) and there was always more forage on these sites than on the 2 west-facing sites, which also did not differ from each other (Tables 2.4, 2.5; Figure 2.2). On burned and control areas, low elevations had 56–119% more forage biomass depending on site than high elevations (Tables 2.4, 2.5).

At a landscape level, vegetation biomass (based on NDVI values) appeared higher in control areas than in burned areas across all areas in the year of the burn (i.e., July 2010). No data were available for 2011, but in 2012 the vegetation biomass on the Richards and Townsley burned areas had increased (from 0.26 to 0.35 g/0.25 m^2) to control levels. Vegetation biomass also increased over this time on Luckhurst, but did not change on Nevis; neither reached control levels by 2 years post-burn (Table 2.3).

Forage volume followed trends similar to forage biomass (Tables 2.4, 2.5 and Tables D.1–D.5). Although there was no difference between burned areas and control areas across seasons (both $z \geq 0.62$, $P \geq 0.530$), there was more forage volume produced on burned areas than control areas from the first to second summer after burning ($F_{1,23} = 15.38$, $P = 0.001$). In burned areas only, pre-burn forage volume in the winter was not different from forage volume the year of the burn, but forage volume almost doubled 1 year after the burn compared to pre-burn amounts when adjusted for all other factors (Table 2.6). On burned and control areas, south-facing slopes (Richards and Townsley) did not differ from each other and always had more forage volume than west-facing slopes (Luckhurst and Nevis) in both seasons (Tables 2.4, 2.5). Low elevations had more forage volume than high elevations

Table 2.6. Adjusted means for winter vegetation in pre-burn versus post-burn conditions in burned areas only. Sampling occurred prior to burning (May 2010), the year of the burn (May 2011) and 1 year after burning (May 2012) at 3 sites (Luckhurst, Richards, Townsley) and 3 elevations (high, mid, low). Mixed-effects regression models where used for vegetation quantity (forage biomass (g/0.25m^2), forage volume (cm^3), forage cover (% herb cover), % shrub cover) and forage quality (crude protein (CP, %), available digestible protein (g DP, g/0.25 m^2), digestibility (g/100 g), available digestible dry matter (g DDM, g/0.25 m^2). Adjusted means sharing the same superscript for the same parameter were not different based on overlapping 95% Bonferroni confidence intervals around those adjusted means; the treatment effects of burn and control were assessed directly from the model output.

Parameter	**Site†**			**Elevation**			**Year**		
	Luckhurst	**Richards**	**Townsley**	**High**	**Mid**	**Low**	**2010**	**2011**	**2012**
Biomass	1.31^{a}	28.51^{b}	23.36^{b}	9.53^{d}	15.18^{d}	18.81^{d}	18.56^{g}	8.82^{h}	16.33^{g}
Volume	813.3^{a}	20997.6^{b}	27523.0^{b}	9793.6^{d}	14048.2^{d}	14844.3^{d}	9346.7^{g}	10383.5^{g}	19809.7^{h}
Herb cover	7.2^{a}	89.7^{b}	93.6^{b}	58.2^{d}	64.3^{d}	68.1^{d}	58.7^{g}	65.1^{g}	66.8^{g}
Shrub cover	69.8^{a}	29.6^{b}	0.46^{ab}	29.6^{d}	63.1^{d}	52.9^{d}	67.0^{g}	32.3^{h}	46.7^{gh}
CP	14.77^{a}	5.96^{b}	5.61^{b}	8.93^{d}	8.46^{d}	8.95^{d}	5.95^{g}	12.95^{h}	7.44^{gh}
g DP	6.72^{a}	49.35^{a}	30.09^{a}	28.59^{d}	17.07^{d}	40.50^{d}	42.18^{g}	25.81^{g}	18.18^{g}
Digestibility	55.61^{a}	48.92^{b}	47.70^{b}	51.14^{d}	51.00^{d}	50.09^{d}	47.35^{g}	49.03^{g}	55.85^{h}
g DDM	9.74^{a}	37.06^{b}	33.47^{b}	21.35^{d}	28.62^{d}	30.30^{d}	28.22^{g}	20.58^{h}	31.47^{g}

†The measured pre-burn site at Nevis did not burn. Consequently, Nevis was dropped from this analysis.

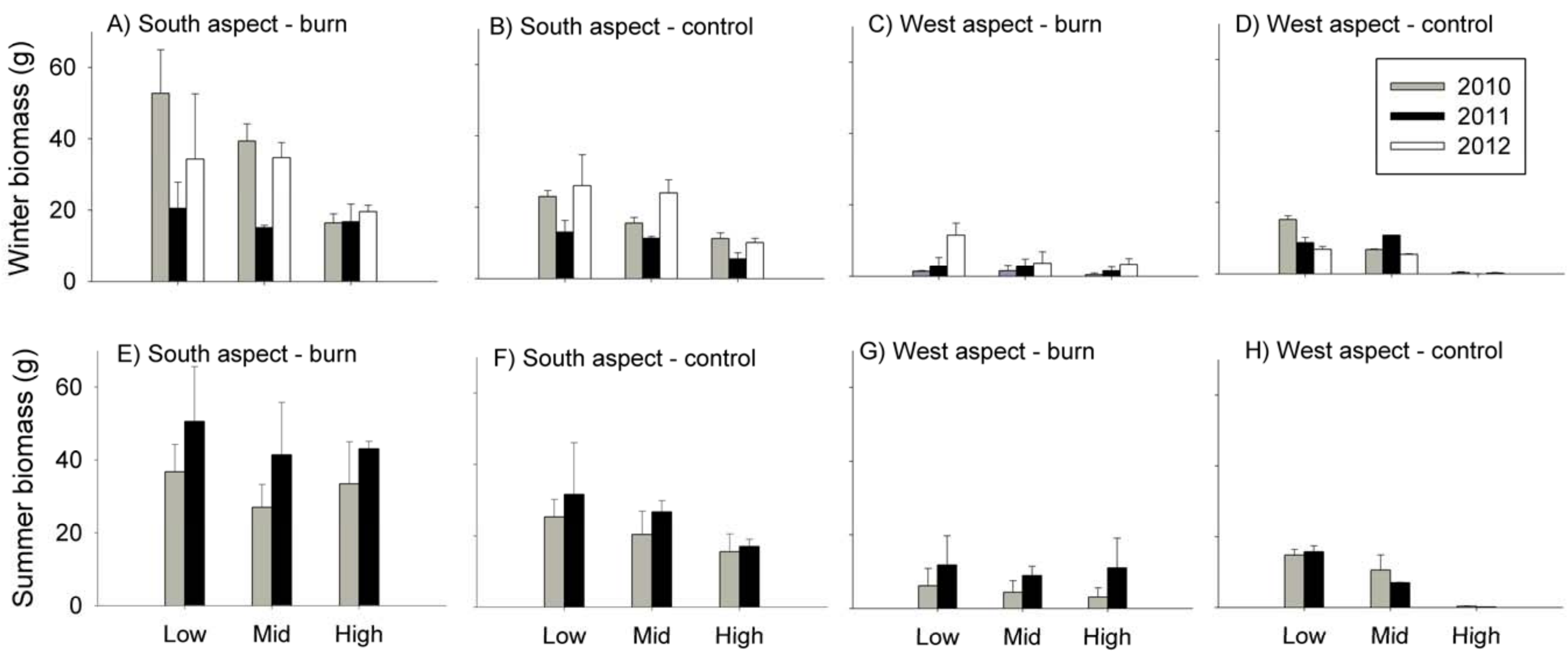

Figure 2.2. Average winter (A-D) and summer (E-H) forage biomass (g/0.25m^2 ± SE) at low, mid, and high elevations on south-aspect (Richards and Townsley) and west-aspect (Luckhurst and Nevis) sites in burned and control areas in the Besa-Prophet area in northern British Columbia. Sampling of vegetation in winter 2010 occurred prior to prescribed burning in May 2010.

in both seasons (Tables 2.4, 2.5).

Forage cover was less on burned areas than unburned control areas in summer (Table 2.4), but there was no significant difference in winter (Table 2.5). Forage cover at Richards, Townsley, and Nevis ranged from 77 to 99% (depending on treatment and elevation) in summer and was 63–91% in winter. At Luckhurst, forage cover ranged from 30 to 43% in both seasons (Tables 2.4, 2.5). On the burned area at Luckhurst, forage cover in summer was only 5–8% depending on elevation in the year of the burn (Table D.4) and 14–26% 1 year after the burn (Table D.5), with bare ground (mostly charred soil) comprising 40–92% of the transects across years and elevation. On all sites, higher elevations had 6–10% less forage cover in winter depending on the site and 26–28% less forage cover in summer compared to mid and low elevations (Tables 2.4, 2.5).

Burning reduced shrub cover across sites in both seasons (Tables 2.4, 2.5). In winter specifically, shrub cover in the year of the burn was less than pre-burn levels. One year later, even after the shrubs had started to rebound, shrub cover was still not at pre-burn levels (Table 2.6). Nevis retained the most post-burn shrub cover (summer: 54 ± 5%, winter: 62 ± 5%). Elevation did not influence shrub cover in either season, when adjusted for treatment and site (Tables 2.4, 2.5).

Vegetation height (mostly shrubs) at the end of the first winter after burning remained lower in burned areas than unburned control areas when adjusted for site and elevation ($F_{1,23}$ = 0.11.31, P = 0.004). Vegetation height across sites was not different ($F_{3,23}$ = 0.11, P = 0.955), but elevation did affect vegetation height ($F_{2,23}$ = 4.59, P = 0.025). Vegetation was taller at mid elevations (adjusted mean = 70.6 cm) than high elevations (adjusted mean = 30.3 cm); vegetation at low elevations was not different from either mid or high (adjusted mean = 53.3 cm) elevations. The transect at mid elevation at Richards had the highest post-burn vegetation height because the transect was located in a stand of dead shrubs (Figure 2.3).

We recorded 71 different plant species while sampling the 1 × 1-m plots during the 2 summers; of these, 57 different species were on south-facing slopes and 48 were on west-aspect slopes (Tables F.1–F.4). The most common species observed on south-facing burned slopes were fuzzy-spiked wildrye, sweet-vetch, fireweed and tall bluebell. On the west-aspect burns, most frequently observed species were fireweed, scrub birch, and bunchberry (*Cornus canadensis*). Burned areas had a lower number of species (i.e., richness) than control areas ($z = 3.40$, $P = 0.001$), with Richards and Luckhurst having the lowest richness (ranging from 7-14 species). Elevation did not affect species richness (Table 2.4). Burned areas also had lower species diversity than unburned control areas (Table 2.4). Species diversity was the lowest in burned areas in the year of the burn (i.e., summer 2010; Table D.2), but was comparable to control levels by 1 year after prescribed fire (Figure 2.4 and Table D.4). Elevation and site did not affect species diversity (Table 2.4)

Forage quality

Forage quality, as measured by digestibility and crude protein, was enhanced by burning, but the amount of increase varied with season. Prescribed burning significantly increased the digestibility of forage compared to control areas (both seasons $z \geq 2.02$, $P \leq 0.044$; Tables 2.4, 2.5), with the greatest difference occurring during the year of the burn when burned areas were 4-5% more digestible depending on site in both seasons. In winter on burned areas, digestibility was not different between the pre-burn year (43.2–51.4%, depending on site) and the year of the burn (42.7–51.0%; Table 2.6), but it increased 1 year after burning (54.3–56.9%; Table 2.6). Digestibility across burned and unburned areas did not differ among sites in summer (59.3–62.5%; Tables 2.4), but in winter Luckhurst had the

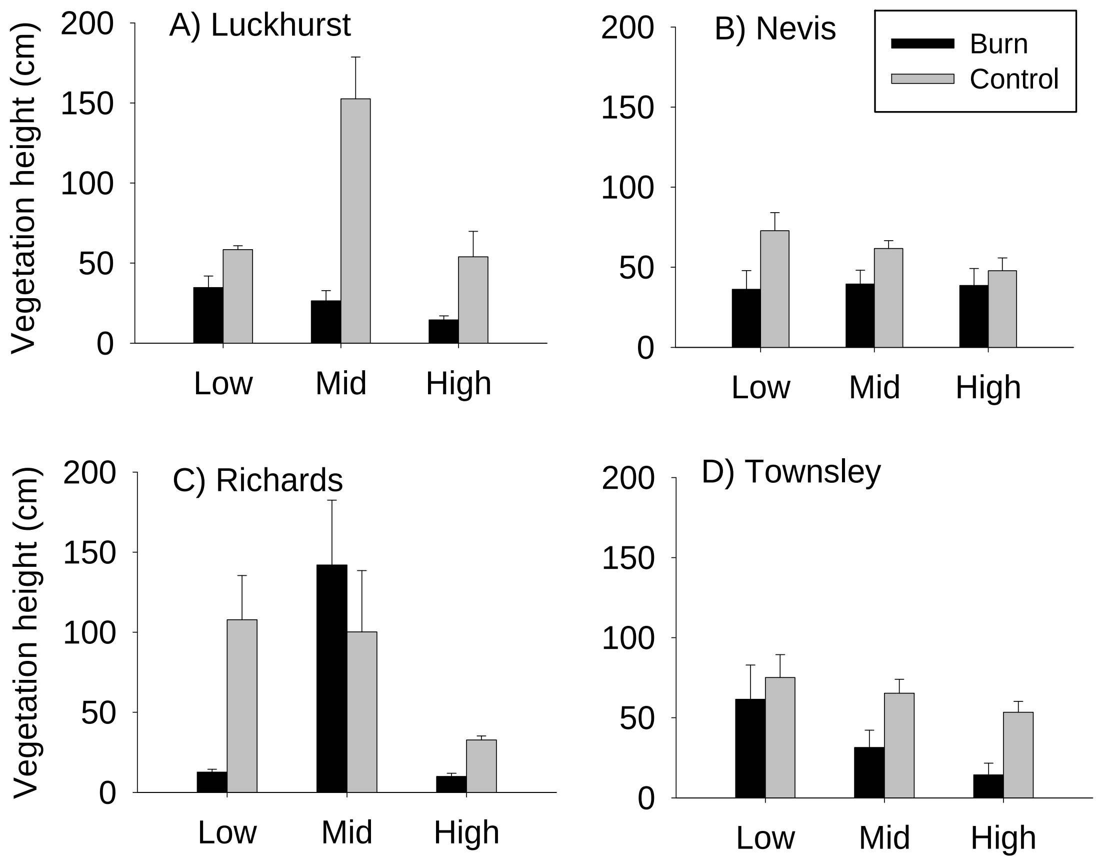

Figure 2.3. Average vegetation height (cm ± SE) measured every 10 m along 50-m vegetation transects at 3 elevations (high, mid, low) on 4 sites (Luckhurst, Nevis, Richards, Townsley) in burned and unburned control areas at the end of the first winter following burning in the Besa-Prophet area in northern British Columbia. Prescribed burns were implemented in May 2010; vegetation heights were measured in May 2012.

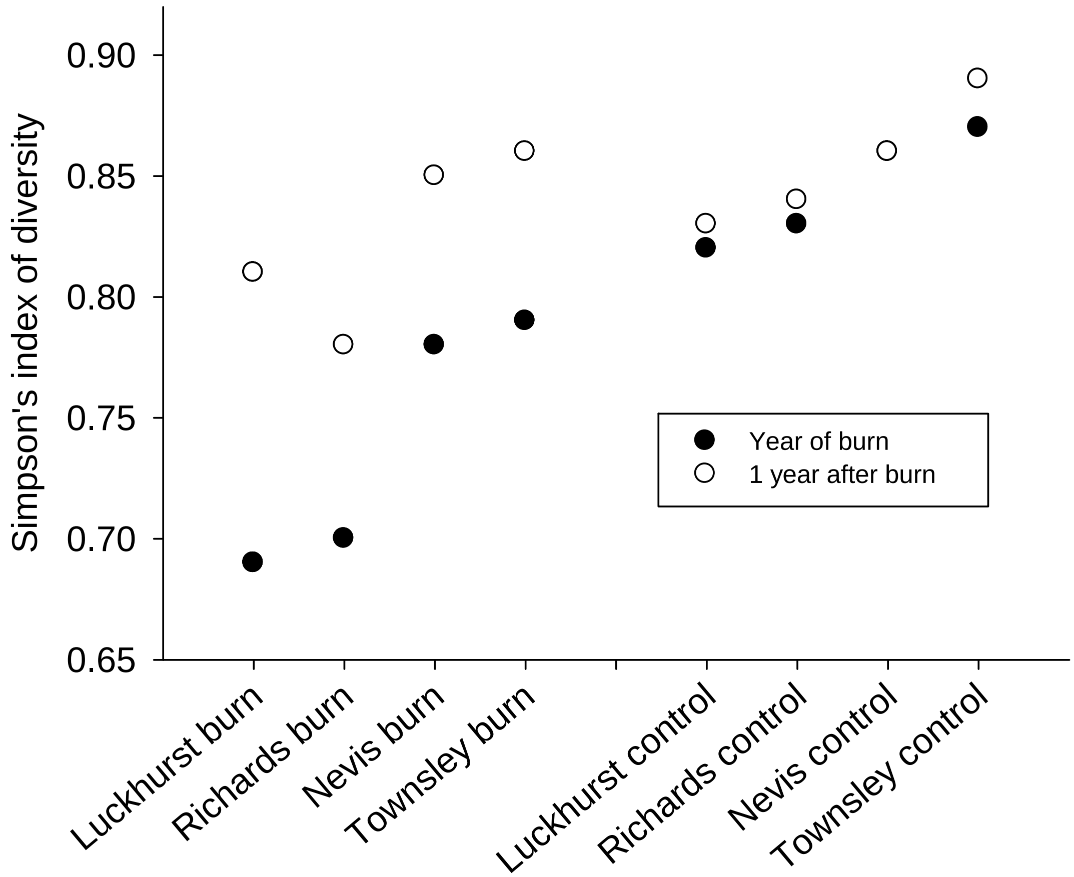

Figure 2.4. Simpson's index of plant diversity in summer the year of the burn (July 2010) and 1 year after burning (July 2011) on burned and unburned control areas at 4 sites (Luckhurst, Richards, Nevis, Townsley) in the Besa-Prophet area in northern British Columbia.

highest digestibility and Townsley the lowest (Tables 2.5, 2.7). Elevation did not influence digestibility in summer (Tables 2.4, D.6). In winter, forage at high elevations was more digestible than at low elevations (Tables 2.5, D.7).

Crude protein in forage was 1.5–2.9% higher depending on site on burned areas than unburned areas in both seasons (Tables 2.4, 2.5, D.10, D.11). In the winter after burning, CP was higher than pre-burn levels, but declined by 1 year after burning to pre-burn levels (Table 2.5). In late winter the year of the burn, CP on the burned area at Luckhurst was more than 2 times higher than other sites (May 2010; Tables 2.6, D.10) and 5 times higher than the unburned area at Luckhurst (Table 2.7). Elevation did not influence CP in either season (Tables 2.4, 2.5).

Available digestible dry matter (g DDM) and g DP followed trends similar to forage biomass (Tables 2.4, 2.5). g DDM was not different between burned and unburned areas (Tables 2.4, 2.5). Compared to winter pre-burn levels, g DDM declined in the year of the burn on burned areas, and increased back to pre-burn levels 1 year after the burn (Table 2.6). Across elevations and treatments, Luckhurst always had the lowest g DDM (winter: 272.5 ± 71.6 g DDM/0.25 m^2; summer: 349.4 ± 101.2 g DDM/0.25 m^2) and Richards had the highest (winter: 847.0 ± 154.2 g DDM/0.25 m^2; summer: 1,922.5 ± 262.0 g DDM/0.25 m^2; Tables D.8, D.9). High elevations had lower g DDM than low elevations in winter (Table 2.5) when adjusted for site and treatment; there was no effect of elevation on g DDM in summer (Table 2.4).

Burning increased g DP in the summer compared to unburned areas (z = 1.54, P = 0.027; Table 2.4), but in winter there was no measurable difference (z = 0.67, P = 0.502; Table 2.5). Available digestible protein in summer on the south-aspect sites of Richards and Townsley was higher than the west-aspect sites of Luckhurst and Nevis, when adjusted for

Table 2.7. Average digestibility (g/100 g ± SE) and crude protein (% ± SE) of forage on burned and unburned (control) areas following prescribed burning in May 2010 at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area in northern British Columbia. Forage collections were made prior to burning (pre-burn–early May 2010) and in summers (July 2010, 2011) and winters (May 2010, 2011) the year of the burn and 1 year after burning**.**

Vegetation Quality	Area	May 2010	July 2010	May 2011	July 2011	May 2012
Digestibility	Luckhurst					
	Burn	54.2 ± 2.2	63.1 ± 1.3	55.8 ± 1.6	60.9 ± 1.1	56.0 ± 0.4
	Control	47.2 ± 6.0	56.1 ± 1.6	46.2 ± 1.8	59.3 ± 0.0	57.7 ± 2.5
	Nevis†					
	Burn		66.4 ± 0.4	48.6 ± 1.1	59.4 ± 0.9	53.4 ± 0.3
	Control		62.1 ± 0.1	45.5 ± 0.2	61.8 ± 0.9	48.1 ± 1.1
	Richards					
	Burn	43.0 ± 0.8	63.2 ± 0.2	48.1 ± 0.9	59.5 ± 0.9	55.6 ± 0.7
	Control	43.5 ± 1.5	56.5 ± 0.8	46.6 ± 3.3	58.0 ± 1.6	54.6 ± 2.6
	Townsley					
	Burn	44.8 ± 1.1	65.3 ± 0.4	44.0 ± 1.3	59.3 ± 0.7	54.3 ± 1.8
	Control	45.8 ± 1.3	63.4 ± 0.9	41.6 ± 1.6	58.0 ± 2.3	54.4 ± 1.6
Crude Protein	Luckhurst					
	Burn	5.8 ± 0.4	19.1 ± 1.7	26.2 ± 5.1	17.8 ± 1.1	12.3 ± 3.4
	Control	4.8 ± 0.6	12.8 ± 1.2	5.3 ± 0.2	13.5 ± 0.8	5.4 ± 0.8
	Nevis††					
	Burn	5.4 ± 0.9	13.3 ± 0.7	6.4 ± 0.9	12.5 ± 1.0	5.6 ± 1.7
	Control	5.0 ± 0.2	13.0 ± 0.4	6.3 ± 0.9	14.2 ± 0.4	4.6 ± 0.1
	Richards					
	Burn	5.9 ± 0.5	16.0 ± 0.4	6.5 ± 0.6	14.4 ± 0.2	5.5 ± 0.2
	Control	5.0 ± 0.4	13.7 ± 1.1	5.7 ± 1.1	14.6 ± 0.1	5.3 ± 0.5
	Townsley					
	Burn	6.2 ± 0.7	16.2 ± 0.5	6.2 ± 0.6	12.7 ± 1.2	4.5 ± 1.0
	Control	5.0 ± 0.4	14.2 ± 0.6	5.3 ± 0.6	13.5 ± 0.4	4.8 ± 0.2

† The pre-burn site in May 2010 at Nevis did not burn and had to be moved in 2011. Consequently, Nevis was not analyzed for digestibility in May 2010.
†† Pre-burn values in May 2010 at Nevis are from an adjacent area that did not burn and are provided for comparative purposes only.

elevation and treatment (Table 2.4; Tables D.12, D.13). In summer, higher elevations had less g DP than low elevations (Table 2.4), but in winter there was no effect of elevation on g DP (Table 2.5, 2.6).

Animal use of burns–pellet counts

We counted 1,613 pellet groups along the transects (covering an area of 48,000 m^2), 504 of which were Stone's sheep and 902 were elk (Tables E.1, E.2). Other species identified along the transects included plains bison, deer, ptarmigan (*Lagopus* spp.), domestic horse, black bear, grizzly bear, moose, and wolf.

Prior to burning at the start of this study, pellet collections represented past use. The number of Stone’s sheep pellet groups removed from each of the 24 transects ranged from 0 to 30. There was higher Stone's sheep use in areas where prescribed burning was planned than on the unburned control areas (z= 3.09, P = 0.002). High elevations had more Stone's sheep use (adjusted mean = 9/400 m^2) than low elevations (2/400 m^2). Townsley had the highest total number of Stone’s sheep pellet groups (Table E.1), but when adjusted for all other factors it was not different from Nevis, presumably because of high variation across elevation. Elk pellet groups collected on the same transects ranged from 0 to 87. There was no difference in elk use between areas planned to be burned and control areas (z= 3.09, P = 0.002). There were significantly more elk pellet groups at high (adjusted mean = 29/400 m^2) and mid (21/400 m^2) elevations than low elevation (8/400 m^2). Townsley and Richards Creek had more elk per transect, when adjusted for all other factors (Townsley: adjusted mean = 38/400 m^2; Richards: 35/400 m^2), than Nevis (3/400 m^2) and Luckhurst (1/400 m^2; Tables E.1, E.2).

After burning, use by Stone’s sheep was always higher on burned areas than unburned areas in both seasons (both $z \geq 2.39$, $P \leq 0.017$; Tables 2.4, 2.5). In summer, use was higher 1 year after burning across all sites than the year of the burn (z = 3.33, $P \leq 0.001$; Table 2.4). In winter, use was highest the year of the burn (z = 7.7, $P \leq 0.001$; Table 2.5). In both seasons, Richards always had the lowest use by Stone's sheep (Tables 2.4, 2.5). In winter, use by Stone's sheep did not differ among thet Luckhurst, Nevis, and Townsley sites (Tables 2.5, E.1). In summer, even though on average Luckhurst had at least 4 times more Stone's sheep pellet groups than Nevis and Townsley, there was high variation among transects and therefore sites were not always significantly different (Tables 2.4). Higher elevations had higher use by Stone's sheep, as indexed by pellet groups, than low elevations (Tables 2.4, 2.5). The most extreme change in use in response to burning occurred in winter on the high transect of the Luckhurst burn where 3 pellet groups were observed in the pre-burn survey, 46 were observed in 2011, and 84 were counted in 2012. Stone's sheep pellet groups were never observed at Richards on mid or low-elevation transects.

The distribution and abundance of elk pellet groups varied by season and site (Tables 2.4, 2.5). Burned areas had more elk use than control areas in winter (z = 2.14, P = 0.033; Table 2.4), but not in summer (z = 1.16, P = 0.248; Table 2.5). In winter, south-aspect sites had significantly more elk use (Richards: 15.0 ± 5.1 pellet groups/400 m^2 across elevations, Townsley: 12.1 ± 3.5) than west-facing sites (Luckhurst: 1.8 ± 0.7, Nevis: 1.3 ± 1.5; Table 2.5). In summer, Richards and Townsley had higher numbers of elk pellet groups than Nevis, while Luckhurst was not different from any site (Tables 2.4, E.2). Elevation did not influence the number of elk pellet groups in either season (Tables 2.4, 2.5).

Animal use of burns–distribution flights

Over the monthly animal distribution flights, 211 Stone's sheep and 650 elk were observed. Other species recorded during the flights included plains bison, black bears, grizzly bears, moose, caribou, mountain goats and wolves. Elk were observed more often in winter (Jan–May) than in summer (Jun–Aug; $z = 2.87$, $P = 0.004$); there was no seasonal difference detected for Stone's sheep ($z = 1.77$, $P = 0.076$). Across seasons, Stone's sheep and elk were always observed more often on burns than on control areas (both $z \leq 2.12$, $P \leq 0.034$; Tables 2.8, 2.9). The largest group of sheep we recorded was 38 animals and the largest herd of elk was 115 individuals, both of which we observed in the winter on the Richards burn. Stone's sheep were always observed at mid and high elevations (Table 2.8), in contrast to elk that were observed at all elevations throughout the year (Table 2.8). Between summer and winter, mean group size changed from 5 ± 2 to 16 ± 5 individuals/group of Stone's sheep and 4 ± 1 to 26 ± 7 individuals/group of elk. No individuals or groups were observed in unburned control areas in winter.

Range exclosures and forage quantity

One year after the prescribed burns, grazing did not appear to have a significant effect on forage quantity (biomass, forage volume, forage cover) or species diversity across sites (Tables 2.10, 2.11). At the scale of the exclosures, forage biomass was higher in burned areas than in unburned areas in both seasons (both $z \geq 2.19$, $P \leq 0.028$); forage volume in burned areas was higher in summer ($z = 4.45$, $P \leq 0.001$), but did not differ from unburned areas in winter ($z = 0.33$, $P = 0.744$). Among sites, Luckhurst had the lowest forage biomass, volume, and cover in both seasons (Tables 2.10, 2.11) and Townsley and Nevis had the highest diversity (Table 2.10).

DISCUSSION

Prescribed burning

Prescribed burns are typically conducted in spring or fall to allow for more control of the burning (Hatten et al. 2012). The burn program in northeastern BC conducts prescribed burning only in the spring. The window of opportunity to burn then is narrow; just after the

Table 2.8. Number of Stone's sheep observed during monthly distribution flights by elevation (high, mid, low) at 4 sites (L = Luckhurst, N = Nevis, R = Richards, T= Townsley) where prescribed burns were implemented in 2010 in the Besa-Prophet area of northern British Columbia. Control areas were adjacent to each burn. Numbers of groups observed are in parentheses.

Month	Elevation	Burn				Control			
		L	**N**	**R**	**T**	**L**	**N**	**R**	**T**
Jun	High			2 (1)					2 (1)
	Mid	7 (1)							
	Low								
Jul	High						18 (1)		
	Mid								
	Low	2 (1)							
Aug	High								
	Mid		6 (1)						
	Low								
Sep	High	4 (1)	2 (1)					4 (1)	8 (1)
	Mid	6 (1)							
	Low								
Oct	High								
	Mid								
	Low								
Jan	High			33 (2)					
	Mid			6 (1)					
	Low								
Feb	High	2 (1)		38 (1)	4 (1)				
	Mid								
	Low								
Mar	High			54 (2)					
	Mid	3 (1)							
	Low								
Apr	High								
	Mid								
	Low								
May	High								
	Mid	7 (2)							
	Low								

Table 2.9. Number of elk observed during monthly distribution flights by elevation (high, mid, low) at 4 sites (L = Luckhurst, N = Nevis, R = Richards, T= Townsley) where prescribed burns were implemented in 2010 in the Besa-Prophet area of northern British Columbia. Control areas were adjacent to each burn. Numbers of groups observed are in parentheses.

Month	**Elevation**	**Burn**				**Control**			
		L	**N**	**R**	**T**	**L**	**N**	**R**	**T**
Jun	High		1 (1)	41 (4)	10 (1)				
	Mid			5 (5)				1 (1)	1 (1)
	Low							2 (2)	
Jul	High			6 (1)	13 (5)				
	Mid		1 (1)	12 (1)					
	Low			1 (1)	2 (1)			1 (1)	
Aug	High			2 (1)					
	Mid		1 (1)	3 (2)	5 (1)				
	Low								1 (1)
Sep	High			8 (1)					
	Mid			18 (7)	3 (1)				
	Low								
Oct	High			7 (2)					
	Mid			13 (2)	4 (1)				
	Low								
Jan	High								
	Mid			122 (2)					
	Low								
Feb	High			81 (3)					
	Mid	8 (1)		12 (2)					
	Low								
Mar	High			115 (1)					
	Mid			27 (1)					
	Low								
Apr	High								
	Mid	3 (1)		55 (4)					
	Low			36 (3)					
May	High			3 (1)					
	Mid			5 (2)					
	Low			14 (5)					

Table 2.10. Adjusted means for the response of summer vegetation to grazing and prescribed burning. Sampling occurred in summer the year of burning (July 2010) and 1 year after burning (July 2011) inside (ungrazed) and outside (grazed) range exclosures that were placed on burned and unburned (control) areas at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area of northern British Columbia. A mixed-effects regression model was used to quantify forage quantity (biomass (g/0.25 m^2), volume (cm^3), % herb cover) and Simpon's diversity index. Adjusted means sharing the same superscript for the same parameter were not different based on overlapping 95% Bonferroni confidence intervals around those adjusted means; the treatment effects of burn and control were assessed directly from the model output.

Parameter	**Treatment**		**Exclosure**		**Site**				**Year**	
	Burn	**Control**	**Ungrazed**	**Grazed**	**Luckhurst**	**Nevis**	**Richards**	**Townsley**	**2010**	**2011**
Biomass	22.1^{a}	8.9^{b}	16.2^{c}	13.4^{c}	1.7^{e}	21.5^{f}	22.2^{f}	22.3^{f}	11.0^{i}	19.1^{j}
Volume	57626.0^{a}	29446.4^{a}	46091.9^{c}	38794.5^{c}	4517.1^{e}	71631.5^{f}	66308.2^{f}	53339.5^{f}	30023.9^{i}	56824.7^{j}
Herb cover	78.6^{a}	72.7^{b}	73.7^{c}	77.7^{c}	21.4^{e}	98.7^{f}	85.5^{f}	97.1^{f}	71.2^{i}	80.1^{j}
Diversity	0.50^{a}	0.63^{b}	0.57^{c}	0.56^{c}	0.51^{e}	0.58^{ef}	0.51^{e}	0.66^{f}	0.53^{i}	0.60^{j}

Table 2.11. Adjusted means for the response of winter vegetation to grazing and prescribed burning. Sampling occurred in the winter the year of burning (May 2010) and 1 year after burning (May 2011) inside (ungrazed) and outside (grazed) range exclosures that were placed on the burned and unburned (control) areas at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area of northern British Columbia. A mixed-effects regression model was used to quantify forage quantity (biomass (g/0.25 m^2), volume (cm^3), % herb cover). Adjusted means sharing the same superscript for the same parameter were not different based on overlapping 95% Bonferroni confidence intervals around those adjusted means; the treatment effects of burn and control were assessed directly from the model output.

Parameter	**Treatment**		**Exclosure**		**Site**				**Year**	
	Burn	**Control**	**Ungrazed**	**Grazed**	**Luckhurst**	**Nevis**	**Richards**	**Townsley**	**2010**	**2011**
Biomass	13.7^{a}	8.8^{b}	12.3^{c}	10.0^{c}	1.2^{e}	14.5^{f}	20.9^{f}	14.8^{f}	8.2^{i}	14.4^{j}
Volume	18844.5^{a}	17526.1^{a}	20034.4^{c}	16414.2^{c}	2594.3^{e}	30687.7^{f}	24576.8^{f}	24473.2^{f}	14741.0^{i}	21977.7^{i}
Herb cover	73.5^{a}	70.5^{a}	73.8^{c}	70.3^{c}	15.1e	99.5^{f}	81.9^{g}	91.7^{fg}	71.0^{i}	73.0^{i}

snow has melted and just before green-up begins, usually in early to mid-May for south aspects and slightly later for east or west aspects. At that time there is typically snow on north-facing slopes and in the alpine, providing natural fire breaks. Although spring burns have the potential to negatively affect some wildlife species (Erwin and Stasiak 1979), they also may result in greater enhancement of above-ground production of herbaceous plants suitable for ungulate forage (Owensby and Anderson 1967). Cook et al. (1994) reported positive effects of spring burning for perennial herbs in south-central Wyoming and that spring burning minimized the introduction of weedy annual species in the first year. There has been some success in the use of fall burns. Merrill et al. (1980), for example, found 1.3–2.2 times greater dry matter production on burned sites than unburned sites in each year up to 4 years after a fall wildfire. After a fall burn, however, vegetation does not rebound until the next spring, greatly reducing forage availability for ungulates during the initial winter after burning and increasing the chance of soil erosion by wind and water during the spring melt (Jourdonnais and Bedunah 1990). Additionally, fall burns are typically larger and more intense (Holl et al. 2012). In northeastern BC, the highest use of burned areas by ungulates is in winter (Peck and Peek 1991, Walker 2005, Gillingham and Parker 2008*a*, this study) and a fall burn would reduce access to forage on those areas.

Burn severity as measured by the above-ground loss of organic material, strongly influences vegetative recovery (Keeley 2009). Hotter burns result in greater plant mortality and exposure of mineral soil. The burn high intensity at Luckhurst resulted in charred soil and bare ground representing 81–92 % of the land cover (depending on elevation) in the winter following burning. The lower burn severity at Nevis resulted in retention of 25–53% of shrub cover. dNBR has been effective for measuring wildfire burn severity (Soverel et al. 2010) and extent (Miller and Yool 2002), but it has not previously been applied to prescribed fires in the mountainous regions of northern BC. Normally after a burn, the extent of the disturbance is visually quantified during a helicopter flight. Our results indicate when cloud-free imagery was available within 2 weeks of a prescribed burn, dNBR was a cost-effective quantitative alternative to flying the extent of the burn. It also allowed us to identify remnant unburned patches within the extent of the burned areas.

Response of vegetation to fire

Every fire event produces unique fine-scale patterning and a trajectory of change (Baker 2009) in plant biomass, vegetation composition, and forage quality. The general plant response to fire has been well documented in North America (Peek et al. 1979, Tracy and McNaughton 1997, Sachro et al. 2005, Van Dyke and Darragh 2007, Greene et al. 2012). Fire consumes the vegetation in its path, resulting in an initial decrease in vegetation biomass, which rebounds and often generates more forage for grazers than adjacent unburned areas (Sachro et al. 2005). In the Besa-Prophet area, we did not detect a difference in forage biomass at the scale of the 50-m transects between burned areas and unburned areas in either winter or summer by 1 year after burning, presumably because of the high variability across elevations and sites or because of insufficient time for regrowth. We did observe, however, that the rate of seasonal growth was higher on burned areas than unburned control areas. By 1 winter after burning, forage cover had exceeded pre-burn amounts. Using NDVI values at the landscape scale, we found that vegetation biomass on burned areas had increased 2 years after burning and at the Richards site had exceeded control amounts. Therefore, forage quantity resulting from fire may not have peaked by the end of our study. This is consistent with some other studies that have documented green forage biomass in burned areas to be equal or greater to that in unburned areas 2 years (Peek et al. 1979, Greene 2010) or 3 years after fire (Cook et al. 1994) and in Banff National Park, where post-burn forage biomass was still increasing and remained higher than unburned areas for more than 7 years after burning (Sachro et al. 2005).

Forage volume provided an additional metric for forage quantity. Volume and bite size affect forage intake rates. If forage volume declines (i.e., less forage in each bite), animals may compensate with higher bite rates. Depending on fiber content, this may however, increase chewing time and decrease intake rate (Spalinger et al. 1988). Although we did not detect a difference between burned areas and controls in either season, forage volume doubled on burned sites 1 year after burning compared to pre-burn levels, potentially resulting in increased foraging efficiency for a grazing ungulate.

In the year of the burn, fires in the Besa-Prophet area reduced the diversity and richness at all sites except one – Richards, which retained the same number of species. Both the burned and unburned areas at the Townsley site were the most diverse and rich areas. The species of vegetation we identified were similar to the plant communities described by Luckhurst (1973) and Walker (2005) in the same area. Communities established after a disturbance are mostly composed of the same pool of species present prior to the disturbance (Vandermeer et al. 1995, Hart 2009). In a post-fire study in Yellowstone National Park, Turner et al. (1997) documented that the majority of the re-established plant cover on burned sites in the first 3 years was resprouting survivors and that patch size and burn severity affected species richness. Not all plant species survive in all fire situations because die-off can change the probability of recovering to the original pre-fire community (Rodrigo et al. 2004). Following prescribed burning in our study, there were 7 different species (*Astragulus alpinus, Botyrchium lunaria, Saxifrage lyallii, Silene uralensis, Taraxacum* spp., *Stellaria longipes*, and *Geranium richarsonni*) identified in burned areas that were not identified in unburned areas. Even with the different species, there was a 30% reduction in the total number of species and no introduction of invasive species. Keeley (2009) noted that fire severity may have a negative effect on diversity and richness of a vegetation community in the first year, but this effect is short-lived and by the second and subsequent years this effect is weak or non-existent (Keeley et al. 2005). On burned areas in our study, species diversity increased almost to that of control areas by 1 year after burning. Even though there was a reduction in shrubs, the prescribed burns did not produce a monoculture grassland, rather burning redistributed the relative proportions of the different species. This shift in the structure of the vegetation community coupled with the increase in bare ground, from 5.1 ± 1.6% prior to burning to 32.3 ± 13.9% in the first winter after burning (averaged across sites and elevations), opened up new areas for herbaceous growth and may translate into an increase in the availability of higher quality forage for grazing ungulates. The prescribed fires top-killed or severely damaged the above-ground portions of shrubs, but new basal growth was observed on all sites. The reduction in overall shrub height also opened up areas with higher visibility, which may reduce predation risk for Stone's sheep and elk by increasing their ability to detect danger at a farther distance and retreat to safer terrain (Geist 1971, Bleich 1999, Smith et al. 1999). The length of time that burned areas remain herb-dominated depends on site-specific characteristics such as grazing (Fuhlendorf et al. 2008), climate (Dale et al. 2001), soil moisture and fertility (Sturgis 1993, Rau et al. 2008), and fire-return interval (Reinhardt et al. 2008, Baker 2009).

Prescribed burning in the Besa-Prophet area also improved forage quality for elk and Stone's sheep in both summer and winter. Our estimates of forage quality are based on the average forage available and are likely conservative, especially for *Ovis* spp., which are known to optimally forage by selecting the most nutritious parts of a plant (Hobbs and Spowart 1984). Dry matter digestibility increased following burning and was highest 1 year after burning. Burning removes litter (Redmann et al. 1993, Tracy and McNaughton 1997), allowing more light to penetrate and increasing photosynthesis (Blair 1997, Tracy and McNaughton 1997). The increased thermal radiation on exposed or charred soil after burning can further increase forage quality by initiating green-up up to 2 weeks earlier in the spring (Peek et al. 1979, Skovlin et al. 1983). The very high burn severity on the Luckhurst site resulted in early green-up of more green shoots than in the other burned areas. At all sites the forage available in the first winter (early May) after burning included some new green shoots, resulting in crude protein values that were up to 2 times higher than pre-burn levels and which began to decline 1 year later. Our results corroborate the short-term post-fire nutrient flush hypothesis (Boerner 1982, Tracy and McNaughton 1997, Greene 2010), which states that nutritional quality can increase after a fire, but the benefits to ungulate forage may be short-lived (≤2–3 years). Nonetheless, Hobbs and Spowart (1984) noted that burning may actually increase the time that grazers have access to new growth. Similar to other temperate ungulates (Albon and Langvatn 1992, Demarchi 2003), elk (Boyce 1991) and Stone's sheep (Walker et al. 2006) track the phenology of plants and in mountainous regions, Stone's sheep in particular move up in elevation to selectively forage as new plants emerge (Seip 1983, Walker et al. 2007). By foraging on a burn when new growth is early and then shifting to unburned areas a few weeks later when new growth is just beginning, the time animals have access to new high-quality forage is extended appreciably.

Use of burns by ungulates

Several studies in the past decade have examined elk-fire relationships (Rupp 2005, Sachro et al. 2005, Van Dyck and Darragh 2007), although there have been only a few in northeastern BC since the inception of the prescribed burn program (Peck 1987, Peck and Peek 1991) and none within the last 20 years. In summer, we observed most elk as paired individuals (usually cows with calves) using burned areas; pellet counts were much lower in summer than in winter. In winter, elk grouped into herds of up to 115 animals and were observed more frequently at higher elevations on burned areas, which is likely due to high snow accumulation at lower elevations. Elk in many parts of western North America commonly move to open grasslands and meadows at low elevations in winter to avoid deep or hard-packed snow that hinders cratering (Adams 1982, Boyce 1991, Pearson et al. 1995). Elk in the Besa-Prophet area and northeastern BC use a different strategy, taking advantage of the early seral communities created by fire on the mid-elevation open slopes that are typically windswept with minimal snow (Peck 1987, Gillingham and Parker 2008*a*, this study). We observed elk foraging on slopes as steep as 30–40°, but typically they do not forage on slopes steeper than 30° (Sachro et al. 2005, this study).

Elk use prior to burning (as documented by pellet counts) was not different in areas planned to be burned and control areas, but after burning both the pellet counts and the survey flights documented more elk use on the 2 south-facing burns (Richards and Townsley), especially in winter. These sites were associated with higher levels of forage biomass, as well as higher levels of available digestible protein and available digestible dry matter. Similar to our findings, Van Dyck and Darragh (2007) observed an increase in use by elk of burned sites for 1–2 years after burning in response to increases in forage quantity and quality. Once forage production and nutritional quality declined from peak levels, so did elk use, despite lasting changes in community composition and vegetation. After 3–10 years, use by elk returned to pre-burn levels.

Prescribed burns in northern BC that target Stone's sheep typically intend to enhance winter range. One of the limitations to these burns can be access through deep snow (Seip and Bunnell 1985b). This is also true for bighorn sheep in Colorado, where snow depths reduced the crude protein levels in winter diets (Goodson et al. 1991). Seip (1983) recommended that burns should target areas that create subalpine grasslands and which are windswept in winter, allowing easier access by Stone's sheep to available forage. Many of the slopes in the Besa-Prophet area are windswept and snow-free, especially by late winter. The use of burns by Stone's sheep in our study was scale-dependent. At the transect scale, we observed highest use on west-facing slopes. One year after burning, 73% of all the Stone's sheep pellet groups counted across all sites occurred on the west-facing Luckhurst burn. This site had the highest burn severity and resulted in the highest crude protein values, especially at the end of winter when CP content of forage in the burned area was more than double that of the unburned area, presumably because new forage was emerging sooner on this site. During the distribution flights, we observed the largest group of Stone's sheep in winter at Richards, the site with the highest forage biomass.

Burning can be important for mountain sheep. For example, higher lamb/ewe ratios and well as fewer lungworm parasites have been documented in Stone's sheep populations that have access to burned areas (Seip and Bunnell 1985*b*). In a demographic study of California bighorn sheep, Holl et al. (2004) reported that after a wildfire consumed parts of the winter-spring range, it had positive effects on the population; they concluded that the new forage produced after the fire increased carrying capacity for the area. Bighorn sheep used burned sites more than unburned sites even after 4 years when vegetation production had leveled off (Peek et al. 1979). The length of time that burned areas remain beneficial to Stone's sheep is unknown, and we recommend continued monitoring of plant communitites in the Besa-Prophet area to determine if prescribed burning every 5–10 years might be appropriate for continued habitat enhancement.

During our monthly flights to record animal use, group sizes of elk in the winter were always much larger than groups of Stone's sheep, probably reflecting population sizes. In the winter of 2012, a survey of Stone's sheep was conducted in the Besa-Prophet area at elevations >1400 m and incidental sightings of elk were recorded; almost twice as many elk as sheep were observed. The survey block with the highest density of sheep (239 sheep/100 km^2) also had the highest density of elk (383 elk/100 km^2; Thiessen 2012).

Intensity of foraging and population densities of herbivores have implications for plant productivity (McNaughton et al. 1988). Elk use, forage production, and crude protein content have been shown to be temporally correlated on burned areas over time, suggesting that grazing by elk on burned areas might have a positive influence on the persistence of elevated quality and quantity of forage (Van Dyck and Darragh 2006). Although we did not detect any consistent differences across sites in plant composition or productivity due to grazing during the short duration of our study, specifically on the burned area at the Richards site where we saw the highest elk use, there was more than 6 times more forage biomass inside the range exclosure than outside by 1 winter after the burn. At the small scale of the exclosures, we detected more forage on burned sites than control sites, in contrast to the lack of a significant effect for biomass estimates measured on transects. Presumably, the 8 × 8-m exclosures were less variable than the 50-m transects. It is likely that as elk numbers increase, there will continue to be increased pressure on burned sites, leading to changes in plant productivity.

Each fire is unique and the changes in plant communities related to forage quantity, quality and visibility are complex. Both plant and animal response to fire varied across the 4 prescribed burns in our study. The 2 south-facing burns (Richards and Townsley) had higher forage biomass and based on fecal pellet counts, had more historic and current elk use. The burn at Richards had the highest forage biomass and g DDM and also the largest groups of both elk and Stone's sheep (observed during survey flights). Townsley had the highest plant diversity and species richness. The 2 west-facing sites (Luckhurst and Nevis) had the lowest forage biomass. Nevis, with the lowest burn severity and retention of many shrubs (both live and dead), had the lowest animal use (both pellets and flights). Luckhurst had the highest burn severity, resulting in the lowest shrub cover, forage cover, and g DDM. The forage available in late winter, however, was the highest in digestibility and CP. Use (based on pellet counts) by Stone's sheep was highest post-burn on Luckhurst, presumably because unlike elk that require much larger amounts of forage, Stone's sheep are able to more selectively forage and pick the most nutritious parts of plants (Seip 1983). In addition to site effects, burning at different elevations can have different results. For example, higher elevations typically had less forage year round, but that forage was of higher quality in the winter than at low elevations.

MANAGEMENT IMPLICATIONS

Fire-disturbed habitats throughout the mountainous regions of the northern Rockies play an important role in maintaining the heterogeneity of the landscape. In northern BC, prescribed fires now represent 41% of the total area burned and 23% of all fires (Louiser et al. 2009). Fire frequencies are well above the natural return intervals and are not random in their distribution, targeting areas considered to have potentially high value for ungulates. The Muskwa-Kechika Management Area has one of the largest and most diverse assemblages of large mammals in North America. Habitat diversity, as enhanced by prescribed fire, appears to play an integral role in this system. In the Besa-Prophet area specifically, government sanctioned prescribed burns have occurred on the same area at rates of up to 6 in 30 years (Table 2.1). In this system with minimal anthropogenic disturbance (other than prescribed burning), however, introduction of invasive plants has been minimal and plant diversity appears to rebound to pre-burn levels within 1 year. Our study shows the short-term benefits of burning to Stone's sheep and elk through increased forage quality and high rates of forage growth, and provides a baseline for continued monitoring.

Prescribed fire may be an effective disturbance agent if the goal in northeastern BC is to maintain or enhance these populations of large game species. By altering animal distributions, however, these burns influence ungulates at a larger scale than the footprint of the burns themselves and have the potential to change complex predator-prey interactions. As increasing elk populations augment total ungulate biomass, there is increasing potential for interspecies interactions and subsequent increases in predator populations. We recommend that a monitoring program be established to better understand the duration of post-fire effects on both forage production and quality, and the interaction between sympatric ungulate species and their predators.

Chapter 3. Resource separation on a landscape of prescribed burns: Stone's sheep and elk in the northern Rockies

ABSTRACT

Sympatric ungulates typically exhibit some form of resource partitioning. In northern British Columbia, where prescribed fire is used to enhance ungulate range, there is concern that expanding elk (*Cervus elaphus*) populations will move up into the traditional ranges of another grazing species, Stone's sheep (*Ovis dalli stonei*), in response to increased forage quantity and quality, and have adverse effects on them. We compared resource selection strategies and patterns of habitat use by both species in response to prescribed fire, including 7 prescribed burns implemented for this study on a landscape with over 138 burns of different ages (0–30 years old). Seasonal range sizes and movement rates of GPS-collared individuals were smallest in winter and late winter and largest in summer for both female Stone's sheep and elk. Both species selected south aspects and avoided conifer stands in all seasons. Stone's sheep selected for prescribed burned areas in fall, winter and late winter and selected to be close to a burn in every season except summer. Elk selected for burned areas in every season, with the highest selection for burn-shrub areas. Stone's sheep typically used younger burns, where as elk were less specific and often used older burns. Although both species selected and used prescribed burns at similar times of the year with the highest potential for overlap occurring during winter and late winter, Stone's sheep and elk partitioned their use of the landscape through elevation and topography. Stone's sheep always selected and used steeper more rugged terrain, and were always at higher elevations, often in rocky areas. Elk always avoided alpine and rocky areas, and were at lower elevations, on flatter less rugged terrain. We recommend continued monitoring of the duration of post-fire effects on movements and niche overlap of these sympatric ungulates. If

expanding elk populations continue to augment total ungulate biomass in a multi-prey multi-predator ecosystem, there is higher potential for competition with Stone's sheep and subsequent increases in predator populations.

INTRODUCTION

The spatial distribution of northern ungulates reflects seasonal trade-offs associated with intra- and inter-specific competition (Stewart et al. 2002), predation risk (Bergerud and Elliot 1998, Milakovic 2008), energy expenditures (Renecker and Hudson 1986), and the availability and distribution of resources (Fortin et al. 2003, Hebblewhite et al. 2008). Disturbance such as fire, which quickly restructures vegetation communities, can alter seasonal trade-offs and therefore animal distributions. Early seral habitats produced after fire benefit grazing ungulates through increases in forage quantity and quality (Sachro et al. 2005, Van Dyck and Darragh 2007, Greene 2010). Thus, prescribed fire has been used as a management tool in northern British Columbia (BC) for over 30 years to create and maintain open high-quality foraging areas for grazing ungulates. The direct effects of fire on the landscape depend on fire intensity, size, frequency and time of year (Baker 2009). Prescribed burns in northern BC are implemented only in the spring, and 2 focal grazers that are known to benefit from the use of prescribed fire are Stone's sheep (*Ovis dalli stonei*) and elk (*Cervus elaphus*).

Stone’s sheep are one of 2 subspecies of thinhorn sheep and are the most abundant sheep in BC (Gordon et al. 2008). Residing in the mountainous regions of northern BC and southernYukon and found nowhere else in the world (Demarchi and Hartwig 2004), these mountain sheep are both ecologically and socially important. Stone's sheep are generally found in subalpine or alpine habitats close to escape terrain, cliffs or steep rocky slopes (Luckhurst 1973, Seip 1983). Similar to other mountain sheep, they show strong site fidelity and philopatry to seasonal ranges (Geist 1971, Seip 1985*a*). Prescribed burning specifically aimed to enhance ranges for Stone's sheep has been recognized as being beneficial by reducing internal parasite loads and increasing lamb/ewe ratios (Elliot 1978, Seip and

Bunnell 1985*b*). The benefits of fire may be less in areas where there is potential for competition between large sympatric foragers. Elk are regarded as adaptive foragers (Houston 1982, Christiansen and Creel 2007) and a competitive species (Johnson et al. 2000, Stewart et al. 2002) in many other parts of their range, and there is increasing concern that expanding elk populations in BC may be adversly affecting other species, including Stone's Sheep (Gillingham and Parker 2008*a*).

Habitat selection influences survival and an understanding of species-specific choice of resources is central to predicting the consequences of landscape change (Millspaugh et al. 2006). From a detailed description of resource selection and use by Stone's sheep (Walker et al. 2007) and a preliminary study on elk (Gillingham and Parker 2008*a*) in northern BC, both species are known to select for and use burns in some seasons. Little is known, however, about the differential use of the landscape by the 2 species. By altering the vegetation, with the goal of enhancing ranges through the use of prescribed fire, there is concern that fire may increase the potential for competitive interactions between Stone's sheep and elk. Our objective was to understand how seasonal selection strategies, movement rates and range sizes varied between the 2 species on the same landscape in relation to prescribed fires, and if seasonal overlap occurred, to examine how these species partitioned their use of resources. Our results will help guide management practices in the future and provide a better understanding of the role that fire plays in a large predator-prey system.

STUDY AREA

The Greater Besa-Prophet Area (GBPA; approximately 741,000 ha) is part of the Muskwa-Kechika Management area (MKMA), which covers 6.4 million ha in northern BC. The GBPA is located between 57°11' and 57°15'N; 121°51' and 124°31'W. It includes the 204,245-ha Besa-Prophet Pre-Tenure Planning Area (a zone that requires specific management planning prior to oil and gas exploration and development), and the 80,771-ha Redfern Keily Provincial Park. Situated in the foothills of the Muskwa Ranges in the Rocky Mountains, there are 3 main drainages: the Prophet River in the north, Sikanni River in the south, and Besa River flowing north through the center of the study area. This area is unique in the Rocky Mountains, in that it consists of many east-west drainages and south-facing slopes that provide excellent winter habitat for large ungulates, supporting one of the most diverse intact predator-prey systems in North America. Ungulates found in the GBPA include Stone's sheep, elk, moose (*Alces alces*), caribou (*Rangifer tarandus*), mountain goats (*Oreamnos americanus*), deer (*Odocoileus* spp.) and bison (*Bison bison*). Predators capable of preying on these ungulates include wolves (*Canis lupis*), grizzly bears (*Ursus arctos*), black bears (*Ursus americanus*), wolverine (*Gulo gulo*), coyotes (*Canis latrans*), and a few cougars (*Puma concolor*).

Elevations in the GBPA range from ~700–2,200 m (Lay 2005). Within valleys at 700–1,300 m, drier areas were dominated by white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*) and trembling aspen (*Populus tremuloides*), and wetter sites were characterized by black spruce (*Picea mariana*), willows (*Salix* spp.) and scrub birch (*Betula glandulosa*) communities. Subalpine habitats at ~1,300–1,600 m were characterized by an abundance of willow and birch, and some subalpine fir (*Abies lasiocarpa*) in non-burned areas. South-facing slopes that have been repeatedly burned were dominated by fuzzy-spiked wildrye (*Elymus innovatus),* fireweed (*Epilobium angustifolium*), tall bluebells (*Mertensia paniculata*) and alpine sweet-vetch (*Hedysarum alpinium*); as the burned slopes aged, aspen, balsam poplar (*P. balsamifera*) and willows dominated the shrub layers (Lay 2005). The previously burned west-facing slopes were typically dominated by scrub birch, willows, and shrubby cinquefoil (*Potentilla fruticosa*) and dwarf shrubs such as lingonberry (*Vaccinium* *vitis-idea*) and bearberry (*Arctostaphylus uva-ursi*) formed understory mats on the ground. Tree line occurred at ~1,600 m and transitioned into the alpine (~1,600–2,200 m). Alpine areas in the GBPA were rocky plateaus with vegetative cover consisting of graminoids (*Poa* spp., *Festuca* spp.), several alpine-flowering plants, bryophytes and lichens (Meidinger and Pojar 1991).

Apart from some seismic oil exploration in the eastern portion of the GBPA, there has been very little industrial activity in the area. Access into the GBPA is limited to some horse trails and 1 government-sanctioned all terrain vehicle (ATV) trail (used for some snowmobiling in the winter). The majority of human activities consists of ATVing, some snowmobiling, guide-outfitting, hunting, fishing and prescribed burning. Since 1980, there have been 138 areas intentionally burned, often repeatedly, in the GBPA (Figure 3.1; Appendix A). Prescriptions are typically identified and prioritized by the Northeast BC Prescribed Burn Council based on the potential to increase the quality and quantity of early seral habitats for ungulates, typically targeting south- and west-aspect slopes.

METHODS

Prescribed burns

Seven prescribed burns were implemented in the GBPA for this study, between 15 May and 01 June 2010 and 2011 as part of the Peace-Liard Burn Program (Tables 3.1, A.1). Prescribed burns were ignited using an aerial ignition-device system (Rothermel 1984), which allows for multiple ignition sites and creates a more heterogenous burn. Four sites were burned in 2010: Richards, a lower elevation south-aspect slope in the northern part of the GBPA in the Richards Creek drainage; Townsley, a higher elevation south-aspect slope in the Townsley Creek drainage; Luckhurst and Nevis, the west faces of 2 parallel mountains in the Nevis Creek drainage. In 2011, 4 sites were planned, but due to bad weather only 3

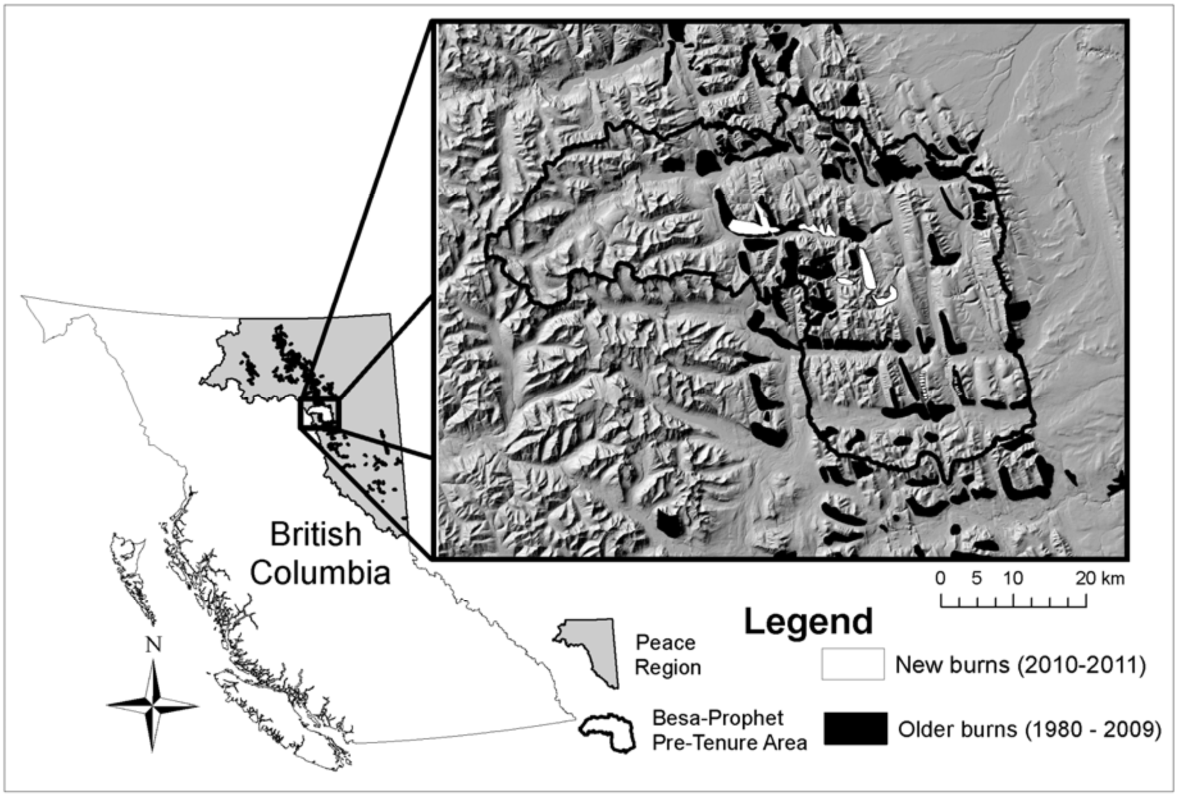

Figure 3.1. The Greater Besa-Prophet Area (GBPA; inset) in northeastern British Columbia (BC). Locations of 7 new prescribed burns (2010–2011) conducted for this study within the GBPA are shown by white polygons and the locations of older prescribed burns (1980–2010) throughout the Peace region (grey area) of northern BC and in the GBPA are shown in black.

Table 3.1. Descriptions and site history of 7 prescribed burns implemented in the Greater Besa-Prophet Area in northern British Columbia in 2010 and 2011.

Site	Area (ha)	Aspect	Date Burned	Years Burned
Luckhurst[a]	150	West	01 June 2010	1984, 1987, 2001, 2010
Nevis	300	West	16 May 2010	1984, 1987, 2001, 2010
Richards	1000	South	15 May 2010	1981, 1985, 1987, 1991, 2002, 2010
Townsley	370	South	16 May 2010	1987, 2010
Richards East	700	South	16 May 2011	1981, 1985, 2002, 2011
Richards South	500	West	02 June 2011	1987, 2011
Duffield	200	South	03 June 2011	1987, 1990, 2011

[a] The 2010 burn on Luckhurst was a new area adjacent to previous burns.

burns were implemented: Richards East, a south-aspect slope east of the Richards burn; Duffield, a south-aspect site in the Duffield Creek drainage south of the Richards drainage; and Richards South, a west-aspect slope southeast of the Richards drainage. These burns ranged in size from 150–1,000 ha.

Field procedures

Between January 2010 and July 2011, 14 female Stone's sheep and 26 female elk (13 in each year) were captured by helicopter using a net gun (Krausman et al. 1985) and fitted with global positioning satellite (GPS) collars (Advanced Telemetry Systems, Isanti, MN; Models G2000 and G2100D) that were programmed to acquire animal locations at 6-h intervals. Capture locations took into account new and existing burns on the landscape in the GBPA to maximize the experimental nature of the study. Capture and handling procedures were in accordance with BC Ministry of Environment protocols. Stone's sheep collars had a 2-year battery and elk collars had a 1-year battery; just before battery depletion they were released from the animal, retrieved, and data were downloaded. Stone's sheep and elk location data were screened for erroneous locations using Spatial Viewer (M.P. Gillingham, unpublished Visual Basic program) and any 2D fix with a dilution of precision >25 or any locations that were beyond the realistic movement potential of any animal were removed (D'Eon et al. 2002, D'Eon and Delparte 2005).

Selection, use and importance of landscape features

We assembled a suite of raster-based Geographical Information System (GIS) layers at 25-m^2 resolution for attributes on the GBPA landscape that we thought would influence Stone's sheep and elk selection and use. We derived several topographic layers using a 1:20,000 digital elevation model (DEM; British Columbia Ministry of Crown Lands 1990): elevation (m), slope (%), aspect (radians) and terrain ruggedness. We used the vector ruggedness measure (VRM; Sappington et al. 2007) to define terrain ruggedness, ranging from 0 (even terrain) to 1 (uneven broken terrain). VRM provided a quantitative measure of ruggedness that was independent of slope and these 2 variables were used to distinguish 2 different, yet biologically meaningful, components of Stone's sheep and elk habitats. We created the VRM layer using a 3 × 3 window in ArcMap (ESRI 2011. ArcGIS Desktop: Release 10. Environmental Systems Research Institute. Redlands, CA; Sappington 2008). Historical locations of prescribed burns were provided as a polygon layer by the BC Ministry of Forest, Lands and Natural Resource Operations. These polygons were from drawings on a map, providing a general area for each burn but potentially including some unburned areas within. We generated a raster surface (25 × 25 m) representing straight-line distance (m) from each animal location to the nearest burn using the Euclidean Distance Spatial Analyst tool in ArcMap.

Land-cover classification was based on Lay's (2005) original 15 classes for the Besa-Prophet area from Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper (+ETM) images. We combined several original classes, using the raster calculator in ArcMap, into the following 10 classes that we believed were biologically meaningful for both Stone's sheep and elk: *Carex* sp., Low shrub, Conifer, Rock/rock crust, Non-vegetative, Subalpine, Riparian, Alpine, Burn shrub, and Burn grass. This set of classes was a hybrid between Walker's (2005) classification developed for Stone's sheep and Gillingham and Parker's (2008*a*) classification for elk in the same area. We updated this land-cover classification using PCI (Geomatics version 10.1, Richmond Hill, ON) by overlaying each of the 7 prescribed burns conducted for our study and called this class New burn, for a total of 11 land-cover classes (Table 3.2). Burn extents for new burns were derived using PCI (Geomatics version 10.1, Richmond Hill, ON), from a combination of Landsat imagery,

Table 3.2. Description and percentage of study area for 11 land-cover classes in the Greater Besa-Prophet Area, based on Lay's (2005) original 15 cover classes. New burns were overlaid and related temporally to elk and Stone's sheep locations.

Land-cover class	% of study area	Original classification[a]	Description
Carex	6.0	*Carex*	Sedge wetland characterized by large open areas at low elevation (<1,600 m), dominated by *Carex* spp. and intermittent willow (*Salix* spp.) shrubs.
Low shrub	5.7	Shrub <1,600 m	Deciduous shrub communities <1,600 m in elevation, characterized by willow (*Salix* spp.), scrub birch (*Betula glandulosa*) and some cinquefoils (*Potentilla* spp.).
Conifer	27.8	Pine + spruce + stunted spruce	Mature and growing coniferous stands of lodgepole pine (*Pinus contorta*), white spruce (*Picea glauca*) and potentially some fir (*Abies lasiocarpa*).
Rock/rock crust	22.4	Rock + rock crust	Rocky areas generally at high elevation including talus slopes, steep outcrops, scree slides, bedrock and rocks covered with black crustose lichen (e.g., *Melanelia haptizon*).
Non-vegetative	1.4	Snow + water	Permanent water bodies or water courses, and glaciers or snowfields.
Subalpine	9.2	Shrub ≥1,600 m + subalpine spruce	Deciduous shrub communities ≥1,600 m; spruce (*Picea glauca*) and shrub (*Salix* spp. and *Betula* spp.) transition area at mid to high elevation.
Riparian	11.8	Riparian spruce + gravel	Wet areas at low elevations (<1,600 m) with spruce (*Picea glauca* or *Picea mariana* in poorly drained sites), often with standing water in spring and summer; gravel bars along rivers and streams and dried river beds.
Alpine	5.4	Dry alpine + wet alpine	Herbaceous vegetation >1,600 m in elevation. Dry alpine tundra dominated by *Dryas* spp.; wet alpine tundra dominated by *Cassiope* spp. and sedge (*Carex* spp.) meadows.
Burn shrub	7.0	Burn-deciduous	Older burns and disturbed areas containing deciduous shrubs (<2 m) and regenerating stands of *Populus tremuloides* and *Populus balsamifera*. Small stands of *Pinus contorta* may also be associated.
Burn grass	3.0	Burn-*Elymus*	Recent burns and disturbed areas characterized by open grass meadows dominated by *Elymus innovatus*, most often found on south-facing slopes.
New burn	0.3	na	The 7 new burns conducted in the spring of 2010 and 2011.

[a] **Lay (2005)**

using the delta Normalized Burn Ratio (dNBR), and helicopter GPS routes. dNBR is a change detection index, calculated by subtracting the post-burn Normalized Burn Ratio (NBR) from the pre-burn NBR (see Appendix C for details). This index has been shown to be sensitive in separating soil, ash and charred wood from live vegetation in a post-fire environment (Hall et al. 2008).

We defined 5 biologically relevant seasons to compare habitat selection between Stone's sheep and elk based on similarities in seasonal life history such as calving and lambing, movement rates (m/h), and behaviour identified from previous work on Stone's sheep and elk in the GBPA (Walker et al. 2007, Gillingham and Parker 2008*a*): spring (15 May–14 Jun), summer (15 Jun–14 Aug), fall (15 Aug–31 Oct), winter (1 Nov–28 Feb), late winter (1 Mar–14 May).

For each collared animal, we calculated GPS fix rate as a percentage of the number of acquired fixes relative to the number that should have been taken at 6-h intervals over the time the collar was deployed. We determined average monthly and seasonal movement rates (m/h) for individuals of both species by measuring the Euclidean distance between consecutive GPS locations, and then averaged the values for individuals by species in each month and season.

For each animal we defined the seasonal range sized based on the animal's seasonal movement potential (Walker et al. 2007). The animal's seasonal movement potential was estimated using GIS (ESRI 2011. ArcGIS Desktop: Release 10. Environmental Systems Research Institute) by placing a circular buffer around each use point (a GPS location) with a radius determined by the 95th-percentile longest distance traveled by each individual in each season between consecutive 6-h fixes (Gustine et al. 2006). To obtain the seasonal range (km^2), we then merged the overlapping buffered points into 1 polygon for each season.

Annual ranges (km^2) were estimated by merging each animal's overlapping seasonal ranges into 1 polygon.

We used logistic regression and the information-theoretic approach to estimate resource selection functions (RSF) that identified selection strategies of Stone's sheep and elk. We examined the resources (i.e., land-cover classes, topographical features and distance to a burn) used compared to resources that were available. We quantified seasonal resources at the level of the individual (i.e., Design III; Thomas and Taylor 1990). We defined resource availability for each animal at the seasonal movement scale, and thus our models represent third-order selection (Johnson 1980). For each use point, we randomly selected 5 points within the buffered area defined by the animal's seasonal movement potential to represent availability locations (as in Gilligham and Parker 2008*a*). To avoid issues with lack of data independence, we examined used and available points for each animal in each season and removed duplicate random points (Manly et al. 2002). Attributes of the raster layers were queried for each used and available point.

We built a set of 6 candidate models *a priori* that might describe resource selection on the landscape, based on previous knowledge of selection by Stone's sheep (Walker et al. 2007) and elk (Gillingham and Parker 2008*a*), but specifically to better understand the influence of prescribed burns. Each model was a combination of land cover, topography, and distance to burns that allowed us to explore both biological and statistical contributions of each variable (Table 3.3). We modeled elevation as a quadratic, with both elevation (km) and elevation^2, in order to test for selection of mid elevations. We transformed aspect into 2 continuous variables: northness (the cosine of aspect) and eastness (the sine of aspect; Palmer 1993). For any pixel with zero slope, we set northness and eastness both equal to zero (as in Steenweg 2011). To avoid issues with complete separation, we identified and dropped land

Table 3.3. Rationale for candidate models describing seasonal resource selection by Stone's sheep and elk in the Greater Besa-Prophet Area of northern British Columbia. Elevation was modeled as a quadratic (elevation + elevation^2); aspect was modeled as 2 continuous variables (northness and eastness), and land cover was defined as 1 of 11 classes in Table 1.

Model Parameters	**Rationale**
Land cover + Elevation + Slope + Aspect + Ruggedness + Distance to burns	Saturated model.
Land cover + Elevation + Slope + Aspect + Distance to burns	Ruggedness may not be selected by elk (in contrast to Stone's sheep).
Land cover + Slope + Aspect	Land cover and slope position drive selection. Both species select more for land-cover classes and slope position than other attributes, particularly in winter.
Land cover + Distance to burns	Land cover and proximity to a burn drive selection. Stone's sheep select for land-cover classes and to be close to a burn more often than elk.
Distance to burns + Elevation	Proximity to a burn and elevation drive selection. Stone's sheep may not select to be on a burn, rather close to a burn and at high elevation (in contrast to elk).
Distance to burns + Ruggedness	Proximity to a burn and ruggedness of the terrain drive selection. Stone's sheep may not always select to be on burn, rather close to a burn and in rugged terrain (in contrast to elk).

cover classes in which use or available points were ≤ 4 (Menard 2002). Consequently the Non-vegetation class was dropped from all models. We used deviation coding for land-cover classes and reran models with different reference categories to obtain selection coefficients (Hendrickx 1999). We used Akaike's Information Criterion corrected for small sample size (AIC_c) to rank models within each set (Burnham and Anderson 2002). We tested covariates in each model for colinearity and used a conservatitve tolerance score threshold of <0.20 (Menard 2002); no variables were dropped. For each model set (i.e., the 6 models for each animal in every season), we calculated Akaike weights (w_i) and evaluated the predictive ability of the top model or suite of competing models (all models required for $\sum w_i$ to be >0.95) using k-fold cross-validation (Boyce et al. 2002) and an averaged Spearman's rank correlation coefficient (r_s). We dropped any model that did not validate (i.e., $r_s \leq 0.648$). We averaged the selection coefficients (β_i) in the remaining top competing models ($\sum w_i \geq 0.95$) to obtain 1 final model for each animal in each season (Burnham and Anderson 2002). Sign of β_i indicates selection (+) or avoidance (-) when all variables in the model are considered together. To obtain global (pooled) models for Stone's sheep and elk, with equal weighting for each individual, we averaged the final models for all individuals in each season (Gillingham and Parker 2008*b*).

Selection strategies result in use of different land-cover classes including burns on the landscape. Therefore, we calculated the proportional use (based on GPS locations) and availability (5 randomly sampled points per GPS fix) of land-cover classes for each animal in each season and then averaged across individuals to compare use and availability seasonally. We also quantified the relative importance of land-cover classes. Importance was calculated as use multiplied by availability, scaled to the sum of 1.0 (Stewart et al. 2010). This calculation helps identify land-cover classes that are important to Stone's sheep and elk, but which might not be identified as selected in the logistic regression because of their abundance on the landscape (Stewart et al. 2002) and helps explain land-cover classes that are 'selected' because of their rarity on the landscape. We used descriptive statistics to examine the differential use of topography (elevation, slope, ruggedness) as well as movement rates, annual and seasonal range sizes, and distance to a burn. All means were calculated for each individual animal and then averaged across seasons (± SE).

We recorded the distribution of groups of elk and Stone's sheep in relation to prescribed burns during monthly fixed-wing flights over a 1-year monitoring period to supplement data from GPS-collared individuals. This information was acquired along a 2-h route over an area that encompassed all GPS-collared animals as well as 28 burns of varying size and age, beginning in June 2011 (Figure 3.2; Appendix A) to help quantify spatial and temporal use of burns by elk and Stone's sheep in the GBPA. For all animal groups observed, we recorded the location, elevation, and dominant land cover (burn versus non-burn, alpine, rocks, conifer stand, valley bottom, mineral lick), as well as group size. In the Besa-Prophet, elevational changes between valley bottom to ridge top are similar among mountains (even if absolute elevations are different); therefore we stratified each mountain into thirds (high, mid, low). We then used descriptive statistics to compared animal numbers and group sizes by species by elevation on burned and unburned areas monthly (see Chapter 2 for specific results relating to the 4 prescribed burns implemented in 2010).

RESULTS

We obtained 21,769 GPS locations from 11 collared female Stone's sheep and 37,054 GPS locations from 22 different collared female elk from 2010–2012. Average fix success rate was 88.5 ± 3.0% ($\bar{x}$ ± SE) for Stone's sheep (ranging from 63.8–96.1%) and 90.4 ± 2.2% for elk (ranging from 65.5–98.5%).

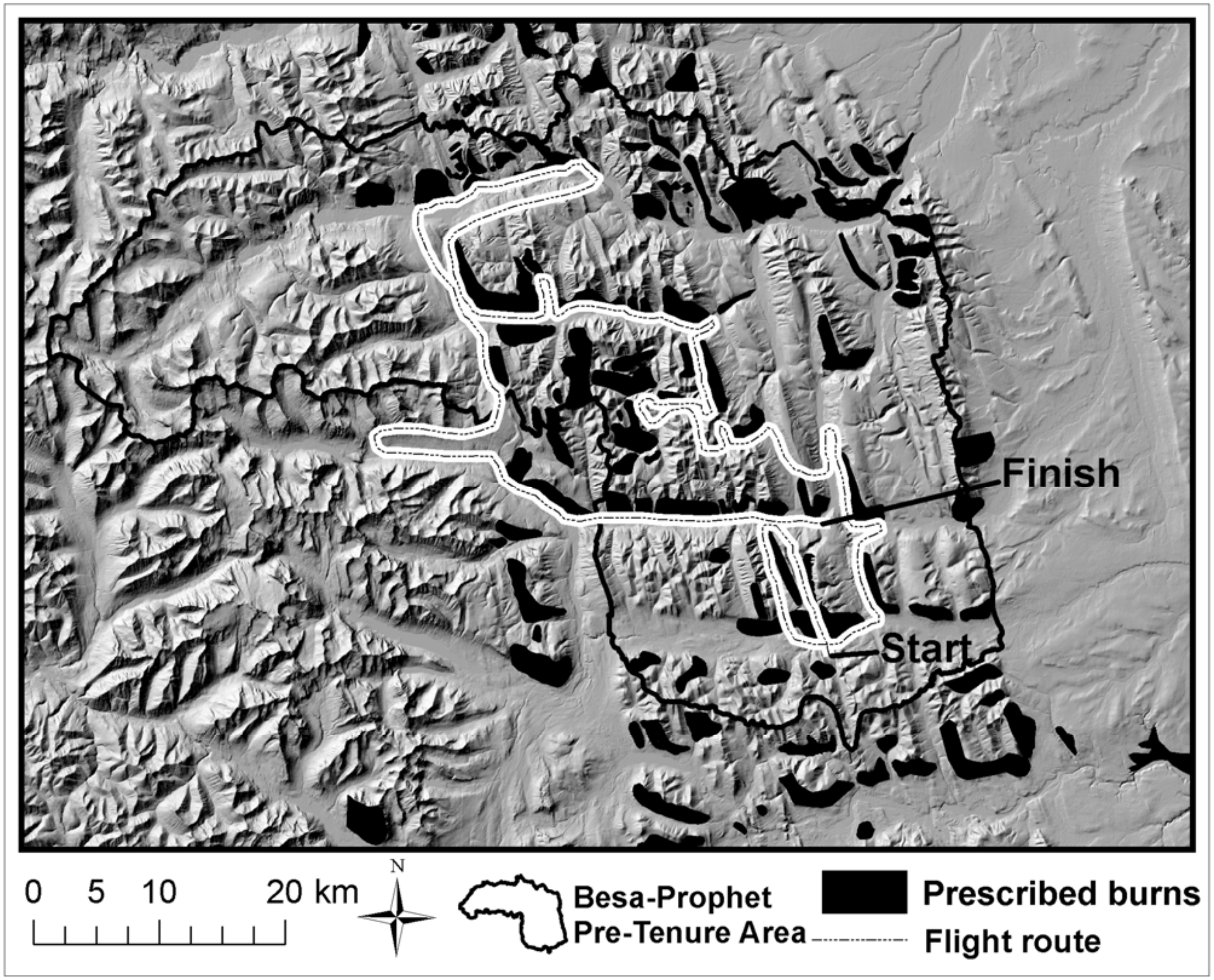

Figure 3.2. Flight route (in white) for animal distribution flights within the Greater Besa-Prophet Area (GBPA) in northern British Columbia. Flights began in June 2011 and occurred monthly for 1 year (except November and December). The boundary of the Besa-Prophet Pre-Tenure Planning Area is outlined in black. Black polygons are areas where prescribed burns have been implemented.

Movement and ranges in relation to prescribed burns

Stone's sheep and elk followed similar patterns in monthly and seasonal movement rates, with highest rates occurring in summer (Stone's sheep: 62–165 m/h depending on animal, elk: 62–147 m/h) and lowest rates in winter and late winter (Stone's sheep: 20–65 m/h, elk: 16–68 m/h). Movement rates were similar between species in winter, late winter and spring, but Stone's sheep had higher average movement rates than elk in summer and fall (Figure 3.3). The longest straight-line distance traveled by a Stone's sheep between 6-h GPS fixes was 7.9 km in the summer of 2011 in the Richards area, where GPS-collared Stone's sheep made long-distance movements (>4 km) seasonally; they moved from their winter range on the 2010 burn across a valley into an area of their summer range with no burns and then back again in the fall. The longest straight-line distance traveled by an elk in 6 h was 9.9 km in the winter of 2010 in the Nevis area.

Annual ranges were similar in size between Stone's sheep (196.4 ± 36.4 km^2) and elk (183.5 ± 17.2 km^2), but were highly variable among individuals of both species (Table 3.4). The burned land-cover classes (Burn shrub, Burn grass and New burn) comprised 6–19% of the annual ranges of Stone's sheep and 9–17% of the annual ranges of elk. Seasonal range size followed trends similar to movement rates. For both species, seasonal ranges were largest in summer and smallest in winter and late winter (Figure 3.4). Range sizes were most variable among individuals in summer for both Stone's sheep (22–318 km^2) and elk (47–338 km^2). The smallest seasonal range was 10 km^2 for a Stone's sheep in late winter and 4 km^2 for an elk in winter (Appendix G). New burns, as the predominant burn class in the seasonal ranges of Stone's sheep, averaged 17 ± 3% of Stone's sheep late-winter range, but only 2 ± 0.4% of summer range (Appendix G). For elk, the percentage of New burn class within seasonal ranges was highest in late winter (15 ± 4%) and lowest in summer (4 ± 1%).

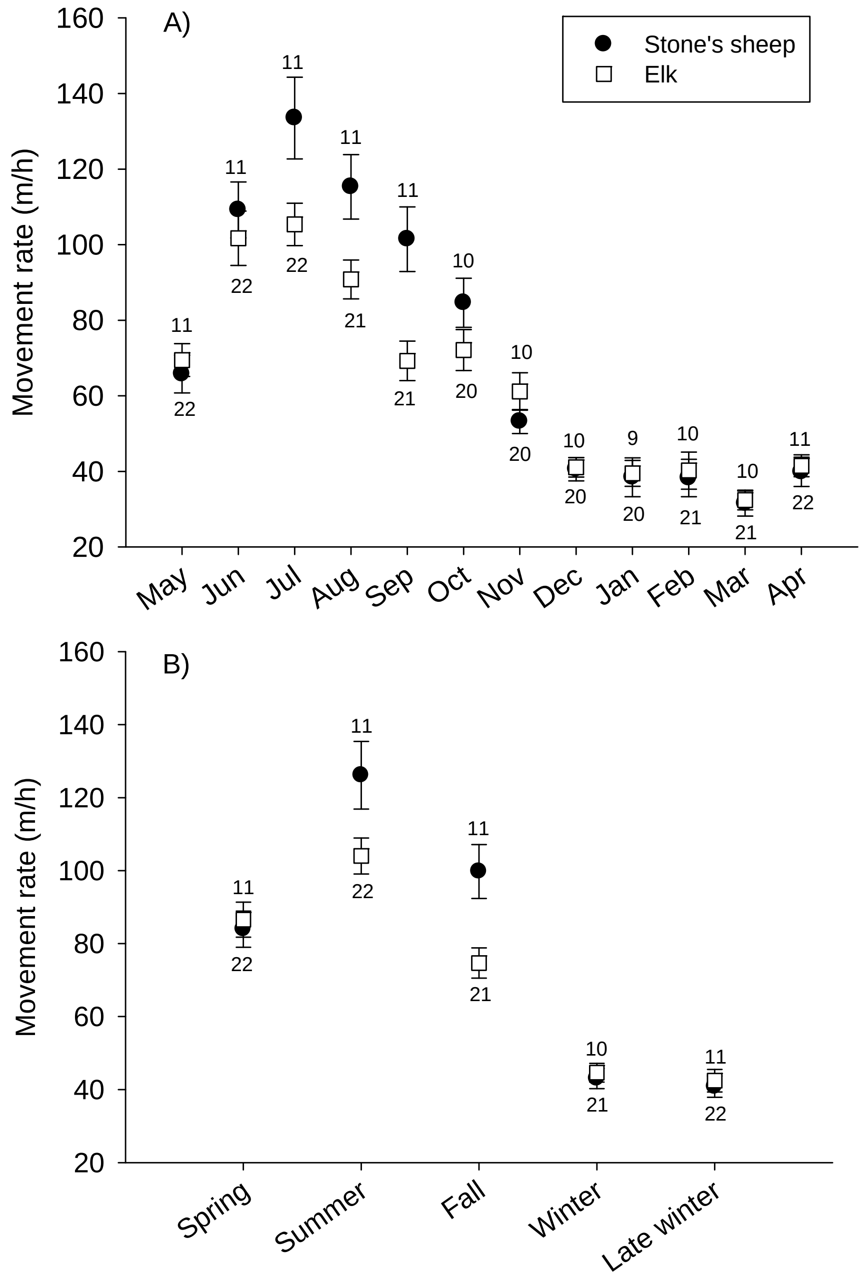

Figure 3.3. A) Monthly and B) seasonal movement rates ($\bar{x}$ ± SE) of GPS-collared female Stone's sheep and elk in the Greater Besa-Prophet Area of northern British Columbia between 2010 and 2012. Averages were calculated for each individual and then averaged across individuals in each month and season. Numbers above error bars indicate the number of individual Stone's sheep and numbers below are the number of individual elk used to calculate means and standard errors.

Table 3.4. Sizes of annual ranges (km^2) of GPS-collared female Stone's sheep and elk based on GPS locations buffered by the 95th percentile longest distance moved in each season in the Greater Besa-Prophet Area of northern British Columbia. Annual range was calculated by merging overlapping seasonal ranges in GIS (ESRI 2011. ArcGIS Desktop: Release 10. Environmental Systems Research Institute). Percentage of range occupied by burned land-cover classes (New burn, Burn grass, Burn shrub) and total area burned in the annual range are given for each individual.

Species	Animal	Range (km^2)	New Burn (%)	Burn Grass (%)	Burn Shrub (%)	Burned (km^2)
Stone's sheep	S-1	104.0	2.5	4.3	6.8	14.0
	S-2	180.8	5.1	1.2	2.4	16.0
	S-3	376.2	2.8	1.5	1.7	22.2
	S-4	280.2	2.7	1.7	1.7	17.1
	S-5	331.5	2.7	1.8	1.6	20.1
	S-6	225.2	3.5	2.0	1.6	16.0
	S-7	96.2	2.5	4.9	11.1	17.9
	S-8	57.0	1.7	4.3	5.3	6.4
	S-9	141.1	1.8	4.9	8.9	22.1
	S-10	335.0	2.5	1.7	1.6	19.1
	S-11	33.5	2.9	5.7	7.5	5.4
	$\bar{x}$ ± SE	196.4 ± 36.3	2.8 ± 0.3	3.1 ± 0.5	4.6 ± 1.1	16.1 ± 1.7
Elk	E-1	225.2	5.3	3.7	7.8	37.9
	E-2	127.7	0.0	4.9	9.7	18.7
	E-3	174.7	7.1	4.9	4.0	27.8
	E-4	243.3	4.8	2.2	3.3	25.0
	E-5	246.9	4.7	1.6	3.1	23.4
	E-6	151.0	7.9	3.0	4.3	22.9
	E-7	147.3	0.6	5.6	8.4	21.4
	E-8	64.1	0.0	7.2	10.0	11.0
	E-9	224.7	0.4	5.5	7.9	30.8
	E-10	342.8	0.8	4.9	7.3	44.2
	E-11	94.8	0.0	6.8	9.8	15.8
	E-12	289.0	4.2	2.0	3.8	28.9
	E-13	153.4	7.2	1.4	2.8	17.5
	E-14	200.5	0.3	5.2	11.3	33.8
	E-15	125.5	9.4	2.2	3.9	19.4
	E-16	89.9	0.8	6.6	7.7	13.6
	E-17	329.8	0.0	2.8	5.9	28.6
	E-18	145.1	7.9	2.8	6.5	25.0
	E-19	140.7	7.9	5.5	3.5	23.8
	E-20	145.4	0.8	5.2	9.7	22.8
	E-21	293.9	4.2	2.9	4.0	32.5
	E-22	82.3	0.0	6.7	8.4	12.4
	$\bar{x}$ ± SE	183.5 ± 17.2	3.4 ± 0.8	4.3 ± 0.4	6.5 ± 0.6	24.4 ± 1.8

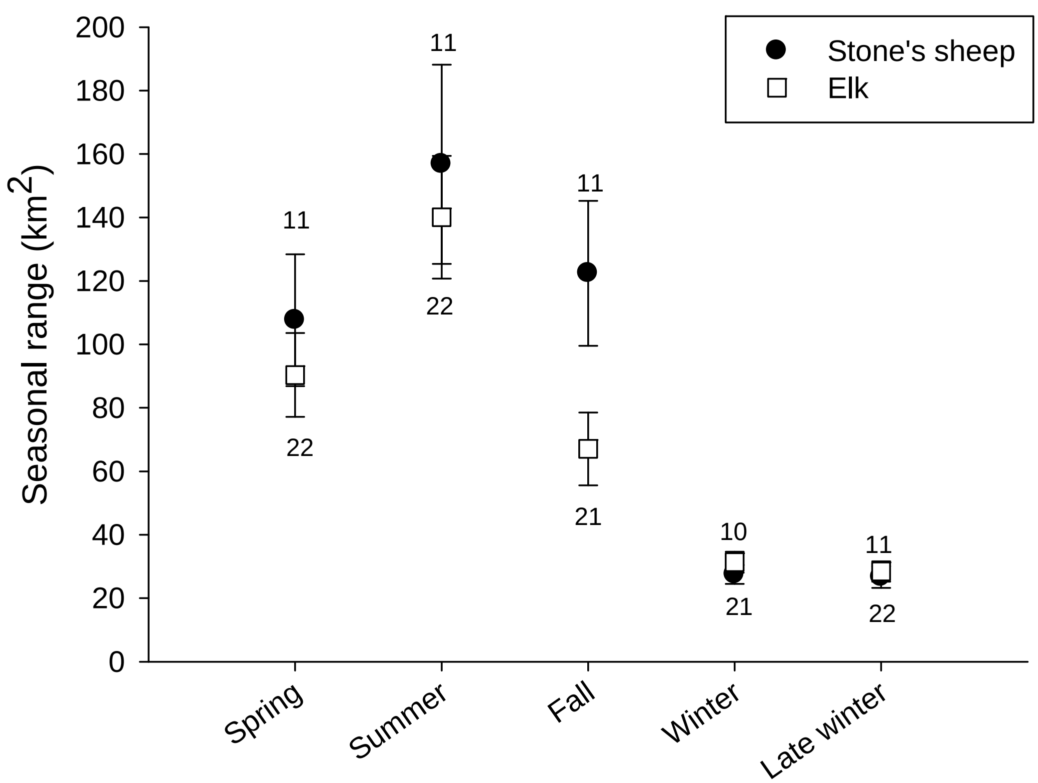

Figure 3.4. Seasonal range sizes ($\bar{x}$ ± SE) of GPS-collared female Stone's sheep and elk in the Greater Besa-Prophet Area in northern British Columbia between 2010 and 2012. Seasonal ranges were calculated for each individual and averaged across individuals in each season. Values above the error bars represent the number of individual Stone's sheep and values below indicate the number of individual elk used to calculate means and standard errors.

The distance between collared individuals and prescribed burns varied by season and species (Figure 3.5), ranging from 0 m (i.e., on the burn) to 17.5 km for Stone's sheep and to 20.2 km for elk. Stone's sheep were closest to a burn in winter (102 ± 29 m) and late winter (103 ± 53 m) and farthest away in summer (3,399 ± 807 m). Elk also were closest to a burn in late winter (55 ± 13 m) and were on average <350 m away from a burn in all seasons except summer (1,357 ± 493 m). Stone's sheep and elk used burns up to 26 and 28 years old, respectively. Stone's sheep most often used younger burns (<3 years old), whereas elk commonly used burns of all ages (Figure 3.6).

Resource selection strategies

Resource selection by both Stone's sheep and elk individuals was best described by the saturated models or an average of several models, but there was variation between species and among animals and seasons. Poor fit (i.e., $r_s < 0.648$) resulted in 4 Stone's sheep models and 25 elk models being dropped. Correlation coefficients (r_s) of models that fit the observed data ranged from 0.72–0.97 for Stone’s sheep and 0.66–0.98 for elk.

Both Stone's sheep and elk selected for south aspects, as described by the global models (pooled across individuals). Otherwise, their selection strategies differed. Selection for topographic features was fairly consistent across seasons for Stone's sheep (Table 3.5). They always selected for steeper more rugged terrain and higher elevations, except in summer when elevation was not a significant parameter. Stone's sheep selected against conifer stands in every season. *Carex*, Low shrub and Riparian were either selected against or avoided in most seasons and even when they were selected for in the global model, the majority of animals (n = 6–10) completely avoided (i.e., no use points) these land-cover classes. Stone's sheep selected for alpine areas in every season except spring. In spring and summer, they selected strongly for rocky areas and against all 3 burn classes, in contrast to

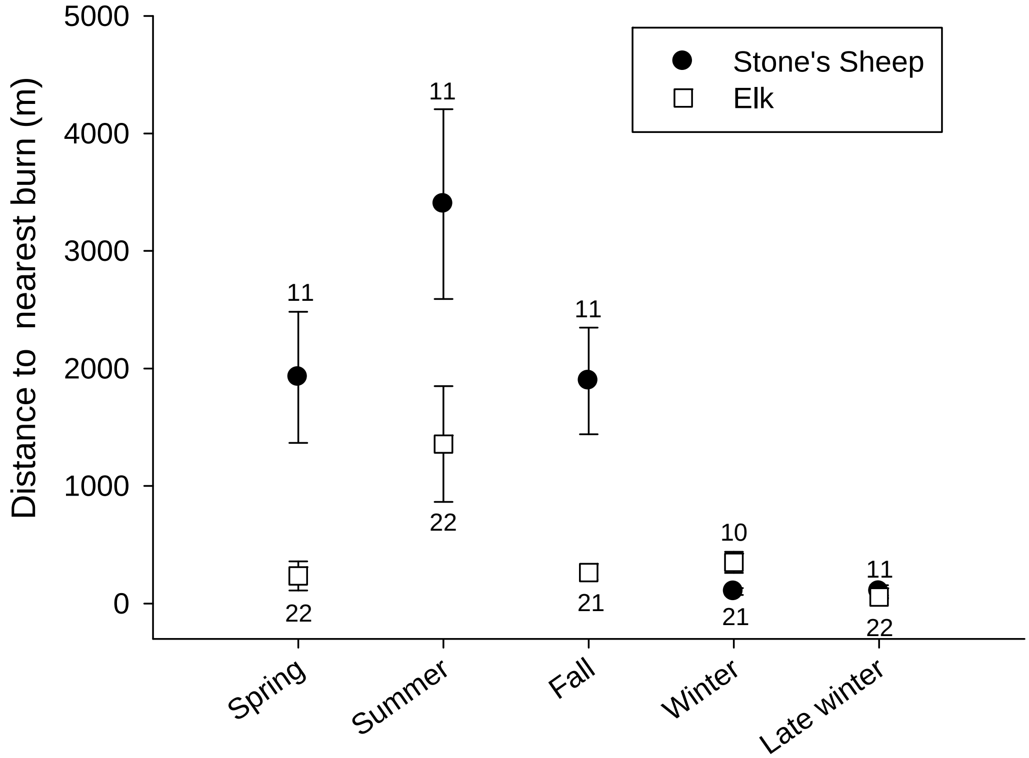

Figure 3.5. Seasonal locations of GPS-collared female Stone's sheep and elk in relation to their distance ($\bar{x}$ ± SE) to the nearest burn in the Greater Besa-Prophet Area of northern British Columbia from 2010–2012. Numbers of individuals (Stone's sheep above and elk below) averaged for each mean and standard error are shown for each season.

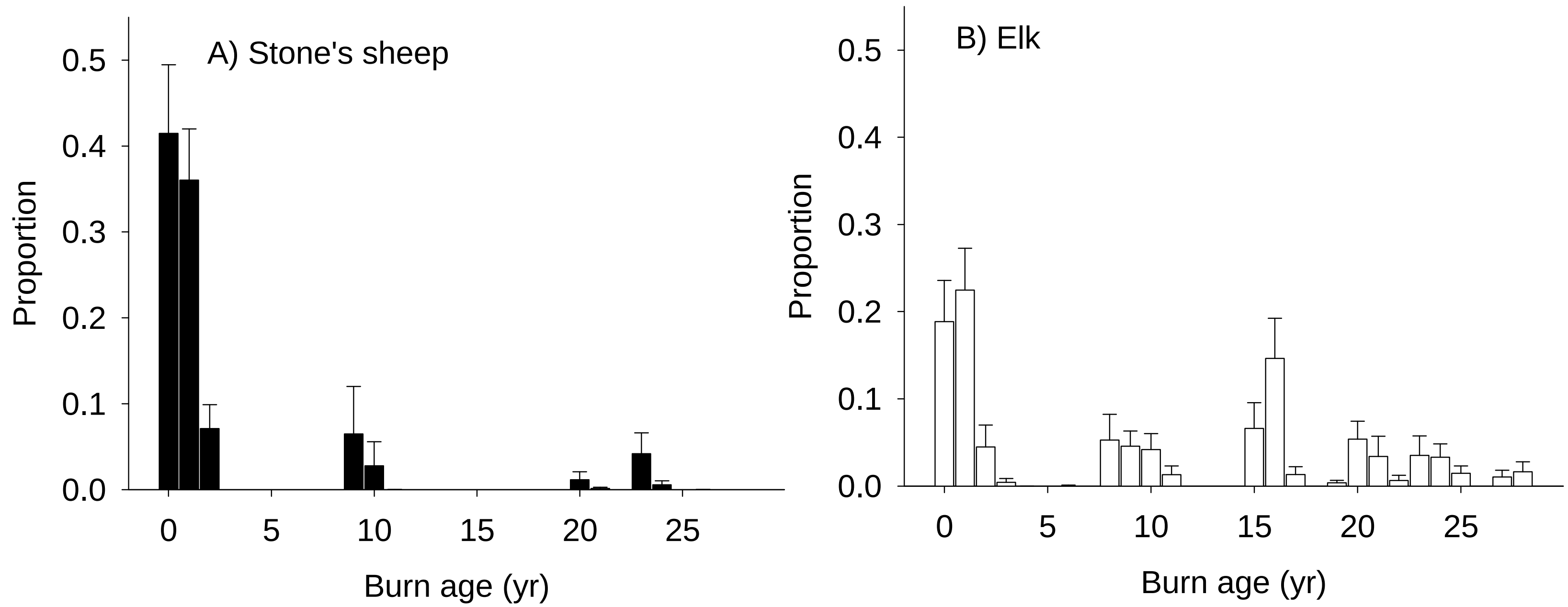

Figure 3.6. Proportional use ($\bar{x}$ + SE) of different aged burns by 11 GPS-collared female Stone's sheep and 22 GPS-collared female elk in the Greater Besa-Prophet Area of northern British Columbia from 2010–2012.

Table 3.5. Selection coefficients ($\bar{x}$ ± SE) in global resource selection models for Stone's sheep, calculated as the average of individual models in each season for 11 female Stone's sheep GPS-collared from 2010–2012 in the Greater Besa-Prophet Area in northern British Columbia. The number of individuals that significantly selected for or against each parameter is indicated under + or –, respectively; the number of individuals for which the parameter was not available or used is shown under X. Number of individual models averaged to develop global models in each season is indicated by *n*.

Parameter	Spring (*n* = 11)						Summer (*n* = 11)						Fall (*n* = 11)					
	Coef	SE	*P*	+	–	X	Coef	SE	*P*	+	-	X	Coef	SE	*P*	+	–	X
Elevation	45.47	4.11	<0.001	10			-2.74	4.42	0.535	6	4		62.06	4.51	<0.001	9		
Elevation^2	-13.25	1.18	<0.001		10		2.37	1.31	0.070	4	6		-16.81	1.28	<0.001		9	
Slope	0.09	0.00	<0.001	11			0.02	0.00	<0.001	5	2		0.03	0.00	<0.001	9		
Northness	-1.16	0.06	<0.001	11			-0.08	0.04	0.033	1	4		-0.52	0.03	<0.001		9	
Eastness	-0.20	0.06	0.001	3	5		0.29	0.03	<0.001	8	1		0.20	0.03	<0.001	5	4	
Dist. to burn	-0.23	0.06	<0.001	1	7		-0.07	0.04	0.052		5		-0.17	0.03	<0.001	1	7	
Ruggedness	12.77	1.17	<0.001	10			8.80	0.91	<0.001	8			5.43	0.61	<0.001	9	1	
Land cover																		
Carex						11	0.06	0.02	0.014			10						11
Low shrub	0.19	0.05	<0.001	1		9	0.09	0.04	0.012			9	-0.07	0.04	0.112	1	2	7
Conifer	-0.52	0.11	<0.001	1	6	1	-0.65	0.12	<0.001		6		-0.52	0.08	<0.001	1	7	
Rock crust	0.44	0.08	<0.001	5		1	0.66	0.08	<0.001	8			-0.17	0.05	<0.001	2	4	
Subalpine	-0.20	0.08	0.010	1	2	2	-0.87	0.11	<0.001		7	1	-0.30	0.04	<0.001	2	6	
Riparian	0.21	0.03	<0.001	1		10	0.29	0.11	0.007	2		6	0.38	0.05	<0.001	2		9
Alpine	0.01	0.09	0.942	1	1		0.57	0.08	<0.001	6			0.18	0.04	<0.001	5	5	
Burn shrub	-0.34	0.11	0.003	1	5		-0.12	0.03	<0.001		1	10	0.13	0.03	<0.001	4	1	3
Burn grass	0.12	0.11	0.275	2	2		-0.04	0.02	0.024			10	0.06	0.07	0.414	4	3	1
New burn	0.09	0.07	0.205	2	1	3						11	0.31	0.06	<0.001	6	2	2

Table 3.5. Continued.

Parameter	Winter (n = 9)						Late Winter (n = 8)					
	Coef	SE	*P*	+	–	X	Coef	SE	*P*	+	–	X
Elevation	30.34	3.25	<0.001	7			39.53	4.37	<0.001	5		
Elevation^2	-6.85	0.96	<0.001		7		-10.55	1.30	<0.001		5	
Slope	0.10	0.00	<0.001	9			0.13	0.00	<0.001	8		
Northness	-0.83	0.05	<0.001		8		-1.47	0.06	<0.001	8		
Eastness	-0.84	0.06	<0.001		6		-0.90	0.07	<0.001		6	
Dist. to Burn	-1.76	0.20	<0.001	2	7		-0.69	0.21	0.001	1	2	
Ruggedness	10.74	0.80	<0.001	8			15.86	0.90	<0.001	8		
Land cover												
Carex						9						8
Low shrub						9	0.24	0.06	<0.001	1		6
Conifer	-0.69	0.07	<0.001		6	1	-0.36	0.10	0.001	1	4	2
Rock crust	-0.95	0.05	<0.001		8		-1.03	0.06	<0.001		8	
Subalpine	0.08	0.04	0.075	2		1	0.23	0.06	<0.001	3		2
Riparian	0.00	0.00		1		8						8
Alpine	0.11	0.04	0.011	2	2		0.16	0.07	0.018	3	1	
Burn shrub	0.65	0.06	<0.001	6	1	1	0.40	0.07	<0.001	3		
Burn grass	0.62	0.08	<0.001	6	2		0.25	0.08	0.001	3		
New burn	0.17	0.06	0.002	3	3	0	0.11	0.05	0.038	2	2	1

fall, winter and late winter, when they selected against rocky areas and usually for all 3 burn classes (except for Burn grass in fall). In all seasons except summer, Stone's sheep selected to be close to a burn.

Elk did not have as consistent a selection strategy for topographic features (Table 3.6). They selected for low elevations in summer and mid elevations in winter, but showed no selection for elevation in the other seasons. Steep slopes were selected for in spring and late winter, but selected against in summer, fall and winter. In all seasons, elk either selected against or showed no selection for ruggedness, or Conifer and Alpine classes. With the exception of late winter, they always selected for Subalpine and to be close to a burn. Elk selected for burns in all seasons, with the Burn shrub class being the most selected (5 of 5 seasons) followed by Burn grass (4 of 5 seasons) and New burns (3 of 5 seasons).

Use, availability and importance of land-cover classes

Seasonal use of land-cover classes by Stone's sheep and elk appeared to correspond to the differential use of elevation and escape terrain. In all seasons, most locations for Stone's sheep were in rocky areas, especially in summer when $70 \pm 4\%$ (across all animals) of the locations were in the Rock/rock crust class (Figure 3.7). The next highest used class was Alpine in summer and fall (22–28%). Stone's sheep rarely used *Carex*, Low shrub, Non-vegetation or Riparian classes (all < 0.1%). They used every burn class to some degree in every season except summer, with highest proportional use in winter and late winter in New burn areas (17–28%).

Elk typically used all 3 burn classes proportionally more (from 7–38% across all animals) than they were available, except in fall when Burn grass was not used much (Figure 3.8). The next most commonly used classes were Conifer (12–20%) and Subalpine (16–31%). Selection for Conifer never occurred because availability of the class was always

Table 3.6. Selection coefficients ($\bar{x}$ ± SE) in global resource selection models for elk, calculated as the average of individual models in each season for 22 female elk GPS-collared from 2010–2012 in the Greater Besa-Prophet Area in northern British Columbia. The number of individuals that significantly selected for or against each parameter is indicated under + or –, respectively; the number of individuals for which the parameter was not available or used is shown under X. Number of individual models averaged to develop global models in each season is indicated by *n*.

Parameter	Spring (*n* = 17)						Summer (*n* = 22)						Fall (*n* = 20)					
	Coef	SE	*P*	+	–	X	Coef	SE	*P*	+	–	X	Coef	SE	*P*	+	–	X
Elevation	37.84	224.99	0.866	12	4		17.65	36.11	0.625	13	5	1	31.57	76.58	0.680	17	1	
Elevation^2	-12.9	20.18	0.523	3	12		-5.24	2.60	0.044	6	13	1	-10.0	7.10	0.159	1	17	
Slope	0.04	0.00	<0.001	10	1		-0.01	0.00	<0.001	6	8		-0.03	0.00	<0.001	3	14	
Northness	-1.32	0.13	<0.001		16		-0.53	0.03	<0.001	1	18		-0.38	0.02	<0.001	2	12	
Eastness	-0.14	0.04	<0.001	4	8		0.08	0.04	0.064	12	7		0.10	0.03	0.001	9	3	
Dist. to burn	-1.92	0.18	<0.001		14		-0.32	0.01	<0.001	1	14	2	-1.11	0.11	<0.001		12	
Ruggedness	-6.52	2.20	0.003	6	6		-1.48	0.87	0.090	5	5	1	-3.64	0.14	<0.001	6	6	
Land cover																		
Carex	0.07	0.01	<0.001			16	-0.02	0.01	0.028		1	19	-0.04	0.01	<0.001			19
Low shrub	0.15	0.06	0.017	3	2	5	0.28	0.05	<0.001	10		2	0.05	0.05	0.330	4	2	7
Conifer	-0.79	0.04	<0.001		11	6	-0.68	0.02	<0.001		18	1	-0.13	0.02	<0.001	4	5	1
Rock crust	-0.57	0.06	<0.001		6	11	-1.09	0.01	<0.001		14	8	-0.33	0.05	<0.001		4	15
Subalpine	0.45	0.09	<0.001	8	3	2	0.57	0.09	<0.001	16		1	0.26	0.09	0.004	10	4	2
Riparian	0.02	0.06	0.785	3	4	8	-0.01	0.07	0.847	3	7	8	0.01	0.12	0.915	4	2	4
Alpine	-0.33	0.06	<0.001		5	10	-0.28	0.05	<0.001	3	7	2	-0.50	0.03	<0.001		8	9
Burn shrub	0.67	0.08	<0.001	13			0.53	0.03	<0.001	16	2		0.44	0.08	<0.001	12	1	2
Burn grass	0.31	0.05	<0.001	8	4		0.26	0.01	<0.001	12	2	2	0.06	0.00	<0.001	5	4	4
New burn	0.02	0.02	0.430	3	2	9	0.45	0.08	<0.001	10		10	0.17	0.03	<0.001	3	1	11

Table 3.6. Continued.

Parameter	Winter (n = 20)						Late Winter (n = 19)					
	Coef	SE	P	+	–	X	Coef	SE	P	+	–	X
Elevation	27.82	2.77	<0.001	13	1		62.59	234.29	0.789	17		
Elevation^2	-8.66	0.54	<0.001		14		-21.09	33.44	0.528		17	
Slope	-0.02	0.00	<0.001	2	15		0.02	0.00	<0.001	11	5	
Northness	-0.79	0.03	<0.001		18		-1.63	0.27	<0.001	1	18	
Eastness	0.02	0.02	0.303	5	7		-0.10	0.04	0.008	5	9	
Dist. to burn	-0.90	0.15	<0.001	8	6		-0.53	1.23	0.668	6	5	
Ruggedness	-0.50	0.49	0.304	4	7	1	4.20	7.90	0.595	10	3	
Land cover												
Carex	0.14	0.03	<0.001	2	1	17	0.11	0.02	<0.001	1		18
Low shrub	-0.04	0.12	0.741	4	6	2	-0.08	0.04	0.054	3	5	4
Conifer	-0.12	0.01	<0.001	3	7		-0.04	0.07	0.546	5	6	1
Rock crust	-0.41	0.05	<0.001		5	14	-0.69	0.08	<0.001	0	8	8
Subalpine	0.20	0.07	0.006	8	4	1	0.06	0.07	0.363	4	3	4
Riparian	0.07	0.04	0.089	4	3	10	0.13	0.04	<0.001	3	0	13
Alpine	-0.49	0.02	<0.001	1	9	2	-0.08	0.05	0.169	2	4	8
Burn shrub	0.58	0.06	<0.001	17	1		0.52	0.05	<0.001	14	1	
Burn grass	-0.04	0.02	0.070	6	6	1	0.16	0.04	<0.001	6		
New burn	0.11	0.02	<0.001	5	2	11	-0.02	0.02	0.179	3	2	10

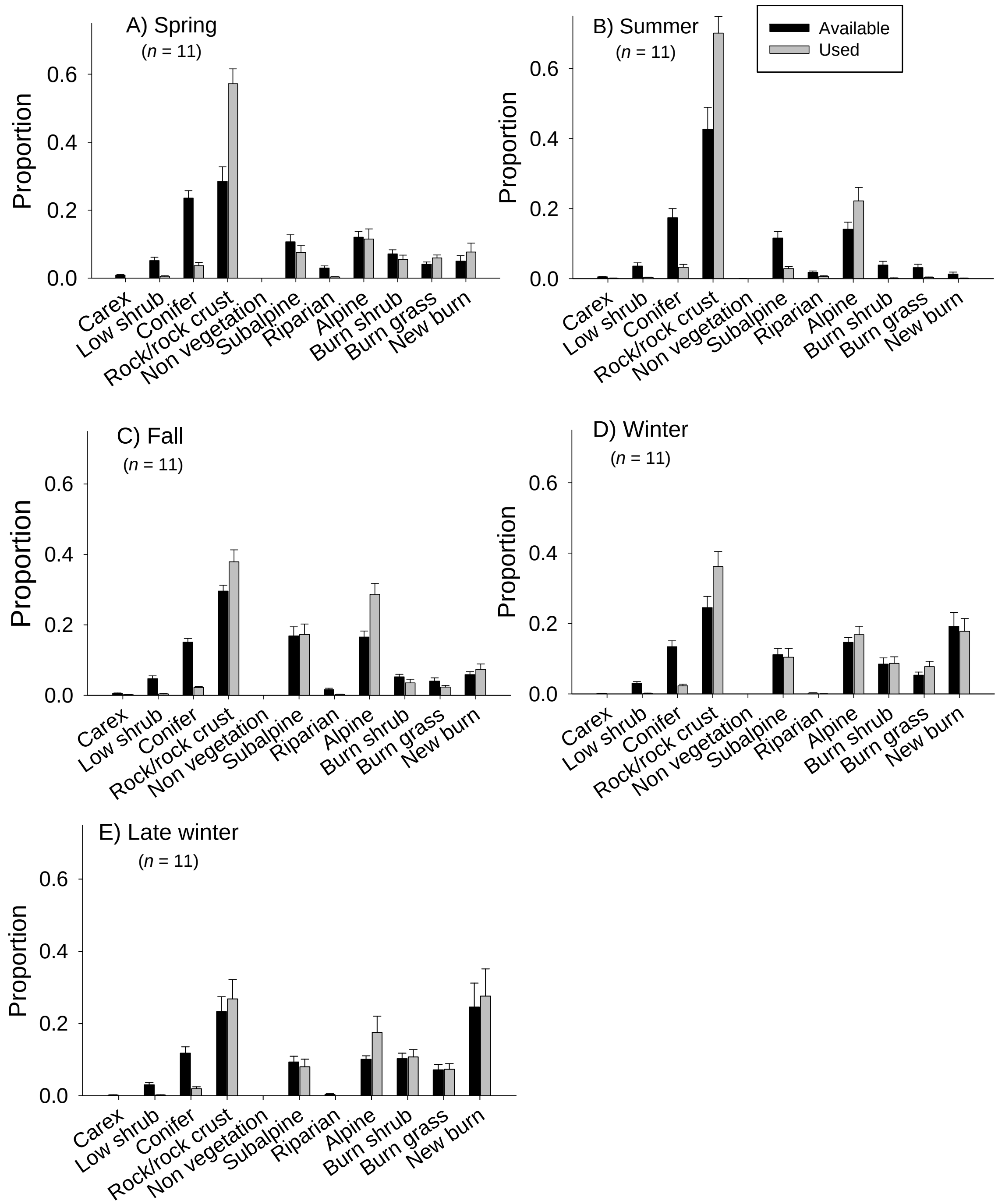

Figure 3.7. Seasonal availability and proportional use ($\bar{x}$ + SE) of land-cover classes by GPS-collared female Stone's sheep in the Greater Besa-Prophet Area of northern British Columbia. Averages from each individual (n) in each season were used to calculate mean proportions and standard errors.

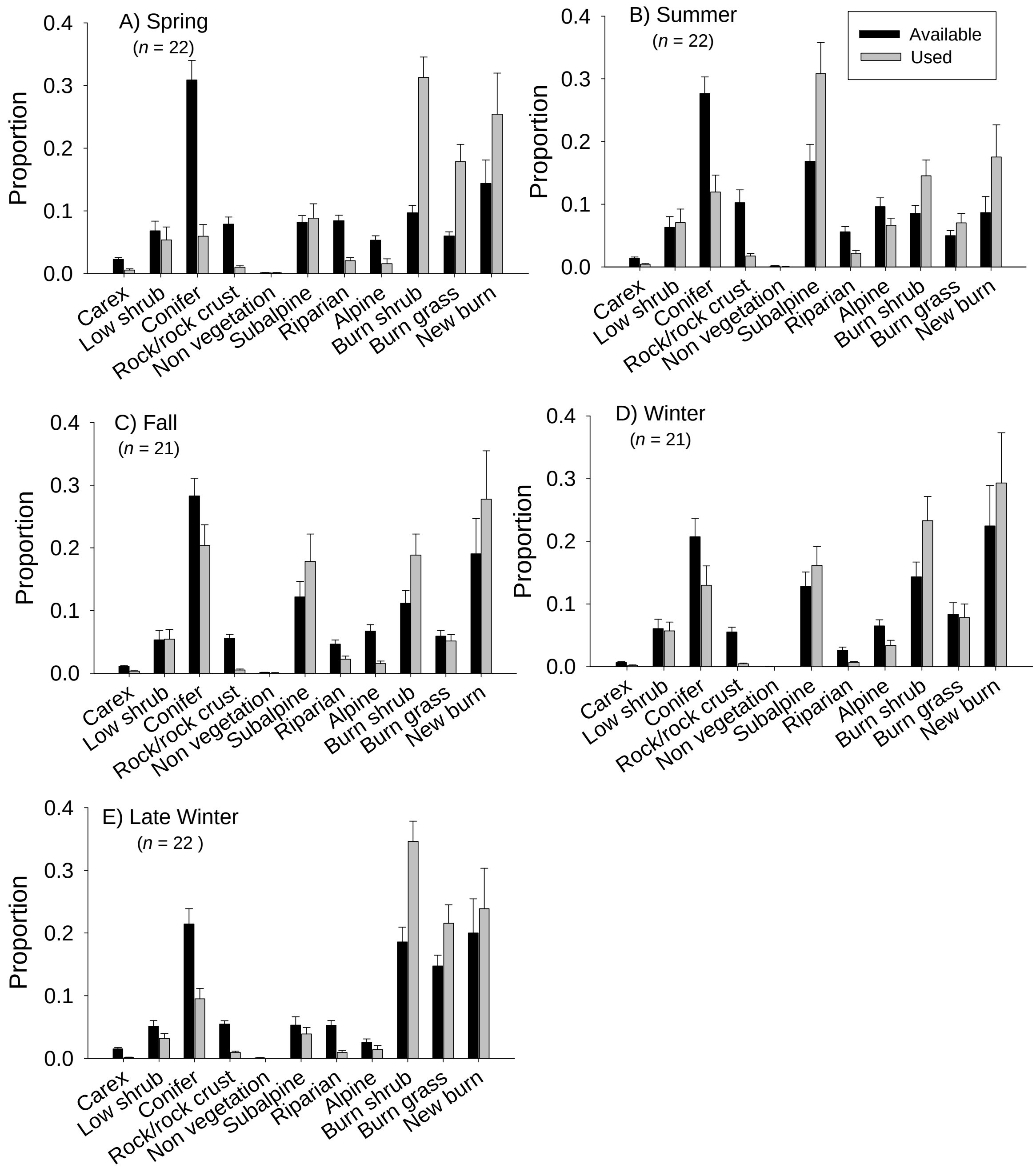

Figure 3.8. Seasonal availability and proportional use ($\bar{x}$ + SE) of land-cover classes by GPS-collared female elk in the Greater Besa-Prophet Area of northern British Columbia. Averages from each individual (*n*) in each season were used to calculate mean proportions and standard errors.

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higher than use. *Carex*, Non-vegetation, Alpine and Rock/rock crust classes were rarely used by elk.

Importance (use × availability scaled to 1.0) of land-cover classes varied seasonally between Stone's sheep and elk (Figure 3.9). Rocky areas followed by alpine areas were the most important classes for Stone's sheep, except in winter and late winter when New burn was more important than Alpine. In contrast, Burn shrub and New burn were most important to elk across seasons, in addition to Subalpine in the summer. *Carex*, Low shrub and Riparian classes were not important to either Stone's sheep or elk in any season.

Differential use of topography in relation to prescribed burns

GPS-collared Stone's sheep and elk showed similar seasonal and monthly patterns in the use of elevation and slope, but Stone's sheep were always at higher elevations (Figure 3.10A, 10B) and used steeper slopes (Figure 3.10C, 10D) than elk. Both species were at lowest elevation in late winter and moved up in elevation from spring to summer. Stone's sheep were at lowest elevation in April (1,639 ± 19 m) and began to move up in elevation each month until reaching their highest elevations in July (1,864 ± 29 m) and August (1,860 ± 26 m). In May, elk were at their lowest elevation (1,396 ± 22 m), moved up for summer, and were at highest elevation in November (1,588 ± 17 m). Both species used steepest areas in late winter and spring and flatter areas in summer and fall. The steepest location used by a Stone's sheep was 61.3^{o} in spring and by an elk was 50.6^{o} in late winter. Throughout the year, Stone's sheep and elk partitioned their use of topography (elevation, slope, ruggedness) with very little overlap occurring except when elk occasionally used more rugged terrain, but always at lower elevation (Figure 3.11A, 11B).

During the monthly fixed-winged flights, we recorded 372 Stone's sheep and 1,018 elk. We always saw more Stone's sheep and elk in winter than in summer (Figure 3.12).

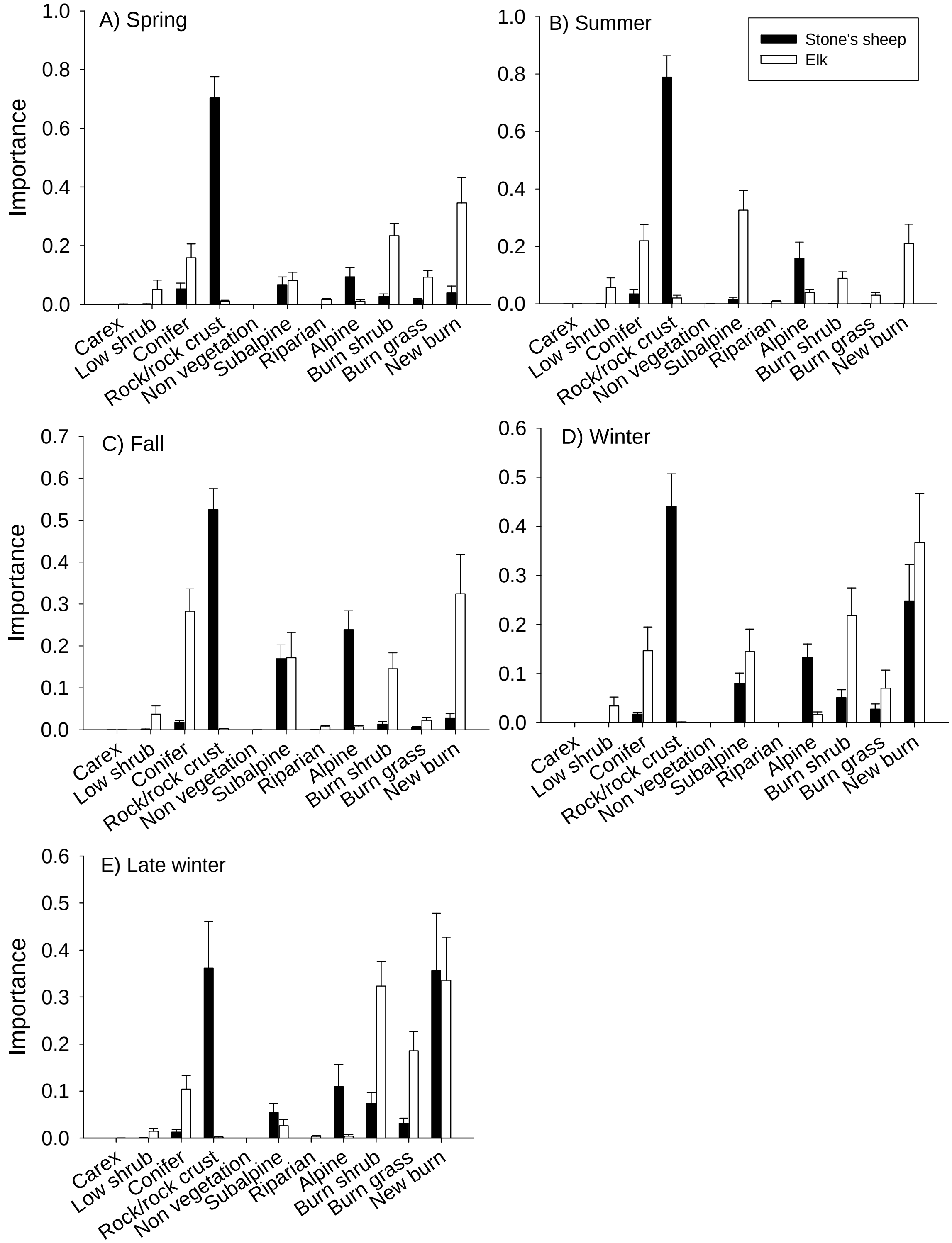

Figure 3.9. Importance of land-cover classes ($\bar{x}$+ SE) for GPS-collared female Stone's sheep and elk in the Greater Besa-Prophet Area of northern British Columbia. Averages from each individual in each season were used to calculate mean importance and standard errors.

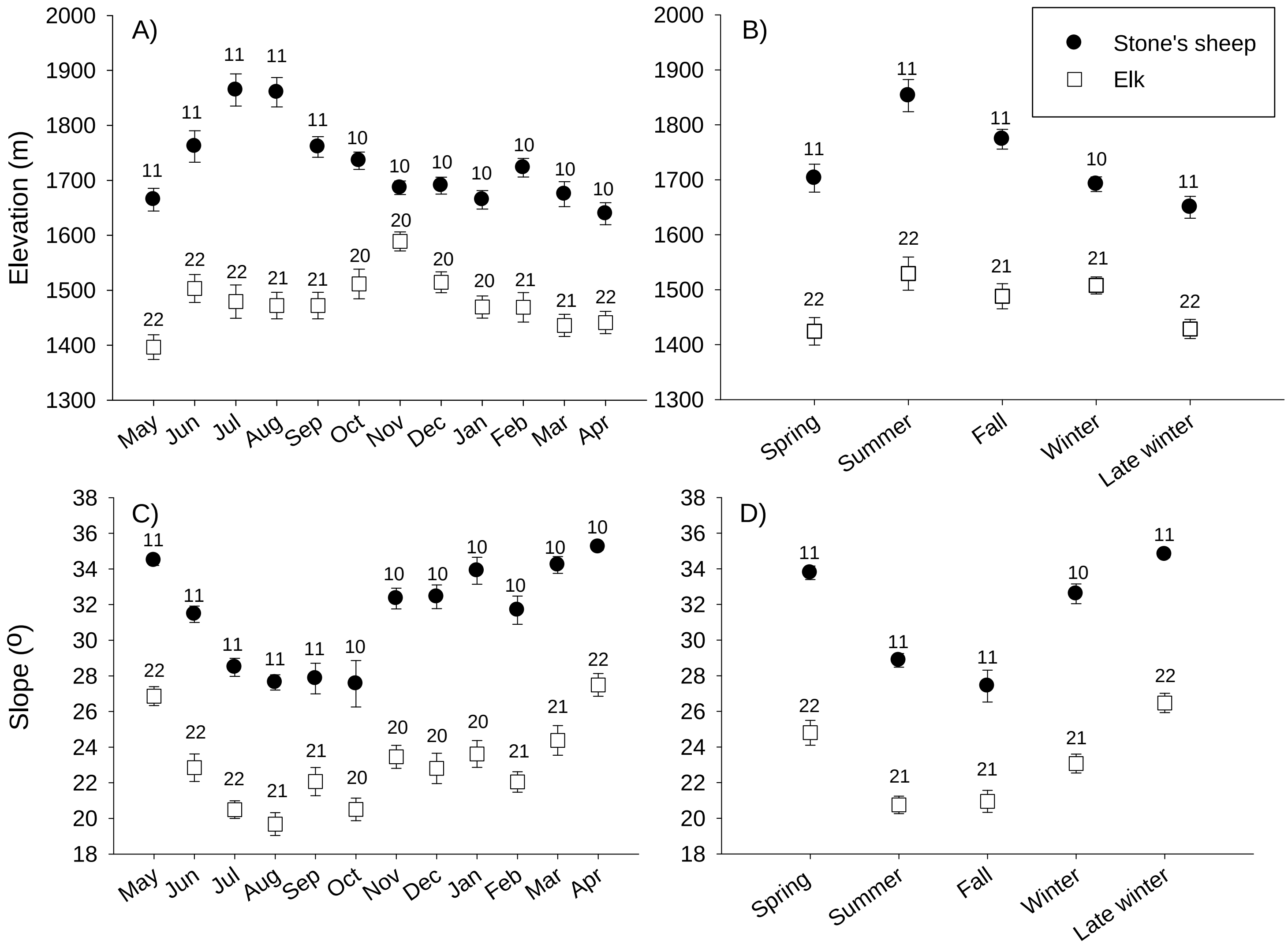

Figure 3.10. Monthly and seasonal use of elevation (A, B) and slope (C, D; $\bar{x} \pm$ SE) by GPS-collared female Stone's sheep and elk in the Greater Besa-Prophet Area of northern British Columbia between 2010 and 2012. Numbers of individuals averaged for each month and season are given.

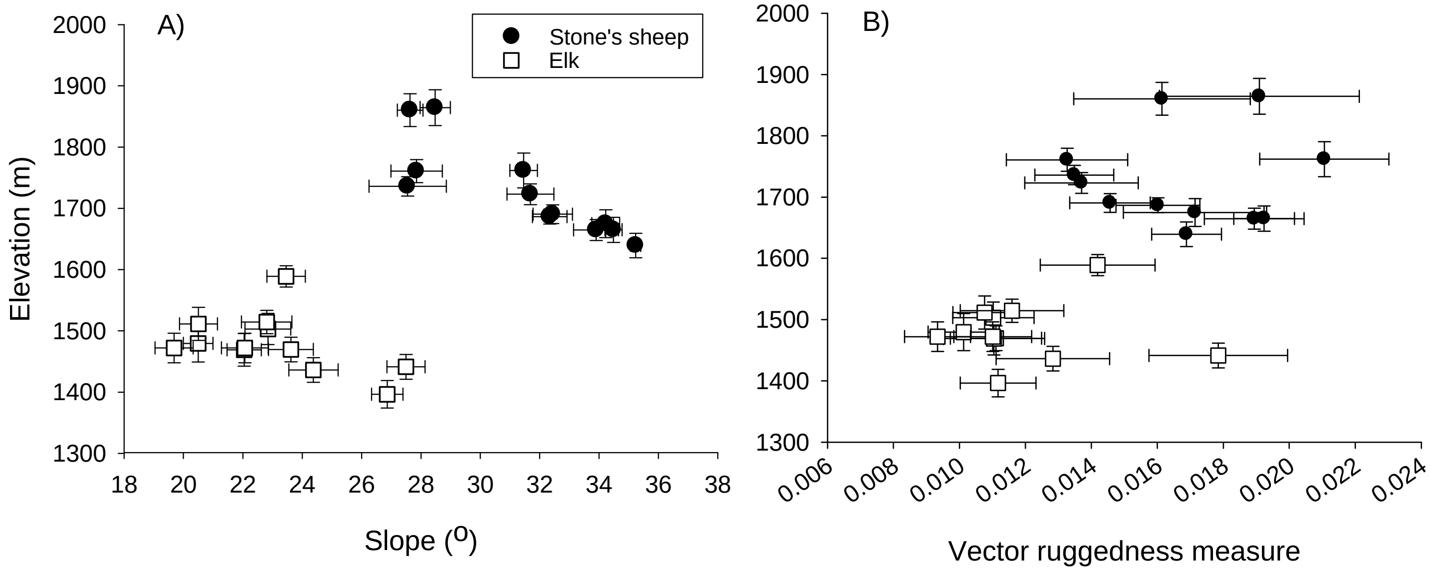

Figure 3.11. Resource partitioning of A) elevation and slope; and B) elevation and ruggedness ($\bar{x}$ ± SE) by GPS-collared female Stone's sheep and elk in the Greater Besa-Prophet Area of northern British Columbia. Individual averages were calculated monthly and averaged across individuals to obtain means and standard errors.

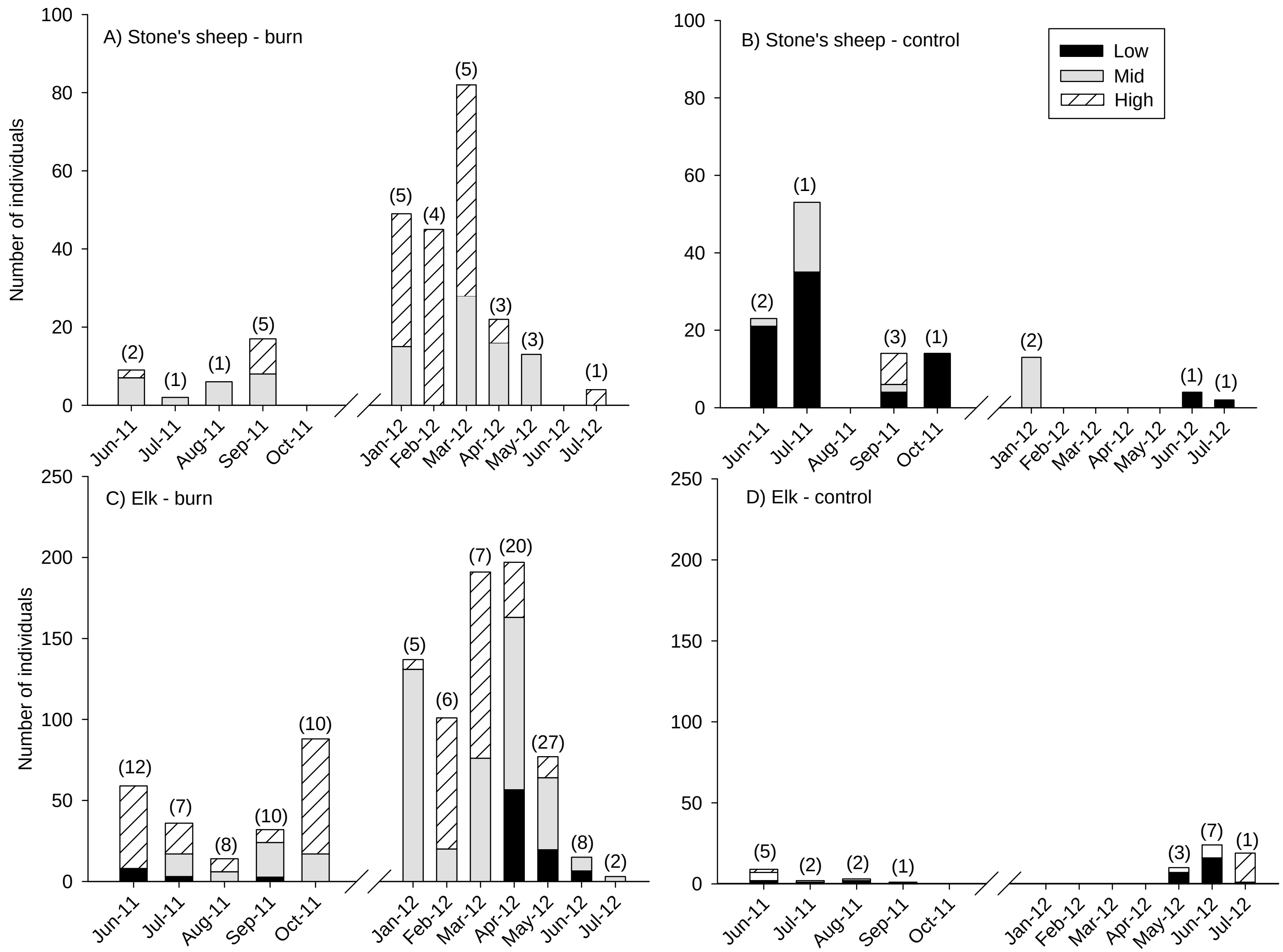

Figure 3.12. Number of individual Stone's sheep and elk observed on prescribed burns or in adjacent unburned areas (controls) at different elevations (high, mid, low) during monthly distribution flights in the Greater Besa-Prophet Area in northern British Columbia (Jun 2011–Jul 2012). Number of animal groups is noted above each sample. These flights followed the same 2-h route every month, which encompassed 28 different prescribed burns.

Both species were most often on burns except in summer and fall, when large groups of Stone's sheep (up to 35 individuals) were observed using lower elevation mineral licks. Stone's sheep using burns were always at high or mid elevation, whereas elk used burns at all elevations. Elk in the high-elevation range were almost always at lower elevations than Stone's sheep. When the 2 species were at similar elevations, Stone's sheep were always on rocky more rugged terrain. Other species recorded during the flights were bison, black bears, grizzly bears, moose, caribou, mountain goats, and wolves.

DISCUSSION

Prescribed fires decrease shrub cover (Chapter 2), opening up areas with increased visibility (Risenhoover and Bailey 1985), and increase the quality and quantity of forage for grazing ungulates (Sachro et al. 2005, Van Dyke and Darragh 2007, Chapter 2). The GBPA provides a rare opportunity in North America to study the impacts of fire on ungulates without the influence of other confounding, cumulative anthropogenic impacts. The seasonal selection strategies of female Stone's sheep and elk in the GBPA resulted in some overlap in their use of resources with the highest probability of overlap occurring in winter and late winter, when both species used prescribed burn areas. However, the 2 species partitioned the landscape through their differential use of elevation and topography.

Movement rates and range size in relation to prescribed burns

Lowest movement rates and smallest ranges occurred in the most energetically demanding seasons (winter and late winter) for both Stone's sheep and elk. During winter, energetic demands associated with snow and cold temperatures can be high, snow may restrict movement, and forage can be scarce or of poorer quality (Skovlin et al. 1983). The smaller ranges used in the winter seasons were typically associated with burned areas, which comprised an average of 26 and 30% of winter and late winter ranges for Stone's sheep and elk, respectively. Recent burns may provide access to higher quality forage (Chapter 2); older burns often provide increased forage quantity (Sachro et al. 2005, Van Dyck and Darragh 2007). These prescribed burns, therefore, facilitate ungulates meeting their energy and nutritional requirements. High variability in movement rates and range sizes among individuals of both species may reflect different seasonal trade-offs (Frair et al. 2005). The higher movement rates by Stone's sheep than elk in summer and fall were surprising, even though the sizes of annual ranges of the 2 species (Stone's sheep range: 34–376 km^2; elk range: 64–343 km^2) were similar. Past research in the GBPA noted that Stone's sheep occupied annual ranges ($\bar{x}$ = 35.5 km^2, range = 16–61 km^2; Parker and Walker 2007) that were less than one-third the size of elk ranges (191 ± 70 km^2; Gillingham and Parker 2008*a*). We attribute this discrepancy primarily to differences among groups of collared Stone's sheep. Animals in our study in the Luckhurst and Townsley areas had annual range sizes similar to those documented by Parker and Walker (2007). We also had Stone's sheep collared in the Richards area that used a much larger area, moving from their winter range on a burn across the valley to slopes on either side of the Richards Creek drainage. The movement in spring before lambing was to rocky areas, presumably to minimize predation risk, which can be high for juveniles in this area (Milakovic and Parker 2011). Movement rates and range sizes for elk were comparable to values determined previously in the GBPA (Gillingham and Parker 2008*a*) and in Yellowstone National Park (Boyce 1991, Forester et al. 2007), where elk move seasonally to utilize burned areas (Pearson et al. 1995).

Selection and use strategies in relation to burned areas

During our study, collared animals had access to over 138 different burns, ranging in age from 0–31 years old in the GBPA. We documented Stone's sheep and elk on burns up to 26–28 years of age. Typically new burns have lower forage biomass until at least 1 year after burning, after which forage biomass increases and remains higher for several years (Chapter 2, Sachro et al. 2005, Van Dyck and Darragh 2007). Stone's sheep showed higher use of newer burns relative to elk. Elk were less particular using new, but also older burns of various ages, which is consistent with their selection for burned shrub areas.

Our seasonal resource selection models pooled from individual Stone's sheep and elk described selection for landscape variables similar to past research in the GBPA (Walker et al. 2007, Gillingham and Parker 2008*a*). Stone’s sheep and elk for most of the year selected for south-facing slopes, which are usually windswept and the first to become snow-free in the spring (Skovlin et al. 1983). This is consistent with studies on Stone’s sheep near Toad River, BC (Seip 1983), Dall sheep (*Ovis dalli dalli*) in interior Alaska (Rachlow and Bowyer 1998), and elk in other parts of western North America (Mackie 1970, Hudson et al. 1976, Pearson et al. 1995, Poole and Mowat 2005). Both species also selected to be close to a burn in 4 of the 5 seasons. Stone’s sheep in Toad River, BC used burned areas seasonally, moving down from their winter range on nutrient-poor alpine ridges to utilize the subalpine burned areas when snow levels retreated (Seip and Bunnel 1985*a*). Elk in the GBPA selected for burned areas in every season and showed the highest selection for Burn shrub areas. A review by Christianson and Creel (2007) of 72 studies on elk winter diets in western North America reported that elk consistently selected graminoids for the majority of their diet, but consumed shrubs in proportion to their availability, implying that the amount of browse in the diet is primarily determined by habitat use rather than selection for shrubs. Burn shrub areas provide excellent foraging opportunities for elk as well as some thermal cover.

Apart from their similar selection for burned areas in winter and late winter, Stone's sheep and elk selected inversely for many other land-cover classes. Selection in spring and summer for rocky areas, which elk avoided, is a reproductive strategy for female Stone's sheep (Walker et al. 2006). In every season except spring, Stone's sheep selected for alpine areas, which elk avoided throughout the year. In contrast, elk usually selected for the Subalpine (except in late winter), which Stone's sheep avoided.

Most ungulates must balance the need to meet nutritional requirements through forage with the risk of predation. Stone's sheep (Geist 1971) and elk (White et al. 2009) rely on their ability to detect danger at a distance, giving them ample time to retreat to safer terrain when needed. Escape terrain for Stone's sheep, consisting of solid-rock features or talus slopes where they can move easily and avoid predation, is a well-recognized component of wild sheep habitat (Bleich et al. 1997, Rachlow and Bowyer 1998, Walker et al. 2006, Sappington et al. 2007). Availability of escape terrain may be one of the limiting factors for Stone’s sheep populations (Walker et al. 2007). Stone's sheep in the GBPA selected for rugged terrain in every season. In contrast, elk selected to avoid rugged areas or showed no selection in the global models across seasons. Landscape attributes that reduce the ease of movement and ability to maneuver increase the vulnerability of elk to predators (White et al. 2009). In Yellowstone National Park, the escape strategy for elk under attack by wolves was to flee, often into rivers in summer (White et al. 2009). The value of prescribed burns for Stone's sheep and elk, therefore, should be considered relative to access to adequate escape areas for each species. We observed the largest groups of both Stone's sheep and elk in the GBPA in winter on prescribed burns. Presumably animals responded to the increased foraging opportunities as well as to minimizing predation risk. Grouping behavior (i.e., larger group sizes in winter than summer) may serve as an anti-predation strategy because larger groups increase the ability to detect predators (Mao et al. 2005, Geist 1971, Heard 1992).

The global models that we present here describe selection of resources by Stone's sheep and elk with equal weighting per individual. The value of these models is in describing selection and avoidance of multiple resources and not just topography or land-cover class alone (Boyce and MacDonald 1999). We also present the variation among individual models to highlight that care should be taken when interpreting global RSF models even with adjustments for individuals (Gillingham and Parker 2008*b*). For example, Stone's sheep in the GBPA rarely used *Carex*, Low shrub and Riparian classes (all use < 0.1%), and the majority of individuals selected against these areas or completely avoided them (Table 3.5). Yet the global models indicated that Stone's sheep selected for these land-cover classes in some seasons. Occasionally some Stone's sheep moved down into the valleys to cross sedge and riparian areas to access another hillside or to use mineral licks associated with these areas (Walker 2005, this study). Selection in the global models, therefore, was driven by 1-2 individuals. Similarly, selection by elk for elevation was poorly defined in our global models. Selection occurred for middle elevations in winter and during the rest of the year elevation was not significant. In every season, however, 60–85% of all individuals selected for middle elevations and in late winter 17 individuals selected for mid elevation while none avoided it (Table 3.6). Yet the individual variation was so high that elevation was not significant in the global model. Elk also appeared to have 2 different strategies in their selection for ruggedness across individuals. In spring, summer and fall, 50% selected for rugged areas and 50% selected against, resulting in no selection for this parameter in the global model. It is unclear why individual elk may have different strategies for the use of rugged areas, but presumably it reflects different trade-offs between predation risk and foraging. Individual moose, for example, have different calving strategies where some calve at high elevation to reduce predation risk and some calve at low elevation to obtain higher forage value (Poole et al. 2007). Differential selection for ruggedness by elk may have been missed if variation among individuals had been ignored.

We caution, therefore, against basing ecological and resource management conclusions solely on the global selection models and recommend examining individual variation, as well as proportional use-availability comparisons (Figures 3.7, 3.8) and calculations of importance (use × availability scaled to 1.0; Figure 3.9). The latter 2 metrics allow for identification of land-cover classes that are important (because of high use) but might not be selected for (because of high availability; Stewart et al. 2010), or that are selected for because of their rarity but with little value to the animal. For example, selection by female Stone's sheep for topography and land cover resulted in the highest use of Rock/rock crust areas in summer, when 70 ± 4% of locations (averaged across individuals) were in that class. Rocky areas were important to Stone's sheep consistently in every season (ranging from 0.28–0.79), yet 'selection' per se for these areas occurred only in spring and summer. In addition, Stone's sheep used high elevation in summer, but this did not show up as selection because the availability of high elevation habitat was abundant.

Resource partitioning and the potential for competition

Sympatric ungulates typically exhibit some form of resource partitioning (Jenkins and Wright 1988), often occurring relative to spatial (Gillingham and Parker 2008*a*, Stewart et al. 2010) and temporal (Stewart et al. 2002, Kronfeld-Schor and Dayan 2003) use of habitats and dietary differences (Kingerly et al. 1996, Stewart et al. 2003, Bowyer and Kie 2004, Beck and Peek 2005). Stone's sheep are habitat specialists requiring steep slopes and high elevations with access to escape terrain to easily evade predators (Walker et al. 2007). Elk are habitat generalists, typically using areas that maximize their foraging efficiency and avoid predators (Gregory et al. 2009). Presently in the GPBA, the 2 species generally occupy different niches defined by elevation, slope and ruggedness. Stone's sheep appear to select and use the landscape similar to other mountain sheep (Geist 1971, Bleich et al. 1997, Rachlow and Bowyer 1998). If prescribed burning facilitates the expansion of elk populations, however, the distribution and behaviour of Stone's sheep may change.

Close coexistence among Stone's sheep and elk could develop into competition (especially in winter and late winter) if resources become more limiting. As noted in other studies examining resource partitioning among ungulates (e.g., Jenkins and Wright 1988), the highest overlap in resource use is likely to occur during nutritionally restrictive seasons, with severe winters and associated low forage availability enhancing the overlap. Although there are dietary similarities between the 2 predominant grazers in the GBPA (Appendix B), it does not appear that forage for Stone's sheep and elk is limiting now on south-aspect burned areas (Chapter 2). Stone's sheep population surveys conducted every 4 years for the past 20 years indicate that populations in the GBPA are stable (Thiessen 2012). The area in the northern section of the GBPA with the highest density of Stone's sheep (239 sheep/100 km^2) also had the highest density of incidental elk (383 elk/100 km^2) observations above 1,400 m. In years of high snowfall and hard snow-crusting events, however, the reduced ability to access forage on south-aspect slopes may increase the potential for exploitive competition (i.e., competition for forage) between Stone's sheep and elk. Poole and Mowat (2005) showed that deep snow reduced the areas used by elk and deer to 4–6% of annual ranges during late winter. Elk require 2–4 times more food per day than Stone's sheep (Seip and Bunnell 1985*b*, Cook 2002), and increasing elk populations will decrease the availability of forage especially on winter ranges.

Habitat selection can change as a consequence of animal density (Hobbs and Hanley 1990, Boyce et al. 2003). Elk in other parts of their range are known to compete for space (i.e., interference competition) with other ungulates, forcing the other species to use less optimal habitats (Jenkins and Wright 1988, Stewart et al. 2002). Johnson et al. (2000) showed that mule deer specifically avoided areas used by elk. We did not measure behavioural changes of Stone's sheep in the presence of elk, but bighorn sheep (*Ovis canadensis*) decreased bite rates and increased vigilance in the presence of other ungulates (Brown et al. 2010). Unfortunately, apart from manipulating the food supply or removal of one of the competing species, these types of competition (exploitative or interference) are extremely difficult to test in a natural environment.

Apparent competition is a potentially important limiting factor for many ungulates that are considered secondary prey species, when generalist predators increase in response to a more abundant primary prey source (Holt 1977). In California, bighorn sheep populations exhibited higher rates of cougar predation in locations with spatial overlap with mule deer (Johnson et al. 2012). Stone's sheep and elk may not compete directly with each other for forage or space at this time, but elk currently comprise the largest biomass of the ungulate species in the GBPA and are an important prey source for wolves (Milakovic and Parker 2011) and grizzly bears (Milakovic and Parker 2013). If elk populations continue to increase, they may support larger numbers of predators that could opportunistically prey on Stone's sheep. Past research on the diets of wolves and grizzly bears in the GBPA has shown that predation on Stone's sheep was highest in winter and spring (Milakovic 2008). In the Richards area of the GBPA, Stone's sheep constituted 35–40% of the seasonal diet of 1 pack of wolves (Milakovic and Parker 2011). By enhancing elk populations, fire has the potential to negatively impact Stone's sheep with the subsequent increases in predator populations.

MANAGEMENT IMPLICATIONS

Prescribed fire is an effective management tool for enhancing ranges used by Stone's sheep and elk. Fire, also alters the distribution of ungulates as they increase use of burned areas. Our study provides a baseline for how Stone's sheep and elk currently partition their use of a heterogeneous landscape, shaped by the diverse topography and prescribed burning. Managers should continue to monitor elk populations to ascertain if they are increasing and if so, if they move in response to the communities that follow prescribed burning into the steeper and higher elevations used by Stone's sheep. Additionally, if elk populations expand at lower elevations, they could augment predator populations that then negatively influence moose numbers (Gillingham and Parker 2008*a*). Managers, therefore, need to have clear objectives for each species in the community. To ensure that continued management efforts are maximized for the use of fire on the landscape, we recommend long-term monitoring of both Stone's sheep and elk populations in relation to the use of burns as burns age and to any changes in niche overlap so that the benefits of fire for both species do not result in negative impacts on Stone's sheep in the future. Ecologically, if both species respond to prescribed burns, species overlap will likely come at a greater cost to Stone's sheep than to elk, which may displace other ungulates when use is concentrated in the same areas. Because Stone's sheep are found only in northern BC and southernYukon, Canada, they are viewed socially as having higher priority than elk.

Chapter 4. Research implications and management recommendations

INTRODUCTION

The use of spring prescribed fires can be an efficient, cost-effective and socially accepted management tool for enhancing ranges by increasing forage value for grazing ungulates (Backmeyer et al. 1992). The Peace-Liard Prescribed Burn Program has been employing this tool as a standard technique for over 30 years in the northeastern portion of British Columbia (BC). This program is supported locally by northern residents and monetarily receives over $100,000 per year from several sources including the Habitat Conservation Trust Foundation, North Peace Rod and Gun Club, Northeast Wildlife Fund, and the Northern Guides Association. Initially the prescribed burns targeted areas to enhance range value for elk (*Cervus elaphus*), but the program has since expanded to benefit Stone's sheep (*Ovis dalli stonei*), moose (*Alces alces*) and mountain goats (*Oreamnus americanus*). In their report on the status of thinhorn sheep in BC, Demarchi and Hartwig (2004) recognized the benefits of prescribed fire for Stone's sheep and other species, but pointed out that the response of different communities to prescribed fire has only been documented in a general sense and there is only anecdotal information to suggest that the program is effective in enhancing some ungulates. As a first step in assessing the effectiveness of the prescribed burn program, a thorough review and synthesis of past fire history in this part of the province was conducted to identify knowledge gaps and provide a framework for a research monitoring plan (Lousier et al. 2009). The 2 most important themes to help identify long-term outcomes of this wildlife/prescribed fire research program were: 1) maintaining ecological diversity; and 2) maintaining the presence and number of species of large wildlife. To properly evaluate the effectiveness in achieving these long-term outcomes and the objectives for wildlife management, Lousier et al. (2009) identified the need to better understand how prescribed burns affect: 1) the density and distribution of target species; 2) the composition and dynamics of burned vegetation communities; 3) the potential for competition for forage and space between sympatric species; and 4) predator-prey dynamics. In response to the research needs identified, my study, in documenting resource use by Stone's sheep and elk in response to prescribed burning and monitoring the indirect effects of fire on these grazers though direct effects on the vegetation, addressed the first 3 research needs for these 2 species and provides a baseline for continued monitoring. In this chapter, I first summarize the general findings of my thesis and expand on the selection, use and importance of burns for individual Stone's sheep and elk. I also discuss the seasonal distribution of these 2 species in the Besa-Prophet area. Secondly, I provide recommendations based on the knowledge gained from this thesis for the continued management of fire on the landscape and to maximize the benefits to target species; and thirdly I identify future research needed to assess the influence of human-induced fire on this landscape.

PRESCRIBED BURNING IN THE BESA-PROPHET

Fire, plant and animal interactions

Fire consumes any vegetation in its path and the new succession of plants that recolonise a burned area benefit graing ungulates (Hobbs and Spowart 1984, Sachro et al. 2005, Van Dyck and Darragh 2007). In my study, the short-term (year of the burn and 1 year after burning) responses of vegetation to fire were quantified relative to changes in forage dynamics for grazing ungulates in the Besa-Prophet area. With the reduction in shrubs following prescribed fire, herbaceous cover increased in burned communities. Species diversity increased to almost that of unburned areas by 1 year after burning. Vegetation biomass continued to increase 2 years after burning and the rate of forage growth was higher on burned areas than unburned control areas. Forage digestibility increased following burning, in both summer and winter, and was highest 1 year after fire. Crude protein was higher in the new growth on burned areas in late winter, but returned to pre-burn levels by 1 year after fire. The availability of high-quality forage for ungulates (quantity × quality) was higher on south-aspect sites than west-facing sites. Benefits of fire in increasing the nutritional quality of the forage available to Stone's sheep and elk are likely underestimated relative to the improvement in diet quality following burning, especially if animals forage selectively (Hobbs and Spowart 1984). Additionally, there were significant site, season and elevational effects of prescribed burning on vegetation response (Chapter 2), as summarized in Table 4.1.

Stone's sheep and elk are 2 focal species that benefit from the early seral vegetation produced following fire (Seip and Bunnell 1985*b*, Van Dyck and Darragh 2007). Based on pellet counts and distribution flights in the Besa-Prophet area, they were the 2 species that used burned slopes most (Chapter 2). Both species selected for south aspects and to be close to a burn (Chapter 3). Stone's sheep selected to be on burn cover classes (Burn grass, Burn shrub or New burn) in fall, winter and late winter, while elk selected to be on burns in every season, with the highest selection for Burn shrub (Figure 4.1). From a management perspective, importance values, calculated as proportional use (GPS locations) × availability (random locations within an animal's movement potential; Chapter 3) scaled to 1.0, are useful in ranking land-cover value to different species. Prescribed burned areas were most important to Stone's sheep in winter and late winter and more important than other cover classes in every season for elk (Figure 4.2). Rocky areas were always important to Stone's sheep, especially during seasons when burned areas were least important (Figure 4.3A). In contrast, elk rarely used rocky areas and therefore they were not calculated as important

Table 4.1. Summary of vegetation response to 4 prescribed burns implemented in the Besa-Prophet area of northern British Columbia in spring 2010, with follow-up monitoring in the year of the burn and 1 year after burning in summer and late winter. Vegetation response varied by site and elevation (see Chapter 2 for specifics).

Vegetation Characteristic	Response to prescribed burning
Forage Quantity	
Biomass	Scale-dependent. Differences between burns and unburned control areas were not detected at the scale of the 50-m transect by 1 year after burning, but there was more forage biomass at the scale of the 8 × 8 m range exclosures by1 year after burning. Based on NDVI values, forage biomass was still increasing 2 years after burning in summer. The rate of forage growth was higher on burned areas than unburned areas. Forage biomass was always higher on south-aspect sites than west-aspect sites.
Green-up	Forage green-up occurred earlier on burned sites than unburned sites and was less hindered by litter.
Forage volume	Similar to forage biomass, there was no detectable difference at the 50-m transect scale between burns and controls, but by 1 year after burning there was more forage volume at the scale of the 8 × 8 m range exclosures.
Forage cover	Shrub cover was reduced following burning at every site, opening up areas for herbaceous cover to increase.
Diversity	Plant diversity declined in the year of the burn, but by 1 year after burning it had rebounded almost to unburned levels.
Forage Quality	
Crude protein	Crude protein increased in the new growth on burned areas, but declined to pre-burn levels by 1 year after burning.
Digestibility	Forage digestibility increased on burned areas, was highest 1 year after burning, and higher on burned areas than controls.
Available Forage (Quantity × Quality)	Available digestible protein and digestible dry matter were higher on south-aspect sites than west-aspect sites. There was no difference between burned and control sites.

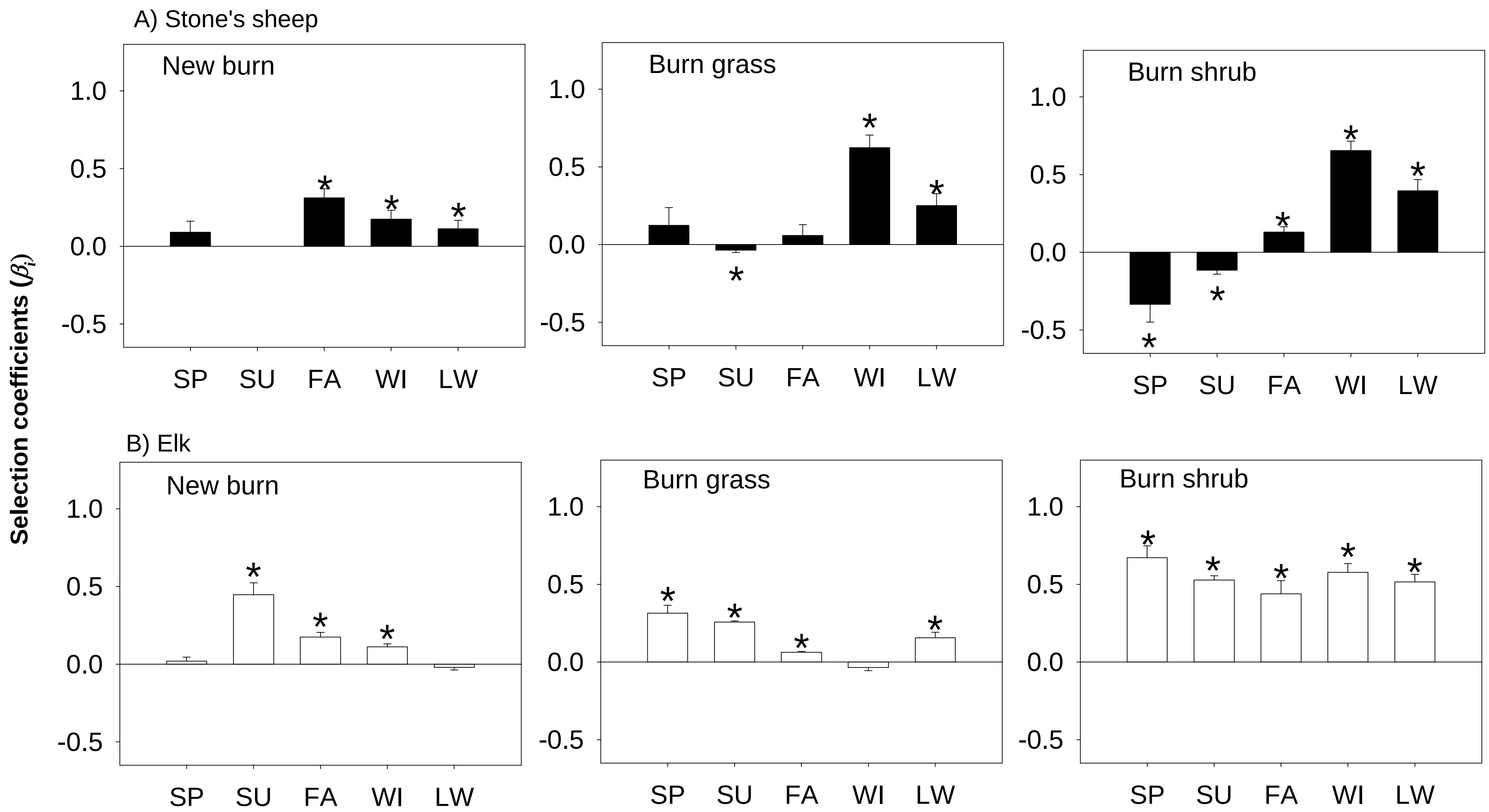

Figure 4.1. Selection coefficients ($\beta_i \pm$ SE) for the 3 burn land-cover classes (New burn, Burn grass, Burn shrub) from the best global resource selection models by season for A) Stone's sheep and B) elk in the Besa-Prophet area of northern British Columbia. Positive β_i indicates selection for a burn; negative β_i indicates selection against. SP = spring, SU = summer, FA = fall, WI = winter, and LW = late winter. * indicates seasonal β_i is different from zero based on 95% confidence intervals.

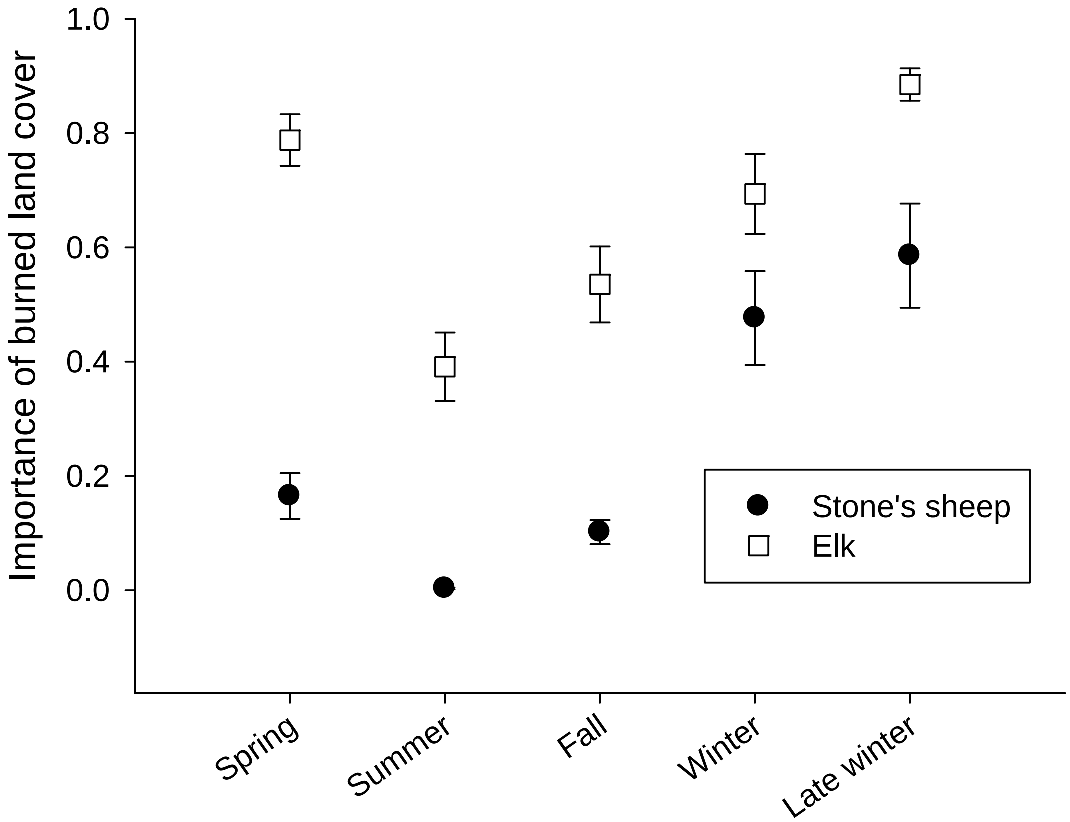

Figure 4.2. Seasonal importance (use × availability scaled to 1.0, $\bar{x}$ ± SE) of burned land-cover classes (New burn, Burn grass, Burn shrub) for 11 GPS-collared female Stone's sheep and 22 GPS-collared female elk in the Besa-Prophet area in northern British Columbia between 2010–2012. Averages from each individual in each season were used to calculate means and standard errors.

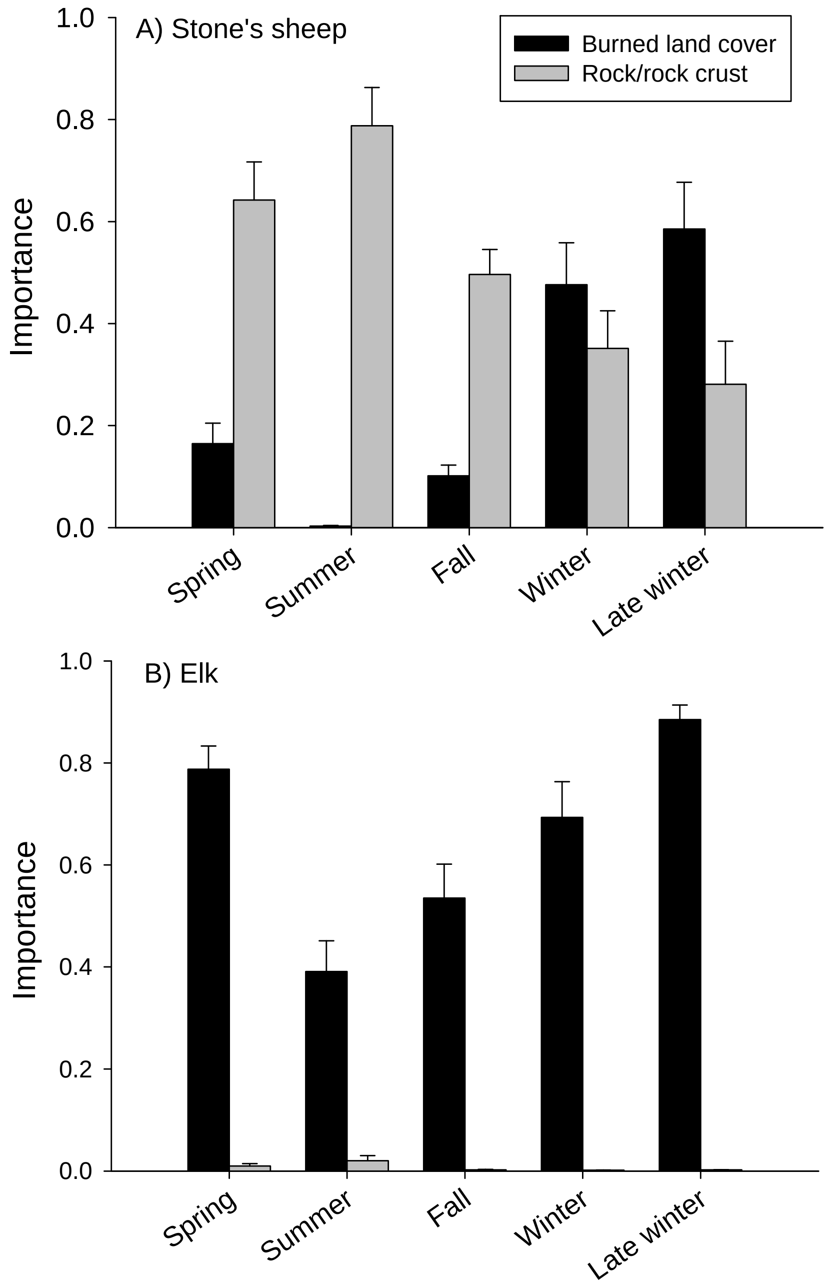

Figure 4.3. Seasonal importance (use × availability scaled to 1.0, $\bar{x} \pm$ SE) of burned land-cover classes (New burn, Burn grass, Burn shrub) and Rock/rock crust for 11 GPS-collared female Stone's sheep and 22 GPS-collared female elk in the Besa-Prophet area in northern British Columbia between 2010–2012. Averages from each individual in each season were used to calculate means and standard errors.

(Figure 4.3B). Table 4.2 provides a summary of both species' response to burning at a fine scale (fecal pellets) and at the landscape scale (GPS-collared individuals and distribution flights to record group locations). Although Stone's sheep and elk both selected for and used burns in similar seasons, the 2 species currently occuped different niches. Stone's sheep always used steeper slopes and higher elevations than elk, with extensive use of rocky areas. When elk used steeper slopes, they were typically at lower elevations (Figure 4.4). For example, in winter and late winter when burns are important to both species (Figure 4.2), Stone's sheep on the Richards burn were in higher elevations and on rocky outcrops compared to elk that were ubiquitous at lower elevations (Figure 4.5).

Seasonal distribution of Stone's sheep and elk–based on GPS data

Similar to other mountain sheep, Stone's sheep are known to show strong site fidelity and philopatry to their seasonal ranges (Geist 1971, Seip and Bunnell 1985*b*). Walker et al. (2007) documented 5 groups of Stone's sheep based on the major mineral lick used within their annual range. In my study, there was considerable variation in annual and seasonal range size among individuals, but the individuals collared in the same area exhibited similar behaviors. Based on movements and where the animals were collared, I monitored 3 different groups of Stone's sheep (Richards, Townsley, and Luckhurst, which included individuals on both Luckhurst and Nevis mountains; Figure 4.6). The annual range sizes calculated previously for Stone's sheep in the Besa-Prophet area averaged 35.5 km^2 (ranging from 15.8–61.2 km^2; Parker and Walker 2007). These were estimated using minimum convex polygons with variable buffers around groups of individuals. These estimates were substantially less than my more conservatively calculated average of 196 ± 36.4 km^2, but they did not include individuals collared in the Richards area. Stone's sheep in the Richards

Table 4.2. Summary of Stone's sheep and elk response to prescribed burns in the Besa-Prophet area of northern British Columbia.

Animal use metric	Response to prescribed burning
Stone's sheep	
Pellet counts	More use was observed in winter than summer. Highest use was at high elevations on Luckhurst, which had high burn severity.
GPS collar locations	Individuals selected for prescribed burned areas in fall, winter and late winter. Burns were most important in winter and late winter. The proportional use of burned areas, averaged across individuals, was highest in late winter when 46% of use points was on prescribed burns (New burns = 27. 6 ± 7%, Burn grass= 7.3 ± 2%, Burn shrub = 10.7 ± 2%).
Distribution flight data	More Stone’s sheep were always observed on burns than on unburned control areas. Larger groups were observed in winter than summer.
Elk	
Pellet counts	Highest use was on south-aspect sites (Richards and Townsley), where there was more vegetation biomass.
GPS collar locations	Individuals selected for prescribed burns in every season. Burns were important in all seasons. The proportional use of burned areas, averaged across individuals, was highest in late winter when 80% of use points was on prescribed burns (New burns = 23.9 ± 6%, Burn grass = 21.5 ± 3%, Burn shrub = 34.6 ± 3%).
Distribution flight data	More elk were always observed on burns than unburned control areas. Larger groups were observed in winter than summer.

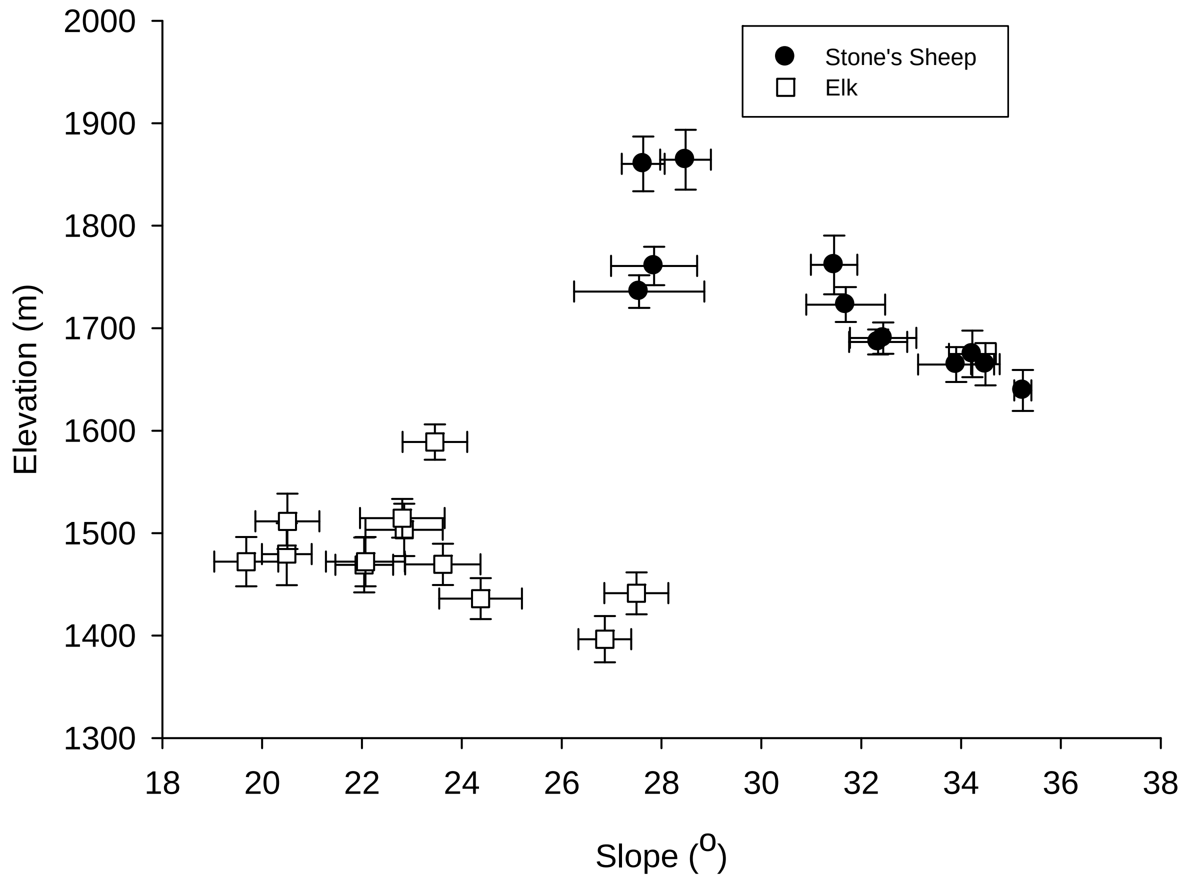

Figure 4.4. Niche partitioning of elevation and slope ($\bar{x}$ ± SE) by GPS-collared female Stone's sheep (n = 11) and female elk (n = 22) in the Besa-Prophet area of northern British Columbia. Individual averages were calculated monthly and averaged across individuals to obtain means and standard errors.

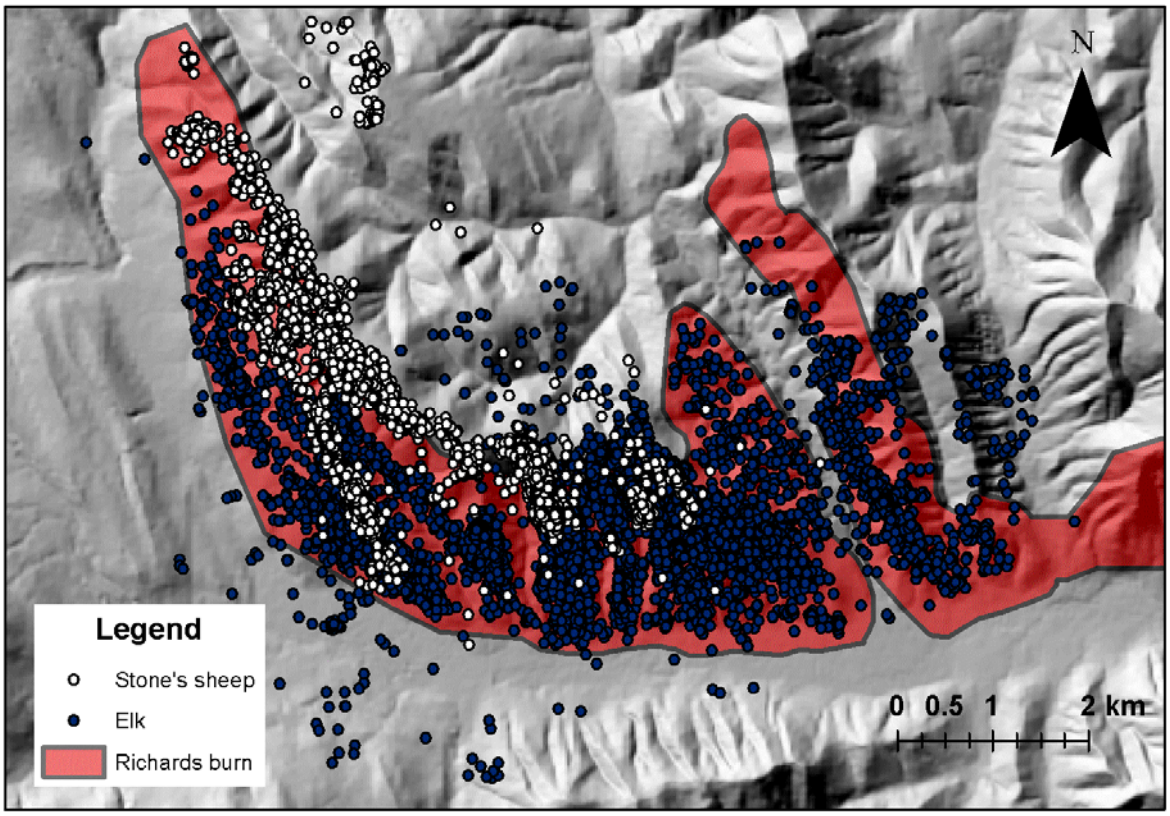

Figure 4.5. Winter and late winter (01 November–14 May) distribution of GPS-collared Stone's sheep and elk in relation to the Richards prescribed burn (red polygon) in the Besa-Prophet area in northern British Columbia, 2010–2012. The prescribed burn was implemented in May 2010.

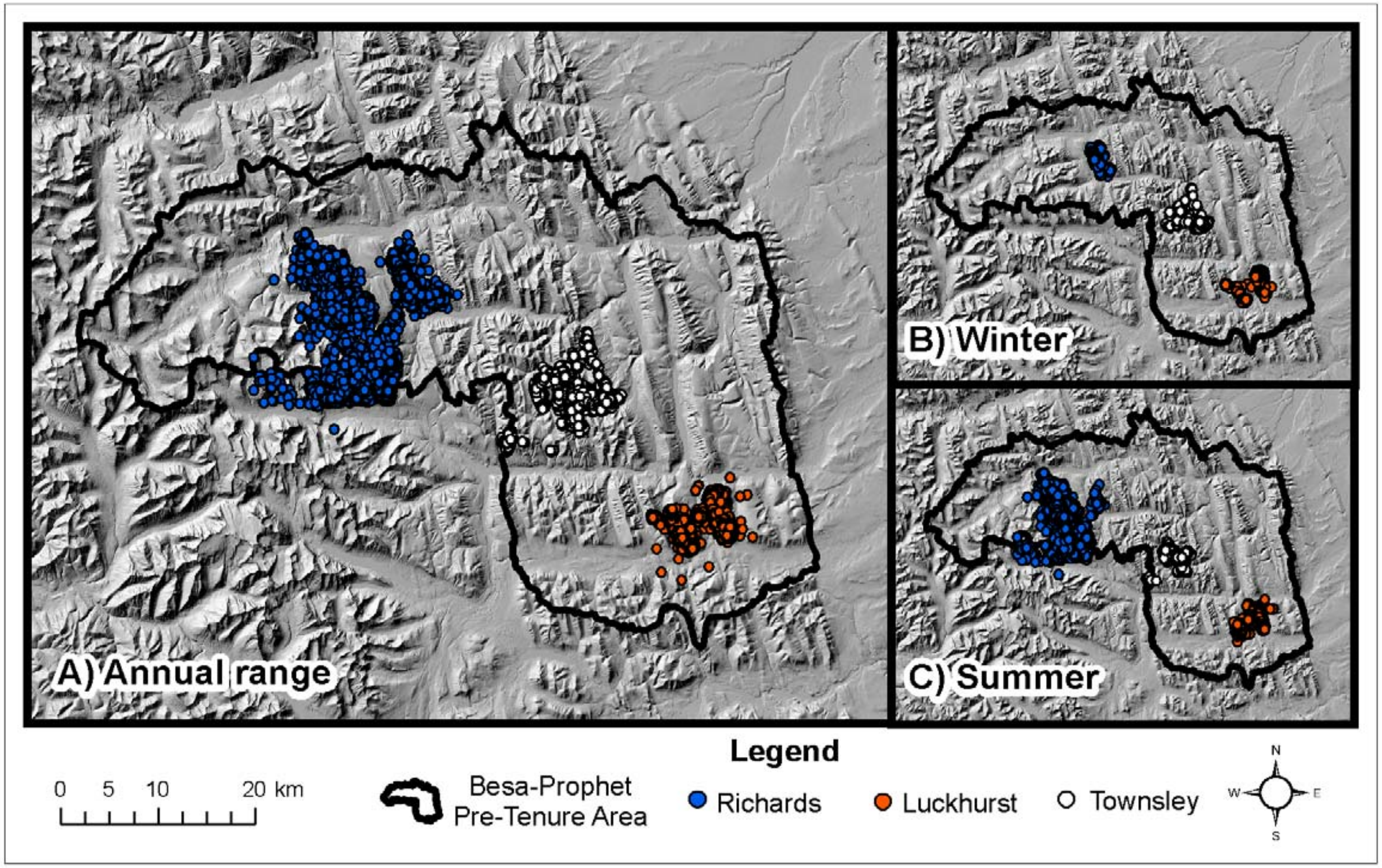

Figure 4.6. A) Annual range, B) winter range, and C) summer range by group (Richards n = 6, Townsley n = 2, and Luckhurst n = 3) of GPS-collared Stone's sheep in the Besa-Prophet area of northern British Columbia. Stone's sheep were collared for a 2-year period between 2010–2012. Winter = 01 Nov–28 Feb; Summer = 15 Jun–14 Aug.

area during my study had an annual range 3 times larger than other individuals in the Townsley and Luckhurst areas (288.2 ± 30.2 km^2 compared to 86.4 ± 18.8 km^2; Figure 4.7A). Seasonally, the 3 groups of Stone's sheep occupied similar-sized ranges in winter and late winter, but the individuals living at Richards had higher movement rates and up to 2.5 times larger ranges than other groups in spring, summer and fall (Figure 4.7B). Every collared Stone's sheep in the Richards area spent the winter and late winter on the burn conducted in 2010. Starting in spring, they all made several long-distance movements (>4 km in 6 h) across the valley and spent the majority of their time on 3 unburned rockier mountains to the west. These animals made the potentially risky crossings up to 5 times throughout the summer and all individuals were back on the burn for the winter by 22 October. The only collared adult female Stone's sheep in our study that died from predation was during one of these crossings. Stone's sheep use rocky areas to reduce the risk of predation, and in the food-risk trade-off dynamic, food becomes increasingly important from fall through late winter (Walker 2005). In spring during lambing, risk outranks food and as summer progresses and lambs become less vulnerable. the importance of food increases. Data from the Stone's sheep collared in the Richards Creek area reflect this trade-off. Female Dall sheep (*Ovis dalli dalli*) in Alaska with lambs restricted their range almost entirely to areas within or near secure cover; females without lambs remained close to secure cover, but the absence of lambs allowed them to exploit resources a little farther away (Corti and Shackleton 2002). Walker et al. (2006) observed a similar trade-off by Stone's sheep in the Besa-Prophet area, suggesting that the presence of lambs caused the adult female Stone's sheep to reduce their predation risk by spending more time in the rocks. The 2010 burned area at Richards included little access to rocky escape terrain and female Stone's sheep likely made the long-valley crossing to be closer to secure terrain in summer when predation by

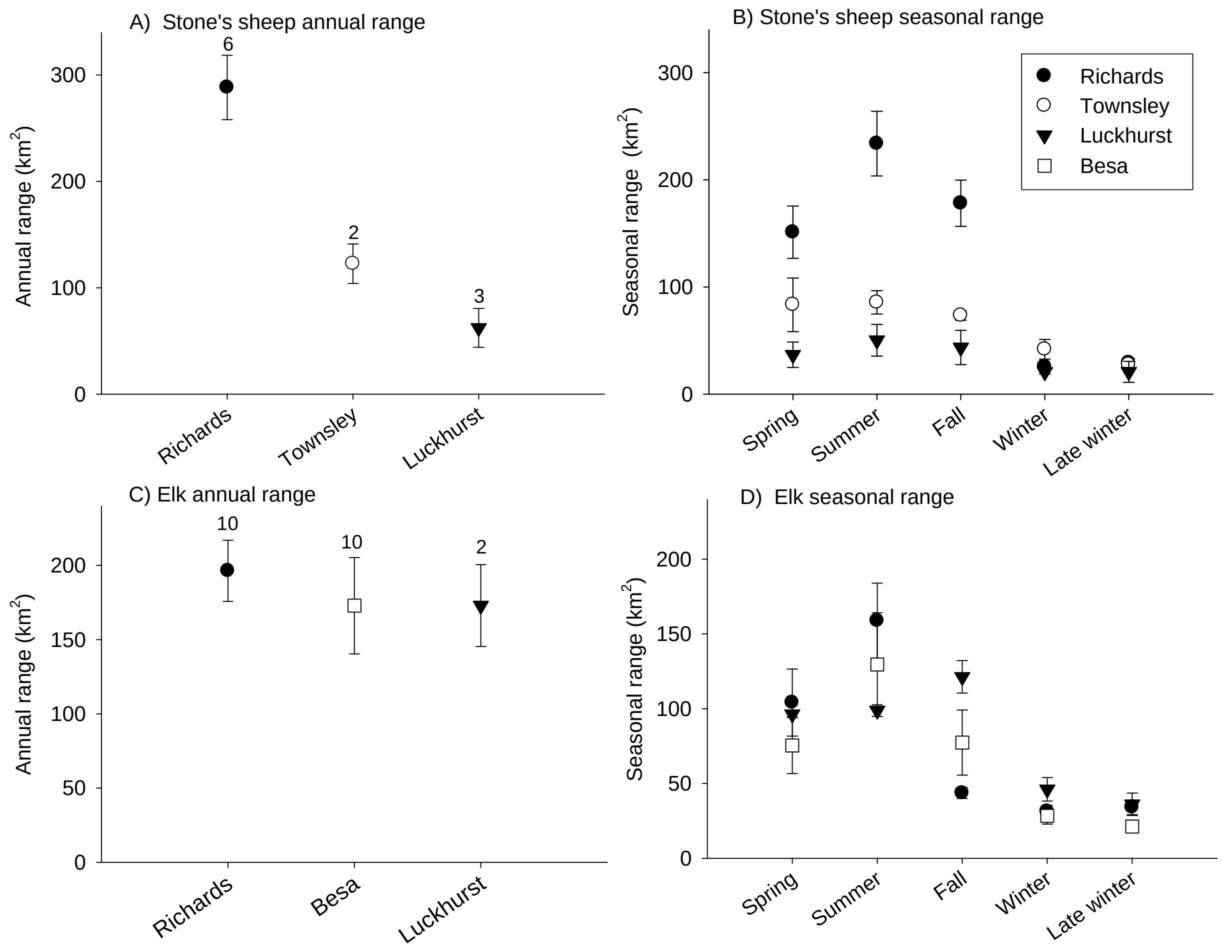

Figure 4.7. A) Annual and B) seasonal ranges ($\bar{x} \pm$ SE) of GPS-collared Stone's sheep by group (Richards, Townsley, Luckhurst) and C) annual and D) seasonal ranges of GPS-collared elk by group (Richards, Besa, Luckhurst) in the Besa-Prophet area of northern British Columbia. Range size was calculated for each individual and then averaged across individuals to obtain means and standard errors.

wolves is known to be higher (Milakovic and Parker 2011).

Elk form intra-specific groups seasonally and are known to show site fidelity to particular ranges (Craighead et al. 1972, Edge et al. 1986). In contrast to Stone's sheep, however, there was no difference in the annual range size between different groups of elk (groups were determined based on where the animals were collared; Figure 4.7C). Elk collared in a particular area generally stayed in that area, but there was some overlap between groups (Figure 4.8). Summer ranges were highly variable among individuals and groups (Figure 4.7D), and there were some long-distance movements (>6 km in 6 h). Gillingham and Parker (2008*a*) documented 1 female elk that traveled over 138 km in 20 days in July in the Besa-Prophet area. One anecdotal speculation (based only on observation and conversations with guide outfitters and biologists) for these long-distance movements is that they occur after a calf dies to escape further risk of predation; presumably movement by the female to another valley would be too costly for a calf. Alternatively, there could be 2 strategies utilized by the elk in the Besa-Prophet, similar to Yellowstone and Banff National Parks where there are both migratory elk that undertake large seasonal movements and residents that do not move seasonally (Craighead et al. 1972, Edge et al. 1986, Hebblewhite et al. 2006). Usually, however, migratory movements tend to occur before calving and during or after rut (Morgantini 1988, Hebblewhite et al. 2006).

RECOMMENDATIONS FOR THE PRESCRIBED BURN PROGRAM

It is important for managers to develop specific objectives for each prescribed burn and to recognize that there is always a trade-off associated with landscape change. For example, if the goal is to increase food for grazing ungulates, the resulting fire will decrease trees and shrubs, which may negatively impact species such as nesting birds (Lousier et al.

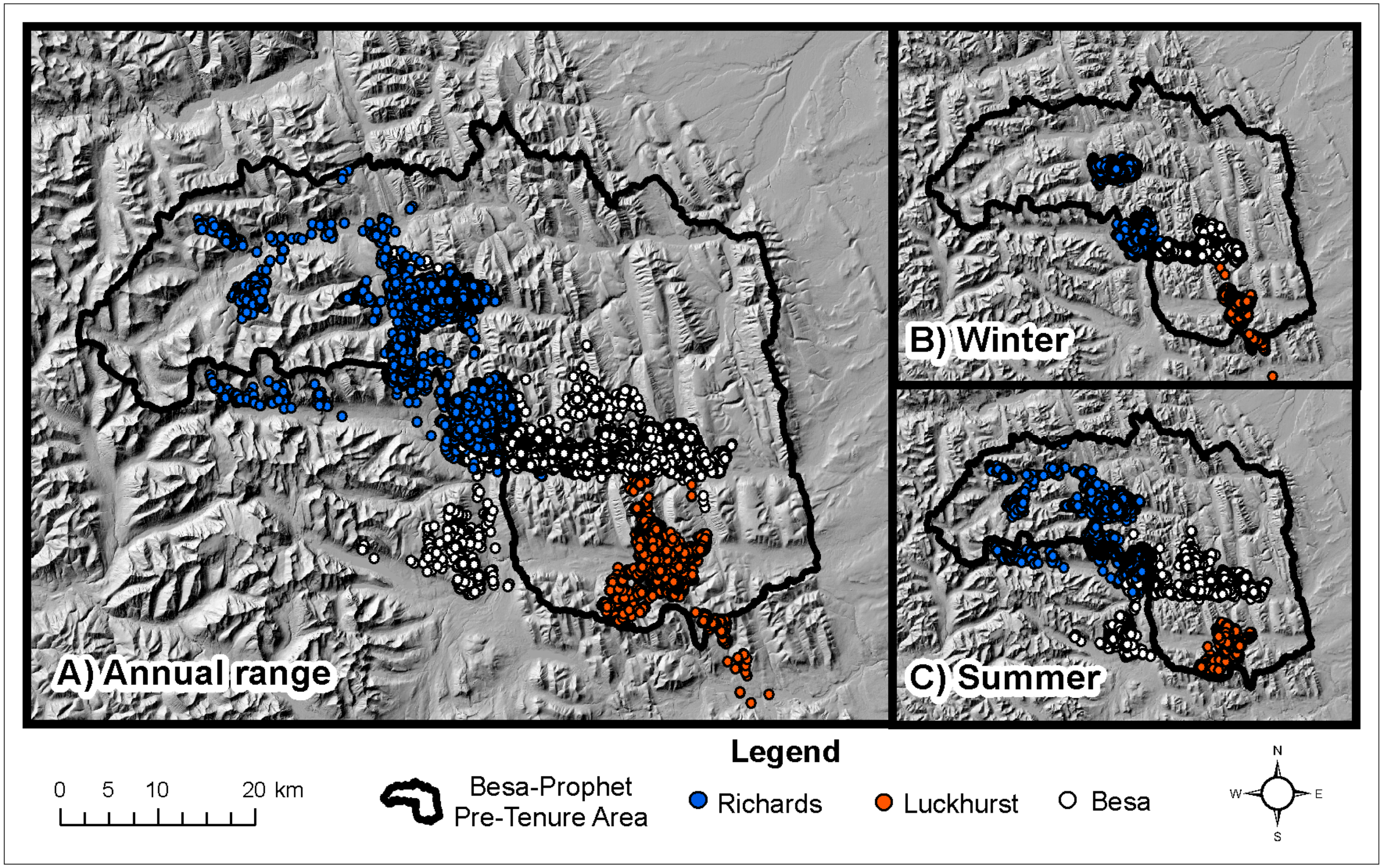

Figure 4.8. A) Annual range, B) winter range, and C) summer range by group (Richards *n* =10, Besa *n* =10, and Luckhurst *n* = 2) of GPS-collared elk in the Besa-Prophet area of northern British Columbia. Elk were collared for a 1-year period between 2010–2012. Winter = 01 Nov–28 Feb; Summer = 15 Jun–14 Aug.

2009); therefore both target and non-target species should be considered. To achieve the desired objective, mangers should have some understanding of fire behavior because pre-burn vegetation, timing, weather and intensity of the burn will all affect post-burn results.

Frequency of burning–based on forage quality and quantity

The length of time that burned areas remain beneficial to Stone's sheep is unknown, and I emphasize the need for continued monitoring of animals in the Besa-Prophet area to determine this timeframe. My findings showed that when Stone's sheep used burned areas, they were most often younger burns with increased nutritional quality (Chapter 2). Forage quality, however, deteriorates with time (Van Dyck and Darragh 2007). Seip and Bunnell (1985*b*) reported that the quality of forage on burned slopes that were up to 9 years old and used by Stone's sheep was not superior to that on unburned slopes, but there were still increased lamb/ewe ratios on these sites (Seip and Bunnell 1985*a*). Use of burned sites by bighorn sheep was still higher than unburned sites after 4 years even though vegetation production leveled off (Peek et al. 1979). Besides plant and animal monitoring over the long term, conducting prescribed burns to increase forage quality and reduce shrub cover every 5–10 years would appear to benefit Stone's sheep. This may not necessarily be true for elk, which in my study showed less preference for the age of a burn. Elk selected for burns all year round with the highest selection for burned shrub areas. Initially I hypothesized that elk would travel long distances to utilize new burns, but elk along the Besa River were on older burns and several individuals spent all year on those burns, even when they had access to new burns nearby.

It is important to recognize that s high intensity burn or burning too often can increase hydrophobicity and result in the soil being less able to soak up water, resulting in leaching and soil erosion (Certini 2005).

Access to escape terrain

The predator avoidance strategies of both Stone's sheep (Geist 1971) and elk (White et al. 2009) rely on the ability to detect danger at a distance, giving them time to retreat to safer terrain when needed. Escape terrain for Stone's sheep consists of solid-rock features or talus slopes where they can move easily and avoid predation; it is a well-recognized component of wild sheep habitat (Bleich et al. 1997, Rachlow and Bowyer 1998, Walker et al. 2006, Sappington et al. 2007). In Yellowstone National Park, the escape strategy for elk under attack by wolves was to flee, often into rivers in summer; and any landscape attribute that reduced their ease of movement and ability to maneuver increased their vulnerability (White et al. 2009). Therefore, prescribed burns aimed to enhance range for both species should take into account access to and proximity of both water and rock features.

Size and aspect of prescribed burns

Slope position and size of a burn affect animal use. To maximize benefits to both Stone's sheep and elk, large prescribed fires should periodically target south-aspect slopes or similar areas that are known to produce high quantities of forage. Based on my distribution flights in the Besa-Prophet area, the largest groups of both Stone's sheep and elk used the largest burn at Richards (Chapters 2 and 3). This burn provided the highest forage biomass and the large area enabled larger congregations of animals. Even though both species were using the burn in winter and late winter, they partitioned their use of it spatially (Figure 4.5). Implementing large burns from the valley bottom to the alpine would enable both Stone's sheep and elk to utilize the burn, and at current population densities, minimize the potential for competition.

Smaller fires result in lower amounts of burned habitat, but increase heterogeneity of the landscape. In chaparral ecosystems in California, it is believed that restoration of bighorn sheep to their historical distribution will likely rely on improving forage quality and reducing visibility with the use of frequent and small summer fires (Bleich et al. 2008). Holl et al. (2012) documented that small fires were successfully used to help stabilize and maintain populations of bighorn sheep. Presumably, small fires that increase heterogeneity also would benefit Stone's sheep. At a fine-scale, I documented more post-burn use based on pellet groups of Stone's sheep (Chapter 2) at Luckhurst, a small west-aspect burn. Even though this site had the lowest forage biomass, the forage quality due to the high intensity of the burn was the highest in late winter compared to other sites. Smaller burns aimed to enhance Stone's sheep should target west-aspect sites with access to escape terrain. West-aspect sites tend to have more moisture; to achieve desired results (reducing shrubs and increasing forage quality), the burns planned for west-aspects should be implemented later in spring to obtain higher intensities. The challenge with planning small burns is that they may increase the probability of overlap in use between elk and Stone's sheep and the potential for competition by funneling large groups of elk into a small area and thereby, reducing forage availability. In the Besa-Prophet area, however, many of the west-facing slopes have rocky outcrops and talus scree slopes intermixed with vegetated sections that fan outwards downslope. These areas are less frequented by elk, especially large groups of elk.

North aspects are usually snow-covered and burning these slopes could not occur until late in the summer. These areas, because of heavy snow accumulation, provide less benefit to ungulates and if the objective is to enhance ungulate habitats, burning north-aspect slopes would be inefficient.

Winter range and season for prescribed burning

In contrast to elk, which use burns in every season, Stone's sheep in the Besa-Prophet area showed the highest use and selection for burned areas in winter and late winter. This is consistent with other studies for both Stone's sheep (Walker et al.2007) and bighorn sheep (Greene 2010). Prescribed burning aimed to enhance Stone's sheep populations should place conserving and enhancing winter and late winter range as the highest priority. Even without higher protein levels in winter forage, ungulates wintering on burned grasslands have better body condition due to increased foraging efficiency and increased access to forage (Hobbs and Spowart 1984, Seip and Bunnell 1985*b*). Turner et al. (1994) showed, using interactive models of elk and bison (*Bison bison*) populations, that winter severity was the dominant driver for ungulate survival and the effects of fire become particularly important to increasing survivorship by enhancing quality and production of forage in average to severe winters. Prescribed burning in areas where Stone's sheep and elk are known to winter would benefit both species, especially when nutritionally stressed in severe winters.

In summer, risk of predation outranks food as a priorityfor female Stone's sheep. Although prescribed burning does enhance summer range quality, Stone's sheep with access to burns in the summer (i.e., Luckhurst and Nevis burns) did not appear to select these areas. Presumably there was enough high-quality forage available in other areas where predation risk was lower.

Prescribed burns targeting winter range should be conducted in spring. Spring burns result in greater enhancement of above-ground production of herbaceous plants suitable for ungulate forage (Owensby and Anderson 1967). The conditions required to burn green vegetation in summer make it difficult to achieve the burn intensities required to meet the objectives of enhancing ungulate habitats, and fires are often more volatile and harder to control (Hatten et al. 2012). There has been some success from fall fires to increase habitat value (Merrill et al. 1980). After a fall burn, however, vegetation does not rebound until the next spring, greatly reducing forage availability for ungulates during the initial winter after burning and increasing the chance of soil erosion by wind and water during the spring melt (Jourdonnais and Bedunah 1990). Additionally, fall burns are typically larger and more intense (Holl et al. 2012). In northeastern BC, the highest use of burned areas by ungulates is in winter (Peck and Peek 1991, Walker 2005, Gillingham and Parker 2008*a*, this study) and a fall burn would reduce available forage on those areas.

FUTURE RESEARCH

My research provides a baseline for monitoring the effectiveness of prescribed burning for Stone's sheep and elk and provides insights on the short-term vegetation dynamics in response to fire in a mountainous region of the northern Rockies. I have shown that at this point in time there does not appear to be a conflict for space or forage between Stone's sheep and elk and that they partition their use of the landscape based on elevation, slope, and ruggedness. I have not, however, quantified the long-term demographic effects on these species or other target species in response to fire or changing predator-prey dynamics. There is some seasonal overlap between moose and elk in the Besa-Prophet area (Gillingham and Parker 2008*a*) and if the elk population continues to expand, it could potentially come at a cost to both moose and Stone's sheep. Additional studies should focus on population estimates and distributions of target ungulates, primarily elk, moose, and Stone's sheep. Caribou (*Rangifer tarandus*) in the Besa-Prophet area appear to avoid burned areas in all seasons (Gustine and Parker 2008), and assuming the number of burned areas does not increase significantly from the current landscape, should not be impacted by the prescribed burns. Because caribou are a far-ranging species potentially affected by any disturbance on the landscape, however, their populations should also be monitored in light of changes in predator-prey dynamics. Demarchi and Hartwig (2004) recommended that prescribed burns be planned and conducted as experiments and monitored over a longer period of time. Developing specific testable objectives would allow for an adaptive management program. The following are research needs that I believe are necessary for continued management of fire on the Besa-Prophet landscape based on questions that arose during my study.

It is important to recognize the need for long-term monitoring of both plant and animal response to fire. The permanent transects on the 4 burned areas and 4 unburned controls (at Luckhurst, Nevis, Townsley and Richards sites) should be revisited in the future to monitor longer term changes in vegetation as well as used as climate benchmarks for the Besa-Prophet area. I found that fire increased the short-term (up to 1 year) nutritional quality of forages available to Stone's sheep and elk, but I was unable to detect a difference in forage quantity on vegetation transects by 1 year after burning, suggesting that biomass may not have peaked. Satellite imagery (NDVI) indicated increasing biomass in the second summer following burning. Other studies have shown that forage quality declines over time (Van Dyck and Darragh 2007) and that forage biomass increases and persists for a longer time (Singer and Harter 1996, Sachro et al. 2005), but these timeframes have not been determined for northern British Columbia. There are currently burns of different ages (0–30 years old) in the Besa-Prophet area that researchers could use to test changes in forage dynamics as burns age. Increased grazing pressure also can alter vegetation communities. The 8×8-m range exclosures built for my study remain on the 4 burned sites and 4 unburned controls. These exclosures provide a metric for monitoring the impacts of changes in herbivore use in response to fire. This is especially important at the Richards site (the site with highest animal use), where after 1 year, I could already detect differences in forage biomass between inside and outside the exclosure on the burned area.

Invasive plant species are a serious threat to rangelands, especially on sites that have been disturbed either from fire or overgrazing (Besaw et al. 2011). Invasive plant species often out-compete native plants and can have detrimental effects on winter forage quality for ungulates (Kohl et al. 2012). I did not document any invasive species at any of the sites during this study, but disturbed sites should be monitored, especially if there is an increase in other anthropogenic disturbances.

In my study, Stone's sheep were at higher elevations than elk in every season. In the Dunlevy/Schooler area along the north shore of the Peace Arm of Williston Lake, BC, Stone's sheep wintering along lower elevation bedrock were observed to have severe hair loss due to winter tick (*Dermacentor albipictus*) infestations (Wood et al. 2010). The close proximity of their winter range to elk and moose populations is believed to be the cause. If prescribed burning facilitates an increase in range overlap between Stone's sheep, elk and moose, there may be an increase in the incidence of winter ticks on Stone's sheep.

In Chapter 3, I discussed how continued increases in the elk population could increase the potential for competition (exploitative or interference) with Stone's sheep. Gillingham and Parker (2008*a*) addressed similar potential conflicts between elk and moose. The Sikanni Valley, just south of the Besa-Prophet Pre-Tenure Planning Area, is the northern boundary of the largest free-ranging herd of plains bison (*B. b. bison*) in BC, approximately 1,300 animals in 2006 with a modeled growth rate of $\lambda = 1.14\%$ (Rowe 2006). Frequently, during the monthly distribution flights in my study, I observed bison in the Nevis Valley (1 valley north); bison use was recorded once on the pellet transects on one of the burns in that area. Past management practices that aimed to divert bison and limit their expansion north or into agricultural areas included placing salt blocks in strategic locations, fencing between Pink Mountain and the Halfway River, limited entry hunting, and native sustenance hunting (Rowe 2006). Bison are known to overgraze areas, often leaving behind large wallows and trampled vegetation (England and DeVos 1969). If this bison population continues to expand north, they could have detrimental effects on native grasses. Additionally, the bison may compete with moose, elk, and Stone's sheep for space and forage, especially if bison move up in elevation in response to prescribed burns. This bison population should be monitored to determine the extent of its range and to ensure that prescribed burning practices do not substantially change patterns of use.

The management action of prescribed fire alters ungulate distributions and the benefits of fire are likely facilitating the expansion of elk, which now provide the largest biomass of prey in the Besa-Prophet ecosystem. Predator populations are also likely to increase in response to the increasing elk prey base. Increased wolf and grizzly bear numbers will affect predator-prey dynamics (Milakovic 2008), potentially increasing the risk of predation on secondary prey species such as Stone's sheep, moose, and caribou. Careful monitoring is required to determine if the prescribed burn program is enhancing predation opportunities.

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Appendix A: Location of prescribed burns, vegetation transect, and range exclosures in the Besa-Prophet area in northern British Columbia

Table A.1. Location (UTM, zone 10), area (ha), and frequency of prescribed burns implemented in the Besa-Prophet area of northern British Columbia. Prescribed burns flown over during monthly survey flights to record Stone's sheep and elk are marked with an *. Easting and northing indicate the middle of the burn. These data were provided by British Columbia government wildlife biologists. ID is the assigned block number.

ID	Watershed	Easting	Northing	Area	Years burned
144	Sikanni River	475608	6339055	150	1987, 1988
145	Sikanni River	482206	6338530	504	1983, 1985, 1989
146	Sikanni River	484975	6339942	327	1989
147	Sikanni River	480638	6342128	135	1983, 1984
148	Big Mt. Sikanni R.	465332	6338512	397	1984, 1985, 1987, 2007
150	Sikanni River	457100	6338638	268	1987, 1989
151	Sikanni River	441029	6342817	786	1989
152	Sikanni River	464872	6341019	467	1984, 1985, 1987, 1989
153	Sikanni River	464927	6344009	659	1984, 1985, 1987
154	Sikanni River	470723	6342367	43	1989, 1995
155	Sikanni River	472435	6343748	43	1984, 1987
156	Sikanni River .	476663	6345126	699	1984, 1989, 1991, 2007
157	Sikanni River	481332	6346556	277	1980, 1983, 1991, 2005
158	Sikanni River	484501	6347137	330	1980 , 1983 , 2005
159	Sikanni River	489677	6347834	1118	1980, 1983, 1991, 2005
160	Sikanni River	505100	6347960	1080	1987
161	Chicken Creek	496670	6349404	126	1987
162	Chicken Creek	493041	6350235	591	1987, 1988
163	Chicken Creek	490784	6352663	128	1987
164	Chicken Creek	489287	6354229	455	1987
165	Sikanni River	482380	6349094	134	2005
166	Sikanni River	476179	6348726	355	1987, 1995
167	Trimble Lake	467629	6350503	408	1987
168	Trimble Lake	465093	6349084	183	1987
169	Trimble Lake	463698	6350009	170	1987
170	Trimble Lake	462495	6349794	140	1987
171	Nevis Creek	477280	6354911	170	1987
172	Nevis Creek	473333	6354393	225	1987
173	Nevis Creek	466880	6354640	271	1987
174	Nevis Creek	463066	6355574	218	1987
175	Besa River Redfern	454880	6355213	915	1987, 1988
176	Besa River Redfern	454575	6357770	60	1987
177	Besa River Redfern	453895	6360761	739	1987, 1988
178	Besa River Redfern	451498	6365050	69	1987
179	Besa River Redfern	452891	6365872	292	1987

Table A.1. Continued.

ID	Watershed	Easting	Northing	Area	Years burned
180	Kelly Creek *	453064	6371065	398	1989
181	Besa River *	456059	6368594	540	1984, 1987, 1988
182	Besa River *	461012	6368093	297	1984, 1985, 1987, 1991, 1995, 2001
183	Besa River *	463036	6367861	158	1984, 1985, 1987, 1991, 1995
184	Besa River *	466396	6367718	623	1984, 1985, 1987, 1991, 1995
185	Besa River *	469538	6367648	75	1984, 1989, 1991, 1995
186	Besa River *	470860	6368000	121	1984, 1989, 1991, 1995
187	Besa River *	473197	6367581	289	1984, 1985, 1987, 1991, 1995
188	Besa River *	476407	6368121	354	1987, 1989, 1991
189	Besa River	469010	6363966	134	1987
190	Little Ram Besa *	474198	6362881	369	1987
191	Nevis Creek	472141	6360409	157	1987
192	Nevis Creek *	473979	6358487	817	1984
193	Nevis Creek *	478349	6358608	591	1984, 1987, 2001
194	Nevis Creek *	481556	6361307	483	1984, 1987, 2001, 2010
195	Buckinghorse .	485931	6359503	273	1984, 1987, 2001
196	Buckinghorse	489517	6359509	228	1984, 1987
197	Pocketknife	488626	6367843	369	1989
198	Besa Pocketknife *	480081	6368534	699	1987, 1989, 1995, 2003
199	Pocketknife Creek	489329	6372472	624	1987
200	Besa Canyon	478591	6380261	686	1981, 1985, 1995
201	Townsley Creek *	471135	6374322	387	1987, 2010
202	Richards Creek	463735	6371793	54	1987
203	Richards Creek	461563	6371235	203	1987
204	Richards Creek *	462210	6373703	660	1987
205	Richards Creek	461138	6375189	19	1987
206	Besa River	456168	6373289	411	1987
207	Richards Creek	454516	6374904	96	1987
208	Richards Creek	456186	6376703	49	1987
209	Richards Creek	457860	6378785	1035	1990
210	Richards Creek	462006	6379434	268	1990
211	Richards Creek *	461580	6377865	686	1987, 1990
212	Duffield Creek *	465351	6376528	158	1987, 1990, 2011
213	Richards Creek *	466609	6379453	251	1990
214	Richards Creek *	468434	6377968	652	1987, 2011
215	Richards Creek	470108	6384125	105	1987
216	Richards Creek *	466215	6383489	677	1987
217	Richards Creek	458822	6384239	1220	1981, 1985, 2002, 2011
218	Richards Creek	450741	6384845	1821	1981, 1985, 1987, 1991, 2002, 2010
219	Klingzut Mt.	453064	6371065	181	1985

Table A.1. Continued.

ID	Watershed	Easting	Northing	Area	Years burned
219	Richards Creek	453484	6381646	565	1987
220	Klingzut Mt.	483964	6386267	308	1985
220	Richards Creek	451432	6379129	303	1987
221	Klingzut Mt.	484141	6388428	329	1985, 1989, 1991, 2005
222	Klingzut Mt.	484388	6390403	281	1985, 1989, 2005
223	Prophet River	480027	6387019	220	1985, 1991, 1995
224	Prophet River	483892	6392157	39	1989
225	Prophet River	479810	6391961	782	1987, 1989, 1992, 2005
226	Prophet River	483257	6395798	182	1987, 1989, 2005
227	Prophet River	480741	6395371	302	1987, 2005
228	Prophet River	478490	6394264	287	1987, 2005
229	Prophet River	472129	6392101	1416	1987, 1989, 2008
230	Prophet River	468720	6394522	7	1987
231	Kravac Creek	467840	6392700	368	1989
232	Kravac Creek	466425	6393440	12	1987
233	Kravac Creek	466528	6393053	21	1987
234	Kravac Creek	466694	6391905	4	1987
235	Kravac Creek	466550	6391452	4	1987
236	Prophet River	465583	6391027	73	1989
237	Prophet River	463363	6391738	382	1989
238	Prophet River	465023	6393161	121	1987
239	Kravac Creek	464626	6395076	194	1987
240	Kravac Creek	464445	6397049	183	1987
241	Kravac Creek	462467	6396508	98	1987
242	Prophet River *	458414	6395739	163	1989
243	Prophet River *	455237	6394790	577	1989
244	Prophet River	454663	6396667	127	1987
245	Prophet River	452989	6396581	97	1987
246	Prophet River	451839	6395530	127	1987
247	Prophet River	451070	6394716	9	1987
248	Prophet River	449599	6395068	132	1987
249	Prophet River *	449711	6393538	193	1989
250	Prophet River *	446246	6392962	815	1985, 1987
251	Prophet River	441579	6392556	446	1989, 2008
252	Prophet River	448327	6394868	142	1987
253	Prophet River	448035	6396469	23	1987
254	Prophet River	447906	6397984	40	1987
255	Prophet River	448175	6399637	26	1987
256	Prophet River	449135	6399400	55	1987
257	Prophet River	449520	6400207	30	1987

Table A.1. Continued.

ID	Watershed	Easting	Northing	Area	Years burned
258	Prophet River	450417	6400096	36	1987
259	Prophet River	451159	6400338	25	1987
260	Crehan Creek	445684	6402911	95	1986, 1987
261	Crehan Creek	459234	6401642	231	1986
262	Bat Creek	466260	6402033	464	1989
263	Muskwa River	463032	6411686	543	1984, 1985, 1987, 1989
264	Crehan Creek	454410	6412006	19	1987
265	Crehan Creek	455054	6412065	19	1987
266	Crehan Creek	455953	6411529	45	1987
267	Crehan Creek	456165	6409962	362	1984, 1989
268	Crehan Creek	457366	6407454	632	1984, 1989
269	Crehan Creek	453706	6405389	426	1985, 1987, 1989
270	Crehan Creek	451654	6407307	389	1986
271	Crehan Creek	448817	6405881	6	1987
272	Crehan Creek	448093	6405955	8	1987
273	Crehan Creek	446216	6405725	115	1986, 1987
274	Crehan Creek	445011	6405955	10	1987
275	Crehan Creek	444064	6406139	20	1987
276	Crehan Creek	444284	6407176	41	1987
277	Muskwa River	440978	6406852	393	1989
278	Muskwa River	443847	6409169	36	1986
279	Muskwa River	442145	6411152	862	1985, 1987, 1989
620	Little Ram *	467215	6363080	151	2010

Table A.2. Location of vegetation transects at high, mid and low elevations and range exclosures at 4 prescribed burns (on Luckhurst, Nevis, Richards and Townsley sites) in the Besa-Prophet area of northern British Columbia. Prescribed burns were implemented in the spring of 2010. Dominant vegetation communities were recorded in 2010 at the beginning of each transect.

ID	Prescribed Burns						
	Easting	**Northing**	**Elevation (m)**	**Slope (°)**	**Aspect (°)**	**Bearing (°)**	**Dominant Vegetation Community**
Luckhurst							
High	476324	6363040	1580	35	280	190	*Betula glandulosa, Vaccinium* spp. with moss and lichen below.
Mid	467215	6363080	1500	30	280	190	*Betula glandulosa, Ledum glandulosum* with moss and lichen below.
Low	476116	6363102	1430	35	280	190	*Betula glandulosa, Vaccinium* spp. with moss and lichen below.
Exclosure	476273	6362978	1550				
Nevis							
High	484312	6361090	1500	32	240	330	*Betula glandulosa, Vaccinium* spp. and *Empetrum nigrum.*
Mid	451259	6361056	1454	32	260	339	*Betula glandulosa,* and *Vaccinium* spp.
Low	481192	6360861	1381	19	255	338	*Betula glandulosa, Vaccinium* spp. and *Ledum glandulosum.*
Exclosure	481274	6360943	1413				
Richards							
High	451895	6385000	1436	23	182	182	*Elymus innovatus* and course woody debris.
Mid	451870	6383260	1334	23	187	187	*Elymus innovatus*, *Populus tremuloides* and lots of course woody debris.
Low	451843	6382953	1227	27	177	177	*Elymus innovatus*, *Populus tremuloides* and lots of course woody debris.
Exclosure	451902	6383411	1406				
Townsley							
High	470039	6373563	1737	22	200	100	*Elymus innovatus* with some *Betula glandulosa* and rock.
Mid	469986	6373475	1663	37	200	110	*Elymus innovatus* with some *Betula glandulosa* and *Salix* spp.
Low	469905	6373509	1579	34	200	110	*Elymus innovatus* with *Betula glandulosa, Salix* spp. and some *Arctostaphylus uva-ursi.*
Exclosure	469968	6373509	1673				

Table A.3. Location of vegetation transects at high, mid and low elevations and range exclosures at 4 unburned control areas near prescribed burns (on Luckhurst, Nevis, Richards and Townsley sites) in the Besa-Prophet area of northern British Columbia. Dominant vegetation communities were recorded in 2010 at the beginning of each transect.

ID	Control						
	Easting	**Northing**	**Elevation (m)**	**Slope $(^{o})$**	**Aspect $(^{o})$**	**Bearing $(^{o})$**	**Dominant Vegetation Community**
Luckhurst							
High	477193	6359494	1636	28	213	329	*Betula glandulosa, Arctostaphylus uva-ursi*, rocks, lichen and occasional small *Picea* spp.
Mid	477062	6359371	1530	29	234	341	*Pinus contorta, Vaccinium* spp., *Elymus innovatus* and course woody debris.
Low	476792	6359196	1427	13	240	340	Dense with *Salix* spp., with *Betula glandulosa, Vaccinium* spp. and *Eylmus innovatus.*
Exclosure	477057	6359539	1573				
Nevis							
High	481598	6360918	1575	32	250	176	*Betula glandulosa* with rock, moss and lichen below.
Mid	481424	6360869	1483	31	250	173	*Betula glandulosa* with some *Salix* spp. and *Arctostaphylus uva-ursi.*
Low	481256	6360796	1381	15	250	153	*Betula glandulosa* with some *Salix* spp., *Arctostaphylus uva-ursi* and several grass species.
Exclosure	481333	6360800	1418				
Richards							
High	457763	6389450	1410	33	183	230	*Elymus innovatus* and *Hedysarum* spp.
Mid	457764	6383758	1300	35	175	222	*Elymus innovatus, Hedysarum* spp. and *Salix* spp.
Low	457760	6383591	1203	28	187	200	*Elymus innovatus, Salix* spp. and *Populus tremuloides.*
Exclosure	457745	6383923	1395				
Townsley							
High	468510	6373033	1751	27	230		*Elymus innovatus, Betula glandulosa* and some *Salix* spp.
Mid	468441	6372902	1650	35	222		*Elymus innovatus* and *Betula glandulosa.*
Low	468473	6372720	1543	28	200		*Elymus innovatus, Betula glandulosa.*and some *Populus balsamifera*.
Exclosure	468464	6372980	1694				

Appendix B: Forage species of Stone's sheep and elk in northern British Columbia

Table B.1. Forage species for Stone's sheep and elk in northern British Columbia documented from past research.

Species	Valuable Forage Species			Reference and Location
	Grasses and Sedges	Forbs	Shrubs	
Stone's sheep	*Elymus innovatus* *Agropyron subsecundum* *Festuca scabrella* *Festuca ovina* *Poa* spp. *Korbresia mysoruoides* *Carex* spp.	*Oxytropis* spp. *Myosotis alpestris* *Zygadenus elegans* *Erigeron* spp.		Luckhurst (1973) Nevis Creek area, BC, in the Besa-Prophet area
	Elymus innovatus *Poa* spp.	*Oxytropis* spp.	*Salix* spp. (leaves) *Betula glandulosa* (leaves) *Populus* spp. (leaves)	Seip (1983) Toad River, BC, in the northern Rocky Mountains
	Elymus innovatus *Festuca ovina* *Poa* spp.	*Saxifraga tricupsidata* *Solidago multiradata* *Potentilla uniflora* *Lupinus arcticus*	*Potentilla fruticosa* *Salix glauca* *Salix reticulata*	Walker (2005) Besa-Prophet area
Elk	*Elymus innovatus* *Bromus* spp.	*Vicia americana* *Lathyrus ochroleucus* *Epilobium angustifolium*	*Populus* spp. *Salix* spp. *Rosa acicularis* *Viburnum edule*	Peck (1987) Tuchodi River, BC, in the northern Rocky Mountains

Appendix C: Landsat imagery protocols

I used Landsat TM/+ETM imagery to quantify landscape-level vegetation response to fire. Landsat satellites pass over the Besa-Prophet area approximately every 2 weeks and are made available for free download at U.S. Geological Survey Earth Resources Observation and Science Center (EROS) website: http://glovis.usgs.gov/. The entire Besa-Prophet area is located on path 50 row 20; the northwestern half can also be found in path 51 row 20 and the southern portion can be seen on path 49 row 20. Available cloud-free imagery from preburn, post-burn and maximum green-up time periods was downloaded, examined and the highest quality data were used.

The Normalized Difference Vegetation Index (NDVI) was used to measure changes in forage biomass over time. NDVI relies on the observation that healthy green vegetation reflects light in the near infrared wavelengths (760-900 nm) and absorbs energy in the visible red wavelength (630-690 nm; Jensen 1995). NDVI is calculated as:

$$NDVI = \left(\frac{NIR - RED}{NIR + RED}\right)$$

where NIR is the near infrared represented by band 4 TM/+ETM and RED is the visible red spectrum represented by band 3 TM/+ETM.

The Normalized Burn Ratio (NBR) was used to determine landscape-level burn severity and to measure the extent of each burn. The equation for NBR is similar to NDVI except mid-infrared (2080-2350 nm) wavelength is used in place of the visible red wavelength. The near-infrared and mid-infrared differences have shown the largest differences in pre- and post-burn images (Key and Benson 2006, Miller and Thode 2007). NBR is calculated as:

$$NBR = \left(\frac{NIR - MID}{NIR + MID}\right)$$

where NIR is the near-infrared represented by band 4 TM/+ETM and MID is the mid-infrared represented by band 7 TM.

The delta Normalized Burn Ratio (dNBR) was derived by subtracting a post-fire NBR from a pre-fire NBR multi-spectral image. dNBR is correlated with the amount of pre-vegetation photosynthetic activity and provides an indication of how much vegetation was killed or consumed by the fire (Miller and Thode 2007). dNBR is calculated as:

$$dNBR = NBR_{PRE-FIRE} - NBR_{POST-FIRE}$$

where $NBR_{PRE-FIRE}$ represents the NBR before a fire and the $NBR_{POST-FIRE}$ represents the NBR after a fire.

The dNBR calculation derived for the Luckhurst 2010 prescribed burn is shown in Figure C.1.

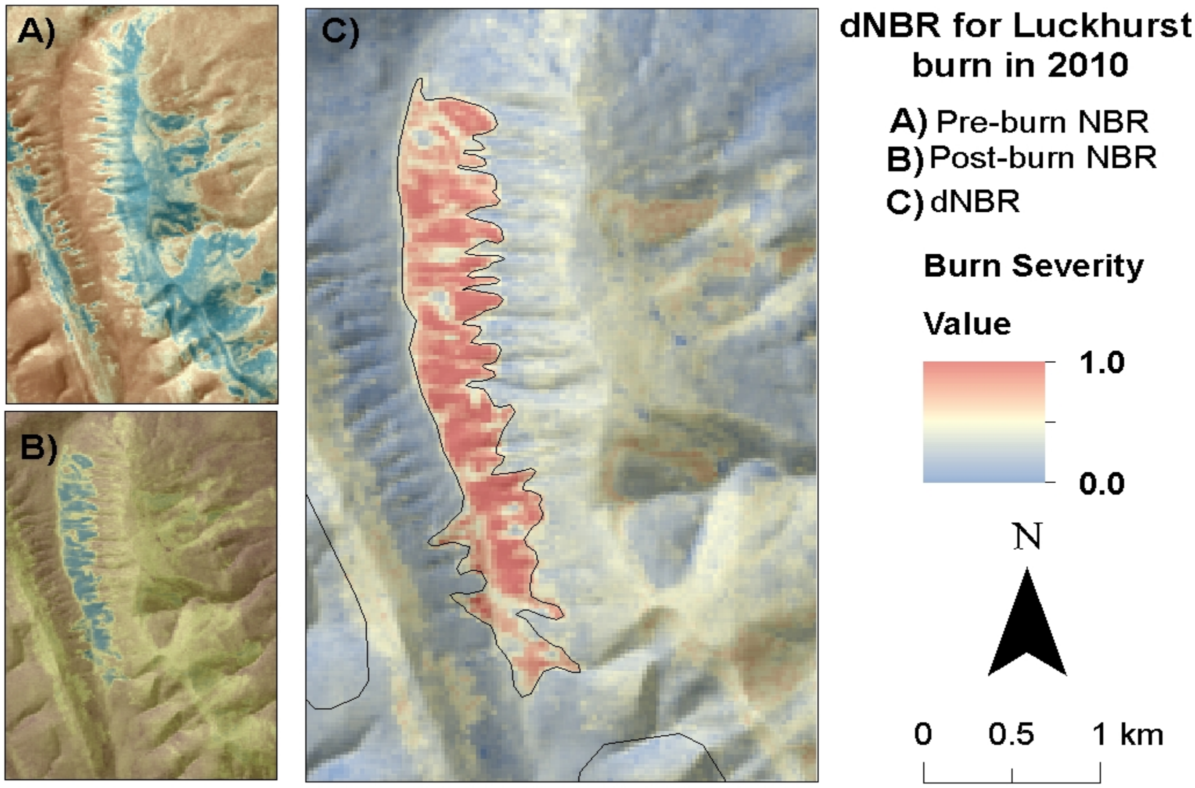

Figure C.1. Delta-Normalized Burn Ratio (dNBR) showing the change in vegetation before and after prescribed burning at the Luckhurst site, Besa-Prophet study area, northern British Columbia. The difference between the pre- and post-fire images (C) indexes the extent of the burn and corresponds well with the area visually estimated from a helicopter survey (outlined in black).

Appendix D: Forage quantity and quality tables

Table D.1. Pre-burn winter forage quantity (biomass, volume, cover) at high, mid and low elevations at 4 sites (Luckhurst, Nevis, Richards, Townsley) prior to prescribed burning in May 2010 in the Besa-Prophet area, northern British Columbia. Prescribed burns were implemented in the spring of 2010, after vegetation monitoring was complete.

Site	Biomass[a]						Volume[b]		Cover[c]	
	Burn	±	SE	Control	±	SE	Burn	Control	Burn	Control
Luckhurst										
High	0.89	±	0.45	0.02	±	0.02	298.1	0.0	1.7	0.6
Mid	2.96	±	1.82	6.55	±	2.41	1425.7	6804.2	0.5	67.7
Low	1.22	±	0.88	14.20	±	2.07	766.8	36172.9	4.5	97.4
Nevis										
High	0.00	±	0.00	0.57	±	0.57	n/a	106.7	1.6	2.4
Mid	0.14	±	0.14	6.95	±	1.84	n/a	15000.0	4.4	97.1
Low	1.59	±	0.83	22.68	±	2.31	n/a	15465.9	5.5	95.7
Richards										
High	13.81	±	5.27	12.82	±	2.95	8975.0	49916.0	59.7	56.1
Mid	44.15	±	22.95	17.09	±	5.40	16355.2	27504.2	87.9	85.6
Low	64.96	±	11.20	24.70	±	7.45	19423.5	39804.2	75.3	99.5
Townsley										
High	18.90	±	5.25	9.56	±	5.34	15452.7	17139.6	66.8	41.0
Mid	34.53	±	3.95	13.90	±	1.66	16349.8	28168.8	98.2	100.0
Low	40.47	±	20.23	21.23	±	2.03	30006.7	17941.7	97.4	99.6

[a] Forage biomass = grasses and forbs ($g/0.25m^2$)
[b] Estimated available forage volume (cm^3) = (percent cover × area) × mean height
[c] Percent cover of forage (grasses and forbs) along a 50-m transect

Table D.2. Winter forage quantity (biomass, volume, cover) on burned and unburned (control) areas in winter (May 2011) the year of prescribed burning at high, mid and low elevations and inside (ungrazed) and outside (grazed) range exclosures at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia.

Site	Biomass[a]						Volume[b]		Cover[c]	
	Burn	±	SE	Control	±	SE	Burn	Control	Burn	Control
Luckhurst										
High	0.25	±	0.19	0.00	±	0.00	296.9	0.0	2.1	0.0
Mid	0.77	±	0.36	10.72	±	2.96	842.3	11255.8	3.3	74.8
Low	0.26	±	0.12	7.33	±	1.71	511.0	14261.2	6.6	97.6
Ungrazed	0.66	±	0.48	0.00	±	0.00	2479.2	293.8	15.3	0.7
Grazed	0.11	±	0.11	0.86	±	0.85	343.8	1118.1	8.3	12.8
Nevis										
High	0.10	±	0.05	0.07	±	0.04	1310.4	156.3	33.5	2.4
Mid	4.75	±	0.74	10.87	±	5.61	4627.1	18814.7	75.3	89.8
Low	5.24	±	1.55	10.17	±	1.66	13342.8	18792.8	83.8	96.9
Ungrazed	6.89	±	2.84	13.81	±	6.26	10495.5	46496.7	98.7	100.0
Grazed	8.64	±	0.84	12.59	±	2.96	16069.8	31754.7	100.0	100.0
Richards										
High	11.68	±	3.21	7.19	±	3.99	17924.2	13671.9	92.4	51.3
Mid	15.67	±	5.27	10.82	±	3.44	16183.3	21239.9	99.4	90.6
Low	27.85	±	6.52	16.28	±	2.13	27056.3	32431.2	99.3	98.1
Ungrazed	32.34	±	8.69	18.61	±	7.29	20240.3	38794.5	98.9	79.6
Grazed	18.29	±	0.33	14.29	±	2.83	24795.0	16866.7	80.0	78.6
Townsley										
High	21.71	±	6.96	3.72	±	2.72	20458.3	18051.6	97.0	58.0
Mid	14.40	±	1.79	11.76	±	1.48	18226.7	25646.8	89.3	98.1
Low	13.10	±	1.02	9.65	±	1.43	20914.2	20255.3	94.2	100.0
Ungrazed	7.96	±	1.63	10.26	±	4.10	16667.7	24517.7	89.1	98.9
Grazed	15.00	±	3.41	12.67	±	2.99	14707.2	27929.5	86.9	88.8

[a] Forage Biomass = Grasses and Forbs ($g/0.25m^2$)
[b] Estimated Available Forage Volume (cm^3) = (percent cover × area) × mean height
[c] Percent cover of forage along a 50- m transect

Table D.3. Winter forage quantity (biomass, volume, cover) on burned and unburned (control) areas in winter (May 2012) 1 year after prescribed burning at high, mid and low elevations and inside (ungrazed) and outside (grazed) range exclosures at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia.

Site	Biomass[a]						Volume[b]		Cover[c]	
	Burn	±	SE	Control	±	SE	Burn	Control	Burn	Control
Luckhurst										
High	1.55	±	1.11	0.00	±	0.00	3024.3	104.2	14.6	0.0
Mid	0.20	±	0.12	5.15	±	3.30	374.0	5790.4	5.7	95.1
Low	8.15	±	3.07	7.63	±	3.57	946.6	17168.1	26.0	100.0
Ungrazed	13.31	±	3.53	0.04	±	0.04	9983.1	381.9	36.7	0.0
Grazed	5.19	±	3.13	0.37	±	0.07	20242.7	719.9	31.1	15.6
Nevis										
High	4.86	±	3.99	0.34	±	0.34	5987.5	631.1	56.2	2.3
Mid	6.83	±	0.94	5.61	±	1.49	15326.1	12581.2	70.1	99.1
Low	14.82	±	3.61	5.96	±	2.64	26468.0	12694.1	94.7	98.4
Ungrazed	18.75	±	4.14	17.78	±	1.54	33153.0	34249.0	96.9	100.0
Grazed	26.53	±	8.74	16.23	±	1.58	71445.2	20722.0	100.0	100.0
Richards										
High	17.77	±	6.38	8.79	±	3.30	22864.8	33782.4	75.2	78.6
Mid	30.38	±	4.50	27.71	±	2.33	37665.4	49201.6	99.3	97.5
Low	52.60	±	13.77	34.71	±	1.85	29339.1	49454.2	100.0	100.0
Ungrazed	50.19	±	6.75	17.67	±	3.05	42271.3	20533.9	100.0	77.8
Grazed	8.00	±	0.37	14.13	±	1.98	9789.1	32311.9	64.7	75.7
Townsley										
High	21.32	±	3.69	11.30	±	4.20	23717.8	27568.1	90.7	82.2
Mid	38.93	±	4.30	20.27	±	3.85	72123.9	30428.5	94.9	99.7
Low	15.91	±	2.99	17.27	±	7.79	49499.6	15421.1	94.8	100.0
Ungrazed	24.78	±	6.45	16.59	±	4.48	46768.3	41210.5	87.4	100.0
Grazed	23.78	±	6.13	15.37	±	0.81	18600.0	14832.3	82.7	100.0

[a] Forage Biomass = Grasses and Forbs (g/0.25m^2)
[b] Estimated Available Forage Volume (cm^3) = (percent cover × area) × mean height
[c] Percent cover of forage along a 50-m transect

Table D.4. Summer forage quantity (biomass, volume, cover, species richness and diversity) on burned (B) and unburned (control; C) areas in summer (July 2010) the year of prescribed burning at high, mid and low elevations and inside (ungrazed) and outside (grazed) range exclosures at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia.

Site	Biomass (g)[a]						Volume (cm^3)[b]		Cover[c]		Richness[d]		Diversity[e]	
	B	±	SE	C	±	SE	B	C	B	C	B	C	B	C
Luckhurst														
High	0.49	±	0.47	0.25	±	0.13	585.6	233.6	4.8	0.9	7	7	0.77	0.78
Mid	1.07	±	0.98	6.30	±	0.51	2480.2	26194.1	6.2	80.8	7	16	0.70	0.86
Low	1.36	±	1.17	13.17	±	3.31	853.3	63337.6	8.2	96.9	6	15	0.56	0.84
Ungrazed	0.45	±	0.25	0.10	±	0.03	2793.5	819.4	11.5	3.1	6	8	0.75	0.80
Grazed	2.24	±	2.24	0.70	±	0.29	3596.3	1758.7	19.2	20.0	4	8	0.69	0.82
Nevis														
High	5.63	±	3.10	0.48	±	0.48	3760.1	522.8	59.3	26.5	8	10	0.72	0.80
Mid	7.58	±	1.88	14.81	±	2.15	10037.2	47255.0	92.8	100.0	12	17	0.81	0.86
Low	10.87	±	2.39	16.42	±	1.93	15048.9	48251.8	87.1	100.0	11	21	0.84	0.91
Ungrazed	15.69	±	3.70	14.44	±	1.23	55577.0	39515.7	92.1	100.0	15	17	0.76	0.84
Grazed	19.49	±	3.39	18.93	±	1.43	72538.3	47480.1	97.9	100.0	16	20	0.74	0.88
Richards														
High	21.83	±	3.85	10.55	±	1.80	72042.5	36484.4	87.0	75.2	14	12	0.71	0.81
Mid	33.23	±	11.13	26.88	±	8.80	61430.2	68006.1	94.0	98.3	11	13	0.72	0.83
Low	44.29	±	11.56	30.19	±	7.67	100839.0	104591.3	95.6	99.3	10	13	0.61	0.83
Ungrazed	34.67	±	2.34	11.51	±	3.11	117105.0	27970.4	95.5	57.9	10	12	0.77	0.82
Grazed	16.61	±	3.36	8.48	±	2.98	63481.2	33922.3	81.6	78.3	12	14	0.72	0.85
Townsley														
High	45.04	±	5.57	20.52	±	5.43	38378.5	39980.0	95.7	87.0	18	20	0.86	0.82
Mid	20.74	±	3.13	13.92	±	2.87	53460.8	33110.2	97.2	100.0	17	20	0.72	0.86
Low	29.24	±	11.97	20.35	±	2.27	40538.7	59586.6	97.6	100.0	12	18	0.75	0.88
Ungrazed	17.42	±	3.14	25.85	±	5.45	26960.6	41477.8	92.7	100.0	15	22	0.83	0.91
Grazed	20.49	±	4.71	12.17	±	1.93	31882.0	30709.8	90.2	100.0	21	20	0.82	0.88

[a] Forage biomass = grasses and forbs ($g/0.25m^2$)
[b] Estimated available forage volume (cm^3) = (percent cover × area) × mean height
[c] Percent cover of forage (grasses and forbs) along a 50-m transect
[d] Richness = number of species in 3 (1 × 1 m) plots along a 50-m transect
[e] Diversity = Average Simpson's Diversity Index from 3 (1 × 1 m) plots along a 50-m transect

Table D.5. Summer forage quantity (biomass, volume, cover, species richness and diversity) on burned (B) and unburned (control; C) areas in summer (July 2011) 1 year after prescribed burning at high, mid and low elevations and inside (ungrazed) and outside (grazed) range exclosures at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia.

Site	Biomass (g)[a]						Volume (cm^3)[b]		Cover (%)[c]		Richness[d]		Diversity[e]	
	B	±	SE	C	±	SE	B	C	B	C	B	C	B	C
Luckhurst														
High	3.78	±	0.95	0.15	±	0.10	10808.8	1243.8	19.8	0.6	9	7	0.85	0.75
Mid	6.37	±	5.34	6.92	±	2.89	11372.2	28175.6	13.6	99.5	9	14	0.80	0.90
Low	3.86	±	0.43	17.41	±	3.55	42611.8	54326.6	26.0	100.0	7	21	0.76	0.90
Ungrazed	10.90	±	2.74	0.23	±	0.23	23530.2	2122.0	42.8	1.0	11	10	0.84	0.82
Grazed	6.30	±	3.65	0.60	±	0.48	12698.5	1775.8	39.5	34.0	8	12	0.82	0.83
Nevis														
High	11.47	±	3.22	0.08	±	0.07	9346.4	482.6	63.5	45.4	12	10	0.83	0.69
Mid	19.71	±	2.88	7.13	±	2.17	47444.6	50268.6	88.0	100.0	19	20	0.89	0.91
Low	26.11	±	1.78	14.04	±	3.92	82277.5	44936.8	98.5	100.0	17	22	0.90	0.90
Ungrazed	48.39	±	17.29	19.17	±	8.47	114497.0	86336.1	100.0	100.0	17	21	0.83	0.91
Grazed	36.50	±	10.42	10.07	±	2.25	111591.0	64062.7	100.0	100.0	20	16	0.82	0.88
Richards														
High	41.03	±	2.34	15.01	±	1.76	124063.6	43639.8	94.5	86.0	12	13	0.73	0.86
Mid	27.16	±	3.21	29.81	±	7.39	109023.0	90649.4	92.6	100.0	11	15	0.83	0.82
Low	65.67	±	13.69	46.02	±	5.37	113049.5	132118.6	97.2	100.0	10	15	0.75	0.84
Ungrazed	70.31	±	12.46	13.14	±	3.60	159594.0	68984.6	100.0	83.8	10	14	0.79	0.81
Grazed	35.67	±	9.15	11.86	±	0.28	70156.0	35131.6	100.0	86.7	11	10	0.75	0.86
Townsley														
High	45.11	±	13.55	19.02	±	9.62	102085.1	62588.4	100.0	97.6	18	22	0.86	0.90
Mid	55.80	±	6.93	23.64	±	1.94	136666.1	92067.4	100.0	100.0	14	20	0.84	0.90
Low	35.53	±	9.97	17.18	±	1.91	92754.2	81306.0	97.7	100.0	14	17	0.84	0.90
Ungrazed	36.89	±	12.2	19.17	±	5.57	99622.8	53956.9	68.2	100.0	18	18	0.83	0.90
Grazed	45.90	±	9.25	13.84	±	6.48	135093.0	44312.5	96.5	98.9	19	21	0.88	0.89

[a] Forage biomass = grasses and forbs ($g/0.25m^2$)
[b] Estimated available forage volume (cm^3) = (percent cover × area) × mean height
[c] Percent cover of forage (grasses and forbs) along a 50-m transect
[d] Richness = number of species in 3 (1 × 1 m) plots along a 50-m transect
[e] Diversity = Average Simpson's Diversity Index from 3 (1 × 1 m) plots along a 50-m transect.

Table D.6. Winter dry matter digestibility (%) of forage from burned and unburned (control) areas in winter prior to burning (May 2010), the year of burning (May 2011), and 1 year after burning (May 2012) at high, mid and low elevations at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia. Dry matter digestibility was calculated as in Hanley et al. (1992) from sequential detergent analyses. Transects with blank values did not have enough sample for analysis. Nevis pre-burn site did not burn, so the sampling site was moved to the burned area for May 2011 and May 2012 measurements.

Site	May 2010						May 2011						May 2012					
	Burn	**±**	**SE**	**Control**	**±**	**SE**	**Burn**	**±**	**SE**	**Control**	**±**	**SE**	**Burn**	**±**	**SE**	**Control**	**±**	**SE**
Luckhurst																		
High	56.5	±	1.6				57.4	±	0.0				55.6	±	2.0			
Mid	49.8	±	2.7	53.2	±	3.3	54.3	±	3.2	48.0	±	1.5				60.2	±	1.2
Low	56.3	±	0.1	41.2	±	1.1	0.0	±	0.0	44.4	±	1.1	56.4	±	5.0	55.2	±	1.8
Nevis[a]																		
High							50.8	±	4.8				53.1	±	1.5			
Mid							47.2	±	1.9	45.7	±	3.4	53.1	±	2.3	47.0	±	1.6
Low							47.6	±	1.8	45.3	±	1.7	54.0	±	1.0	49.2	±	1.1
Richards																		
High	44.6	±	1.9	46.2	±	2.6	48.3	±	0.8	51.9	±	3.0	54.4	±	1.1	59.7	±	1.2
Mid	42.4	±	1.8	41.2	±	2.8	46.4	±	1.8	40.6	±	3.0	56.8	±	0.5	52.2	±	2.9
Low	42.0	±	0.9	42.9	±	1.7	49.6	±	0.9	47.3	±	1.7	55.7	±	0.6	51.8	±	0.7
Townsley																		
High	46.2	±	2.6	48.4	±	2.7	46.1	±	1.4	44.2	±	2.2	54.3	±	1.8	57.3	±	0.6
Mid	41.2	±	2.8	44.4	±	0.9	44.1	±	1.4	41.7	±	3.3	57.5	±	0.8	54.3	±	1.8
Low	42.9	±	1.7	44.5	±	1.3	41.8	±	1.5	38.8	±	1.9	51.1	±	1.4	51.6	±	1.4

[a] Pre-burn site at Nevis did not burn and therefore samples were not analyzed.

Table D.7. Summer dry matter digestibility (%) of forage from burned and unburned (control) areas in the year of burning (July 2010) and 1 year after burning (July 2011) at high, mid and low elevations at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia. Dry matter digestibility was calculated as in Hanley et al. (1992) from sequential detergent analyses. Transects with blank values did not have enough sample for analysis.

Site	July 2010						July2011					
	Burn	**±**	**SE**	**Control**	**±**	**SE**	**Burn**	**±**	**SE**	**Control**	**±**	**SE**
Luckhurst												
High	65.6						55.6	±	2.0			
Mid	61.2	±	0.8	57.7	±	0.9				60.2	±	1.2
Low	62.4	±	0.5	54.4	±	0.8	56.4	±	5.0	55.2	±	1.8
Nevis												
High	67.0	±	1.2				53.1	±	1.5			
Mid	65.6	±	2.1	62.2	±	0.9	53.1	±	2.3	47.0	±	1.6
Low	66.7	±	0.5	62.0	±	1.3	54.0	±	1.0	49.2	±	1.1
Richards												
High	63.6	±	1.1	57.3	±	2.3	54.4	±	1.1	59.7	±	1.2
Mid	63.4	±	1.0	54.8	±	2.1	56.8	±	0.5	52.2	±	2.9
Low	62.8	±	0.6	57.4	±	1.5	55.7	±	0.6	51.8	±	0.7
Townsley												
High	64.5	±	1.9	63.3	±	1.6	54.3	±	1.8	57.3	±	0.6
Mid	65.4	±	1.2	61.9	±	1.9	57.5	±	0.8	54.3	±	1.8
Low	66.0	±	1.8	65.0	±	0.6	51.1	±	1.4	51.6	±	1.4

Table D.8. Winter available digestible dry matter (g/0.25m^2) on burned and unburned (control) areas in winters prior to prescribed burning (May 2010), the year of burning (May 2011), and 1 year after burning (May 2012) at high, mid and low elevations at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia. Available digestible dry matter was calculated by multiplying dry matter digestibility (Hanley et al. 1992) by forage biomass. Transects with blank values did not have enough sample for analysis. Nevis pre-burn site did not burn, so the sampling site was moved to the burned area for May 2011 and 2012 measurements.

Site	May 2010				May 2011				May 2012			
	Burn	± SE	Control	± SE	Burn	± SE	Control	± SE	Burn	± SE	Control	± SE
Luckhurst												
High	0.2	± 0.2			0.2	± 0.2			0.7	± 0.7		
Mid	1.4	± 0.9	3.5	± 1.3	0.4	± 0.2	5.2	± 1.6	0.0	± 0.0	3.1	± 2.0
Low	0.6	± 0.5	5.8	± 0.8			3.2	± 0.7	4.7	± 2.0	4.2	± 2.0
Nevis[a]												
High					1.3	± 1.3			2.3	± 2.3		
Mid					2.2	± 0.3	4.4	± 1.8	3.6	± 0.5	2.6	± 0.7
Low					2.5	± 0.8	4.7	± 0.9	8.1	± 2.1	3.0	± 1.3
Richards												
High	6.2	± 2.3	5.9	± 1.5	5.7	± 1.6	3.8	± 2.4	9.7	± 3.5	5.2	± 2.0
Mid	17.6	± 8.3	6.9	± 1.9	7.4	± 2.5	4.6	± 1.7	17.3	± 2.6	14.3	± 0.1
Low	27.1	± 4.1	10.8	± 3.4	13.7	± 3.0	7.7	± 1.0	29.1	± 7.2	18.0	± 0.9
Townsley												
High	8.1	± 2.2	4.9	± 3.0	10.2	± 3.4	1.6	± 1.1	11.8	± 2.5	6.5	± 2.4
Mid	16.1	± 1.5	6.2	± 0.8	6.3	± 0.7	5.0	± 1.2	22.4	± 2.7	11.2	± 2.6
Low	17.5	± 8.3	9.4	± 1.0	5.5	± 0.5	3.8	± 0.9	8.2	± 1.8	9.2	± 4.4

[a] Pre-burn site at Nevis did not burn and therefore samples were not analyzed for digestibility.

Table D.9. Summer available digestible dry matter (g/0.25m^2) on burned and unburned (control) areas in the year of burning (July 2010) and 1 year after burning (July 2011) at high, mid and low elevations at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia. Available digestible dry matter was calculated by multiplying dry matter digestibility (Hanley et al. 1992) by forage biomass. Transects with blank values did not have enough sample for analysis.

Site	July 2010						July2011					
	Burn	**±**	**SE**	**Control**	**±**	**SE**	**Burn**	**±**	**SE**	**Control**	**±**	**SE**
Luckhurst												
High	0.3	±	0.3				0.7	±	0.7			
Mid	0.6	±	0.6	3.6	±	0.3				3.1	±	2.0
Low	0.8	±	0.8	7.2	±	2.0	4.7	±	2.0	4.2	±	2.0
Nevis												
High	3.7	±	2.0				2.3	±	2.3			
Mid	4.9	±	1.3	9.2	±	1.2	3.6	±	0.5	2.6	±	0.7
Low	7.2	±	1.5	10.2	±	1.4	8.1	±	2.1	3.0	±	1.3
Richards												
High	13.9	±	2.5	6.1	±	1.2	9.7	±	3.5	5.2	±	2.0
Mid	20.8	±	6.8	14.2	±	3.9	17.3	±	2.6	14.3	±	0.1
Low	27.9	±	7.4	17.1	±	4.0	29.1	±	7.2	18.0	±	0.9
Townsley												
High	29.1	±	3.7	13.0	±	3.3	11.8	±	2.5	6.5	±	2.4
Mid	13.5	±	1.8	8.8	±	2.2	22.4	±	2.7	11.2	±	2.6
Low	18.9	±	7.2	13.2	±	1.4	8.2	±	1.8	9.2	±	4.4

Table D.10. Winter crude protein content (%) of forage from burned and unburned (control) areas in winter prior to burning (May 2010), the year of burning (May 2011), and 1 year after burning (May 2012) at high, mid and low elevations at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia. Crude protein was calculated by multiplying the total nitrogen (g N/g forage) by 6.25. Transects with blank values did not have enough sample for analysis. Nevis pre-burn site did not burn, so the sampling site was moved to the burned area for May 2011 and May 2012 measurements.

Site	**May 2010**						**May 2011**						**May 2012**					
	Burn	**±**	**SE**	**Control**	**±**	**SE**	**Burn**	**±**	**se**	**Control**	**±**	**SE**	**Burn**	**±**	**SE**	**Control**	**±**	**SE**
Luckhurst																		
High	6.6						19.1	±	5.8				14.4	±	3.1			
Mid	5.5	±	1.2	4.3	±	0.4	23.4	±	1.3	5.1	±	0.8	16.8	±		4.7	±	0.1
Low	5.2	±	1.0	5.4	±	0.6	36.1	±	1.9	5.4	±	0.2	5.8	±	1.6	6.2	±	0.4
Nevis [a]																		
High				5.4	±		8.2	±	1.6	8.1	±	0.0	8.9	±	2.7	4.7		
Mid	6.3			4.7	±	0.3	5.8	±	0.7	5.4	±	0.3	4.1	±	0.5	4.6	±	0.2
Low	4.5	±	0.2	4.9	±	0.3	5.2	±	0.6	5.3	±	0.5	3.8	±	0.2	4.5	±	0.1
Richards																		
High	6.2	±	0.6	5.7	±	0.9	7.7	±	1.3	4.1	±	0.8	5.2	±	0.2	4.4	±	0.9
Mid	4.9	±		4.7	±	0.6	5.6	±	0.5	7.7	±	2.6	5.6	±	0.4	5.7	±	0.3
Low	6.7	±	0.4	4.5	±	0.4	6.1	±	0.4	5.4	±	0.6	5.7	±	0.3	5.9	±	0.4
Townsley																		
High	7.6	±	0.2	5.8	±	1.2	7.2	±	0.1	5.9	±	0.4	6.4	±	0.2	4.6	±	0.5
Mid	5.6	±	0.3	4.8	±	0.3	5.2	±	0.5	4.0	±	0.3	3.5	±	0.0	4.6	±	0.0
Low	5.3	±	0.5	4.5	±	0.5	6.2	±	0.4	5.9	±	0.4	3.6	±	0.2	5.1	±	0.7

[a] Pre-burn area at Nevis were taken from an adjacent area that did not burn and are provided for comparative purposes only.

Table D.11. **S**ummer crude protein content (%) of forage from burned and unburned (control) areas in the year of burning (July 2010) and 1 year after burning (July 2011) at high, mid and low elevations at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia. Crude protein was calculated by multiplying the total nitrogen (g N/g forage) by 6.25

Site	July 2010				July2011			
	Burn	**± SE**	**Control**	**± SE**	**Burn**	**± SE**	**Control**	**± SE**
Luckhurst								
High	17.5	± 1.8	14.1		20.0	± 1.4	13.7	± 0.3
Mid	17.5	± 9.6	10.5	± 0.4	16.3	± 5.6	12.0	± 0.8
Low	22.5	± 2.4	13.9	± 1.0	17.1	± 3.1	14.8	± 0.6
Nevis								
High	12.9	± 2.5	13.9	±	13.9	± 2.8	13.7	
Mid	12.2	± 0.8	12.4	± 0.4	13.2	± 0.5	13.9	± 1.1
Low	14.7	± 1.6	12.7	± 1.3	10.5	± 0.3	15.0	± 0.6
Richards								
High	15.4	± 0.9	11.7	± 0.7	14.5	± 1.3	14.5	± 1.1
Mid	15.7	± 0.9	15.6	± 2.4	14.7	± 0.3	14.8	± 0.5
Low	16.8	± 1.8	13.8	± 1.0	14.1	± 0.9	14.7	± 2.3
Townsley								
High	15.2	± 0.7	15.3	± 2.6	14.5	± 0.5	14.3	± 0.6
Mid	16.9	± 1.1	13.5	± 0.9	13.1	± 1.3	12.8	± 0.7
Low	16.6	± 0.6	13.7	± 0.9	10.5	± 0.7	13.5	± 0.6

Table D.12. Winter available digestible protein (g/0.25 m^2) on burned and unburned (control) areas in winter prior to burning (May 2010), the year of burning (May 2011), and 1 year after burning (May 2012) at high, mid and low elevations at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia. Available digestible protein was calculated by multiplying digestible protein (Hanley et al. 1992) by forage biomass. Transects with blank values did not have enough sample for analysis. Nevis pre-burn site did not, so the sampling site was moved to the burned area for May 2011 and May 2012 measurements.

Site	May 2010		May 2011		May 2012	
	Burn ± SE	Control ± SE	Burn ± SE	Control ± SE	Burn ± SE	Control ± SE
Luckhurst						
High	0.02 ± 0.01		0.03 ± 0.02		0.16 ± 0.09	
Mid	0.01 ± 0.01	-0.01 ± 0.01	0.20 ± 0.03	0.08 ± 0.08	0.02 ± 0.02	0.02 ± 0.01
Low	0.02 ± 0.01	0.17 ± 0.10	0.08 ± 0.04	0.08 ± 0.02	0.07 ± 0.14	0.13 ± 0.04
Nevis[a]						
High		0.01 ± 0.01	0.02 ± 0.02		0.02 ± 0.04	
Mid		0.05 ± 0.03	0.08 ± 0.04	0.14 ± 0.09	0.00 ± 0.03	0.03 ± 0.02
Low	0.01 ± 0.00	0.17 ± 0.07	0.03 ± 0.01	0.12 ± 0.07	-0.05 ± 0.03	0.02 ± 0.02
Richards						
High	0.28 ± 0.12	0.15 ± 0.06	0.31 ± 0.08	0.03 ± 0.03	0.14 ± 0.03	0.07 ± 0.08
Mid	0.41 ± 0.30	0.09 ± 0.10	0.18 ± 0.07	0.19 ± 0.07	0.38 ± 0.06	0.39 ± 0.05
Low	1.44 ± 0.05	0.12 ± 0.13	0.55 ± 0.19	0.20 ± 0.11	0.77 ± 0.29	0.57 ± 0.14
Townsley						
High	0.60 ± 0.17	0.21 ± 0.13	0.61 ± 0.20	0.07 ± 0.06	0.43 ± 0.04	0.06 ± 0.06
Mid	0.47 ± 0.13	0.09 ± 0.04	0.12 ± 0.04	-0.02 ± 0.03	-0.25 ± 0.02	0.07 ± 0.01
Low	0.57 ± 0.45	0.05 ± 0.08	0.24 ± 0.05	0.16 ± 0.06	-0.09 ± 0.04	0.08 ± 0.05

[a] Pre-burn area at Nevis were taken from an adjacent area that did not burn and are provided for comparative purposes only.

Table D.13. Summer available digestible protein (g/0.25 m^2) on burned and unburned (control) areas in the year of burning (July 2010) and 1 year after burning (July 2011) at high, mid and low elevations at 4 sites (Luckhurst, Nevis, Richards, Townsley) in the Besa-Prophet area, northern British Columbia. Available digestible protein was calculated by multiplying digestible protein (Hanley et al. 1992) by forage biomass.

Site	July 2010						July2011					
	Burn	**±**	**SE**	**Control**	**±**	**SE**	**Burn**	**±**	**SE**	**Control**	**±**	**SE**
Luckhurst												
High	0.08	±	0.07	0.01	±	0.01	0.58	±	0.17	0.01	±	0.01
Mid	0.22	±	0.21	0.37	±	0.01	0.98	±	0.91	0.52	±	0.22
Low	0.23	±	0.20	1.21	±	0.34	0.44	±	0.08	1.76	±	0.47
Nevis												
High	0.37	±	0.13	0.04	±	0.04	1.09	±	0.47	0.01	±	0.01
Mid	0.58	±	0.18	1.12	±	0.11	1.68	±	0.32	0.68	±	0.28
Low	1.13	±	0.41	1.26	±	0.05	1.52	±	0.13	1.39	±	0.39
Richards												
High	2.35	±	0.56	0.73	±	0.12	3.99	±	0.68	1.41	±	0.23
Mid	3.39	±	0.90	3.24	±	1.56	2.65	±	0.32	3.25	±	1.46
Low	5.42	±	1.76	2.82	±	1.01	6.15	±	1.46	4.60	±	1.05
Townsley												
High	4.69	±	0.89	2.37	±	1.16	4.24	±	1.16	1.88	±	1.05
Mid	2.45	±	0.42	1.15	±	0.12	4.54	±	0.55	1.88	±	0.12
Low	3.47	±	1.57	1.83	±	0.36	2.21	±	0.86	1.48	±	0.13

Appendix E: Pellet counts

Table E.1. Number of Stone's sheep pellet groups counted and removed along 100 × 4-m transects on burned and unburned (control) areas at high, mid and low elevations at 4 sites (Luckhurst, Nevis, Richards, Townsley) in winter (early May) and summer (mid–late July) in the Besa-Prophet area, northern British Columbia.

Site	Winter 2010[a]		Summer 2010		Winter 2011		Summer 2011		Winter 2012	
	Burn	**Control**	**Burn**	**Control**	**Burn**	**Control**	**Burn**	**Control**	**Burn**	**Control**
Luckhurst										
High	3	5	1	1	46	1	37	3	84	1
Mid	4	1	0	0	3	0	8	0	11	0
Low	0	1	0	0	6	0	7	0	2	0
Nevis										
High	12	2	0	0	8	10	0	0	5	7
Mid	2	4	1	0	5	7	5	2	8	2
Low	14	2	0	0	3	0	1	0	0	0
Richards										
High	1	0	0	1	0	0	0	1	0	0
Mid	0	1	0	0	0	0	0	0	0	1
Low	0	0	0	0	0	0	0	0	0	0
Townsley										
High	30	15	8	0	45	19	5	4	8	4
Mid	30	0	2	0	0	0	1	0	0	0
Low	1	0	0	0	2	0	0	0	0	0

[a] Winter 2010 survey was conducted prior to prescribed burning and represents historical use on each transect.

Table E.2. Number of elk pellet groups counted and removed along 100 × 4-m transects on burned and unburned (control) areas at high, mid and low elevations at 4 sites (Luckhurst, Nevis, Richards, Townsley) in winter (early May) and summer (mid–late July) in the Besa-Prophet area, northern British Columbia.

Site	Winter 2010[a]		Summer 2010		Winter 2011		Summer 2011		Winter 2012	
	Burn	Control	Burn	Control	Burn	Control	Burn	Control	Burn	Control
Luckhurst										
High	0	0	0	1	4	1	0	0	5	0
Mid	1	1	0	1	0	0	2	0	1	1
Low	0	6	0	1	0	3	0	3	0	7
Nevis										
High	2	0	0	0	1	0	0	0	0	0
Mid	0	8	0	0	0	1	0	0	2	1
Low	1	8	1	0	5	0	2	0	5	0
Richards										
High	87	32	7	0	55	8	16	1	44	0
Mid	12	59	7	1	13	17	4	0	6	2
Low	16	2	1	0	22	10	0	0	3	0
Townsley										
High	42	67	3	3	39	30	5	11	12	8
Mid	60	30	0	1	14	8	0	0	10	1
Low	21	10	1	1	19	2	2	0	1	1

[a] Winter 2010 survey was conducted prior to prescribed burning and represents historical use on each transect.

Appendix F: Frequency of occurrence of plant species by aspect and treatment

Table F.1. Plant species and their occurrence (shown by 1 in table) in 1 × 1-m plots along 50-m transects on burned and control areas at high (H), mid (M), and low (L) elevations at the Richards site in the year of burning (July 2010) and 1 year after burning (July 2011) in the Besa-Prophet area, northern British Columbia.

		2010						2011					
		Burn			Control			Burn			Control		
Scientific Name	Common Name	H	M	L	H	M	L	H	M	L	H	M	L
Alnus crispa	Mountain Alder												
Achillea millifolium	Yarrow	1	1	1	1	1	1	1	1	1	1	1	1
Aconitum delphiniifolium	Mountain monkshood												
Amelanchier alnifolia	Saskatoon berry					1						1	
Arctostaphylus uva-ursi	Kinnikinnick												
Arnica angustifolia	Alpine arinca		1		1	1		1	1		1	1	
Aster foliaceus	Leafy aster				1	1	1				1	1	1
Astragulus alpinus	Alpine Milk Vetch		1	1									
Betula glandulosa	Scrub birch											1	1
Bistorta vivipara	Alpine bistort												
Carex spp.	Sedge spp.									1			
Castilleja parviflora	Indian paintbrush												
Cerastium arvense	Field chickweed						1				1		1
Cornus canadensis	Bunchberry												
Cystopteris fragili	Fragile fern												
Delphinium glaucum	Tall larkspur	1	1	1				1	1				
Dryas integrifolia	Mountain-aven												
Elymus innovatus	Fuzzy-spiked wildrye	1	1	1	1	1	1	1	1	1	1	1	1
Empetrum nigrum	Crow berry												
Epilobium angustifolium	Fireweed	1	1	1	1	1	1	1	1	1	1	1	1
Equisetum spp.	Horsetail spp.												
Erigeron acris	Bitter Fleabane												
Festuca spp.	Festuca spp.	1									1	1	
Fragaria virgiana	Wild strawberry	1		1		1	1			1			1
Gallium boreale	Northern Bedstraw	1						1					
Gentiana glauca	Inky gentian								1	1	1		
Gentianella amarella	Northern gentian				1								1
Geranium richardsonnii	Richardson's geranium												
Hedysarum spp.	Sweet-vetch spp.	1	1	1		1	1	1	1	1	1	1	1
Juniperus communis	Common juniper												
Lathyrus ochroleucus	Creamy-pea vine	1	1	1				1	1	1			
Ledum glandulosum	Western labrador tea												
Linnea borealis	Twin flower												
Lupinus arcticus	Arctic lupine				1								
Mertensia paniculata	Tall Bluebell	1		1	1	1	1	1	1	1	1	1	1

Table F.1. Continued.

Scientific Name	Common Name	2010						2011					
		Burn			Control			Burn			Control		
		H	M	L	H	M	L	H	M	L	H	M	L
Mentha spp.	Mint spp.												
Moss/Lichen	Moss/Lichen				1		1				1	1	
Thalictrum occidentale	Western meadowrue												
Myosotis alpestris	Mountain forget-me-not												
Oxytropis spp.	Locoweed spp.	1											1
Pedicularis spp.	Lousewort spp.												
Petasites sagittatus	Arrow-leaved coltsfoot												
Picea engelmanni	Englemann spruce												
Pinguicula spp.	Butterwort spp.												
Pinus contorta	Lodgepole pine												
Platanthera orbiculata	Round-leaved orchid												
Poa spp.	Bluegrass spp.	1				1	1	1			1	1	1
Polemonium spp.	Jacob's ladder												
Populus balsimifera	Cottonwood		1	1			1		1	1			
Populus tremuloides	Trembling aspen		1			1	1					1	
Potentilla fruticosa	Shrubby cinquefoil												
Potentilla uniflora	One-flower cinquefoil												
Pyrola asarifolia	Pink winter green				1								
Rannuculus spp.	Buttercup spp.												
Rosa acicularis	Prickly rosea	1	1		1	1	1	1	1		1	1	1
Rumex crispus	Common sorrel												
Salix spp.	Willow spp.				1								
Saxifraga lyallii	Redstem saxifrage	1											1
Saxifraga tricupsidata	Three-toothed saxifrage												
Saxifraga spp.	Saxifrage spp.												
Senecio lugens	Black-tipped groundsel												
Sheperdia canadensis	Soopolallie					1							
Silene uralensis	Bladder campion												
Smilacina racemosa	False solomon's-seal											1	
Solidago multiradiata	Northern Goldenrod												
Stellaria longipes	Long-stalked starwort												
Stellaria spp.	Chickweed spp.												
Taraxacum spp.	Dandelion spp.												
Trisetum spicatum	Spike trisetum							1					
Vaccinium vitis-idaea	Lingonbery												
Zygadenus elegans	Mountain death-camus												

Table F.2. Plant species and their occurrence (shown by 1 in table) in 1 × 1-m plots along 50-m transects on burned and control areas at high (H), mid (M), and low (L) elevations at the Townsley site in the year of burning (July 2010) and 1 year after burning (July 2011) in the Besa-Prophet area, northern British Columbia.

Scientific Name	Common Name	2010						2011					
		Burn			Control			Burn			Control		
		H	M	L	H	M	L	H	M	L	H	M	L
Alnus crispa	Mountain Alder												
Achillea millifolium	Yarrow			1		1	1			1	1	1	1
Aconitum delphiniifolium	Mountain monkshood	1	1		1		1	1	1		1		
Amelanchier alnifolia	Saskatoon berry											1	
Arctostaphylus uva-ursi	Kinnikinnick					1	1						1
Arnica angustifolia	Alpine arinca			1		1	1			1		1	1
Aster foliaceus	Leafy aster												1
Astragulus alpinus	Alpine Milk Vetch	1											
Betula glandulosa	Scrub birch		1	1	1	1			1	1	1	1	1
Bistorta vivipara	Alpine bistort	1			1				1		1	1	
Carex spp.	Sedge spp.	1	1		1			1			1	1	
Castilleja parviflora	Indian paintbrush				1								
Cerastium arvense	Field chickweed	1			1			1			1	1	
Cornus canadensis	Bunchberry												
Cystopteris fragili	Fragile fern	1	1	1		1		1	1		1	1	
Delphinium glaucum	Tall larkspur						1			1			1
Dryas integrifolia	Mountain-aven					1							
Elymus innovatus	Fuzzy-spiked wildrye	1	1	1	1	1	1	1	1	1	1	1	1
Empetrum nigrum	Crow berry												
Epilobium angustifolium	Fireweed		1	1	1	1	1	1	1	1	1	1	1
Equisetum spp.	Horsetail spp.						1						
Erigeron acris	Bitter Fleabane												
Festuca spp.	Festuca spp.	1	1			1					1	1	1
Fragaria virgiana	Wild strawberry		1	1			1			1		1	1
Gallium boreale	Northern Bedstraw					1				1			
Gentiana glauca	Inky gentian								1	1	1		
Gentianella amarella	Northern gentian												
Geranium richardsonnii	Richardson's geranium		1	1									
Hedysarum spp.	Sweet-vetch spp.	1	1	1	1	1	1	1	1	1	1	1	
Juniperus communis	Common juniper												
Lathyrus ochroleucus	Creamy-pea vine												
Ledum glandulosum	Western labrador tea												
Linnea borealis	Twin flower												
Lupinus arcticus	Arctic lupine	1			1			1			1	1	
Mertensia paniculata	Tall Bluebell	1		1	1	1	1	1		1	1	1	1
Mentha spp.	Mint spp.												

Table F.2. Continued.

Scientific Name	Common Name	2010						2011					
		Burn			Control			Burn			Control		
		H	M	L	H	M	L	H	M	L	H	M	L
Moss/Lichen	Moss/Lichen		1								1		
Thalictrum occidentale	Western meadowrue						1						1
Myosotis alpestris	Mountain forget-me-not	1	1		1			1			1		
Oxytropis spp.	Locoweed spp.	1	1				1	1					1
Pedicularis spp.	Lousewort spp.												
Petasites sagittatus	Arrow-leaved coltsfoot												
Picea engelmanni	Englemann spruce												
Pinguicula spp.	Butterwort spp.										1		
Pinus contorta	Lodgepole pine												
Platanthera orbiculata	Round-leaved orchid												
Poa spp.	Bluegrass spp.	1			1			1	1	1	1		
Polemonium spp.	Jacob's ladder				1	1					1	1	1
Populus balsimifera	Cottonwood												
Populus tremuloides	Trembling aspen						1						
Potentilla fruticosa	Shrubby cinquefoil				1	1					1		
Potentilla uniflora	One-flower cinquefoil				1							1	
Pyrola asarifolia	Pink winter green												
Rannuculus spp.	Buttercup spp.						1						
Rosa acicularis	Prickly rosea			1		1	1			1			1
Rumex crispus	Common sorrel	1	1		1	1		1	1				
Salix spp.	Willow spp.		1	1	1	1	1				1		
Saxifraga lyallii	Redstem saxifrage												
Saxifraga tricupsidata	Three-toothed saxifrage	1				1		1					
Saxifraga spp.	Saxifrage spp.							1				1	
Senecio lugens	Black-tipped groundsel												
Sheperdia canadensis	Soopolallie												1
Silene uralensis	Bladder campion		1				1	1	1				
Smilacina racemosa	False solomon's-seal												
Solidago multiradiata	Northern Goldenrod				1	1			1		1		1
Stellaria longipes	Long-stalked starwort				1	1							
Stellaria spp.	Chickweed spp.							1					
Taraxacum spp.	Dandelion spp.												
Trisetum spicatum	Spike trisetum	1							1	1			
Vaccinium vitis-idaea	Lingonbery												
Vaccinium spp.	Blueberry spp.												
Zygadenus elegans	Mountain death-camus	1	1					1	1			1	

Table F.3. Plant species and their occurrence (shown by 1 in table) in 1 × 1-m plots along 50-m transects on burned and control areas at high (H), mid (M), and low (L) elevations at the Luckhurst site in the year of burning (July 2010) and 1 year after burning (July 2011) in the Besa-Prophet area, northern British Columbia.

Scientific Name	Common Name	2010						2011					
		Burn			Control			Burn			Control		
		H	M	L	H	M	L	H	M	L	H	M	L
Alnus crispa	Mountain Alder					1	1						
Achillea millifolium	Yarrow						1					1	1
Aconitum delphiniifolium	Mountain monkshood												1
Amelanchier alnifolia	Saskatoon berry				1	1							
Arctostaphylus uva-ursi	Kinnikinnick										1	1	
Arnica angustifolia	Alpine arinca												
Aster foliaceus	Leafy aster												
Astragulus alpinus	Alpine Milk Vetch	1	1	1	1	1	1						
Betula glandulosa	Scrub birch							1	1	1	1	1	1
Bistorta vivipara	Alpine bistort												
Carex spp.	Sedge spp.												
Castilleja parviflora	Indian paintbrush											1	
Cerastium arvense	Field chickweed	1		1		1							1
Cornus canadensis	Bunchberry									1		1	
Cystopteris fragili	Fragile fern												
Delphinium glaucum	Tall larkspur												1
Dryas integrifolia	Mountain-aven	1		1		1	1						
Elymus innovatus	Fuzzy-spiked wildrye											1	1
Empetrum nigrum	Crow berry	1	1	1	1	1	1		1				
Epilobium angustifolium	Fireweed							1	1	1	1	1	1
Equisetum spp.	Horsetail spp.												
Erigeron acris	Bitter Fleabane												
Festuca spp.	Festuca spp.							1	1	1		1	1
Fragaria virgiana	Wild strawberry												
Gallium boreale	Northern Bedstraw										1		
Gentiana glauca	Inky gentian												
Gentianella amarella	Northern gentian												
Geranium richardsonnii	Richardson's geranium												
Hedysarum spp.	Sweet-vetch spp.					1							
Juniperus communis	Common juniper						1						
Lathyrus ochroleucus	Creamy-pea vine	1	1	1		1							
Ledum glandulosum	Western labrador tea					1	1	1	1	1			
Linnea borealis	Twin flower		1			1	1				1		
Lupinus arcticus	Arctic lupine						1		1			1	1
Mertensia paniculata	Tall Bluebell					1		1					
Mentha spp.	Mint spp.		1		1	1	1						1

Table F.3. Continued.

Scientific Name	Common Name	2010 Burn H	2010 Burn M	2010 Burn L	2010 Control H	2010 Control M	2010 Control L	2011 Burn H	2011 Burn M	2011 Burn L	2011 Control H	2011 Control M	2011 Control L
Moss/Lichen	Moss/Lichen							1	1	1	1		
Thalictrum occidentale	Western meadowrue											1	1
Myosotis alpestris	Mountain forget-me-not												
Oxytropis spp.	Locoweed spp.					1							
Pedicularis sp.	Lousewort spp.								1				
Petasites sagittatus	Arrow-leaved coltsfoot				1		1						
Picea engelmanni	Englemann spruce					1							1
Pinguicula spp.	Butterwort spp.												
Pinus contorta	Lodgepole pine												1
Platanthera orbiculata	Round-leaved orchid		1										
Poa spp.	Bluegrass spp.											1	
Polemonium spp.	Jacob's ladder												1
Populus balsimifera	Cottonwood												
Populus tremuloides	Trembling aspen												
Potentilla fruticosa	Shrubby cinquefoil												
Potentilla uniflora	One-flower cinquefoil						1						
Pyrola asarifolia	Pink winter green						1						
Rannuculus spp.	Buttercup spp.												1
Rosa acicularis	Prickly rosea												1
Rumex crispus	Common sorrel						1						1
Salix spp.	Willow spp.												
Saxifraga lyallii	Redstem saxifrage												
Saxifraga tricupsidata	Three-toothed saxifrage							1					
Saxifraga spp.	Saxifrage spp.											1	1
Senecio lugens	Black-tipped groundsel												
Sheperdia canadensis	Soopolallie												
Silene uralensis	Bladder campion	1			1	1							
Smilacina racemosa	False solomon's-seal												
Solidago multiradiata	Northern Goldenrod												
Stellaria longipes	Long-stalked starwort							1					
Stellaria spp.	Chickweed spp.												
Taraxacum spp.	Dandelion spp.												
Trisetum spicatum	Spike trisetum	1	1		1	1	1		1		1		1
Vaccinium vitis-idaea	Lingonbery	1	1	1	1	1	1	1	1	1	1	1	1
Vaccinium spp.	Blueberry spp.							1					
Zygadenus elegans	Mountain death-camus												

Table F.4. Plant species and their occurrence(shown by 1 in table) in 1 × 1-m plots along 50-m transects on burned and control areas at high (H), mid (M), and low (L) elevations at the Nevis site in the year of burning (July 2010) and 1 year after burning (July 2011) in the Besa-Prophet area, northern British Columbia.

		2010						2011					
Scientific Name	**Common Name**	**Burn**			**Control**			**Burn**			**Control**		
		H	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**
Alnus crispa	Mountain Alder							1	1	1	1		
Achillea millifolium	Yarrow			1				1	1	1		1	1
Aconitum delphiniifolium	Mountain monkshood					1			1				
Amelanchier alnifolia	Saskatoon berry												
Arctostaphylus uva-ursi	Kinnikinnick	1	1		1	1	1	1	1			1	1
Arnica angustifolia	Alpine arinca					1	1		1	1		1	1
Aster foliaceus	Leafy aster												
Astragulus alpinus	Alpine Milk Vetch												
Betula glandulosa	Scrub birch	1	1	1	1	1	1	1	1	1	1	1	1
Bistorta vivipara	Alpine bistort												
Carex spp.	Sedge spp.												
Castilleja parviflora	Indian paintbrush			1			1			1			1
Cerastium arvense	Field chickweed												
Cornus canadensis	Bunchberry	1	1	1	1	1	1	1	1	1	1	1	1
Cystopteris fragili	Fragile fern												
Delphinium glaucum	Tall larkspur												
Dryas integrifolia	Mountain-aven												
Elymus innovatus	Fuzzy-spiked wildrye		1	1		1	1		1	1		1	1
Empetrum nigrum	Crow berry				1						1		
Epilobium angustifolium	Fireweed	1	1	1	1	1	1	1	1	1		1	1
Equisetum spp.	Horsetail spp.												
Erigeron acris	Bitter Fleabane												
Festuca spp.	Festuca spp.	1	1	1		1	1	1	1	1	1	1	1
Fragaria virgiana	Wild strawberry												
Gallium boreale	Northern Bedstraw		1				1		1	1		1	1
Gentiana glauca	Inky gentian								1	1		1	1
Gentianella amarella	Northern gentian												
Geranium richardsonnii	Richardson's geranium			1						1			
Hedysarum spp.	Sweet-vetch spp.												
Juniperus communis	Common juniper				1			1			1		
Lathyrus ochroleucus	Creamy-pea vine					1	1					1	1
Ledum glandulosum	Western labrador tea				1			1		1	1		
Linnea borealis	Twin flower						1		1	1			1
Lupinus arcticus	Arctic lupine	1	1	1		1	1		1	1		1	1
Mertensia paniculata	Tall Bluebell		1				1					1	
Mentha spp.	Mint spp.												

Table F.4. Continued.

Scientific Name	Common Name	2010						2011					
		Burn			Control			Burn			Control		
		H	M	L	H	M	L	H	M	L	H	M	L
Moss/Lichen	Moss/Lichen	1			1	1		1	1		1	1	
Thalictrum occidentale	Western meadowrue												
Myosotis alpestris	Mountain forget-me-not												
Oxytropis spp.	Locoweed spp.												
Pedicularis spp.	Lousewort spp.												
Petasites sagittatus	Arrow-leaved coltsfoot												1
Picea engelmanni	Englemann spruce					1					1	1	
Pinguicula spp.	Butterwort spp.												
Pinus contorta	Lodgepole pine												
Platanthera orbiculata	Round-leaved orchid						1						
Poa spp.	Bluegrass spp.				1								
Polemonium spp.	Jacob's ladder												
Populus balsimifera	Cottonwood						1						1
Populus tremuloides	Trembling aspen												1
Potentilla fruticosa	Shrubby cinquefoil					1						1	
Potentilla uniflora	One-flower cinquefoil												
Pyrola asarifolia	Pink winter green					1	1	1	1			1	1
Rannuculus spp.	Buttercup spp.												
Rosa acicularis	Prickly rosea		1				1		1			1	1
Rumex crispus	Common sorrel												
Salix spp.	Willow spp.		1	1		1	1						
Saxifraga lyallii	Redstem saxifrage												
Saxifraga tricupsidata	Three-toothed saxifrage												
Saxifraga spp.	Saxifrage spp.												
Senecio lugens	Black-tipped groundsel												
Sheperdia canadensis	Soopolallie												
Silene uralensis	Bladder campion												
Smilacina racemosa	False solomon's-seal												
Solidago multiradiata	Northern Goldenrod					1						1	1
Stellaria longipes	Long-stalked starwort												
Stellaria spp.	Chickweed spp.												
Taraxacum spp.	Dandelion spp.												
Trisetum spicatum	Spike trisetum												
Vaccinium vitis-idaea	Lingonbery	1	1		1	1	1	1	1	1	1	1	1
Vaccinium spp.	Blueberry spp.			1			1			1			1
Zygadenus elegans	Mountain death-camus						1		1				

Appendix G: Seasonal ranges of GPS-collared Stone's sheep and elk in the Besa-Prophet area

Table G.1. Seasonal range sizes (km^2) of 11 GPS-collared female Stone's sheep and the percentages of land-cover classes within each animal’s seasonal range in the Besa-Prophet area of northern British Columbia. Seasons are: SP = spring, SU = summer, FA = fall, WI = winter, LW = late winter. Land-cover classes are: CA = *Carex*, LS = Low shrub, CO = Conifer, RO = Rock, NV = Non-vegetative, SU = Subalpine, RI = Riparian, AL = Alpine, BS = Burn shrub, BG = Burn grass, NB = New burn). The area of range burned (km^2) represents the area of the seasonal range in the 3 burn classes (Burn shrub, Burn grass, New burn). Seasonal ranges for each individual were based on the animal's movement potential.

Animal	Season	Range (km^2)	Percentage of land-cover class											Range Burned (km^2)
			CA	LS	CO	RO	NV	SU	RI	AL	BS	BG	NB	
S-1	SP	58.5	0.0	2.4	27.4	14.5	0.0	19.0	0.5	21.9	8.0	3.7	2.6	8.3
S-1	SU	74.7	0.0	3.1	25.2	14.8	0.0	23.0	0.5	21.8	7.1	3.5	1.1	8.8
S-1	FA	77.9	0.1	3.9	26.5	16.3	0.0	18.3	0.4	19.8	7.1	4.6	3.0	11.5
S-1	WI	51.0	0.1	2.9	31.0	17.6	0.0	13.1	0.7	17.5	7.4	4.6	5.0	8.7
S-1	LW	33.2	0.1	2.5	27.2	20.2	0.0	13.8	0.5	16.2	7.2	4.8	7.6	6.5
S-2	SP	102.9	1.3	3.4	32.2	23.1	0.0	11.8	5.0	9.1	3.2	1.8	9.1	14.5
S-2	SU	125.8	1.3	3.2	20.1	37.1	0.0	17.0	3.7	9.6	3.2	1.7	3.3	10.2
S-2	FA	147.2	1.3	3.3	29.0	25.1	0.0	18.4	5.4	8.4	2.9	1.4	4.8	13.5
S-2	WI													
S-2	LW	25.2	2.3	8.2	13.5	8.4	0.0	12.8	3.4	7.0	7.3	4.8	32.3	11.2
S-3	SP	205.1	2.3	4.2	33.8	30.0	0.1	9.7	7.5	3.7	1.7	2.1	4.8	17.7
S-3	SU	234.9	1.6	2.0	17.2	57.5	0.3	9.4	4.3	5.6	1.0	1.1	0.0	5.1
S-3	FA	273.1	2.0	2.5	30.7	32.8	0.0	13.4	5.9	6.0	1.8	1.1	3.8	18.3
S-3	WI	25.9	1.1	6.5	24.3	8.7	0.0	19.4	1.5	8.2	7.5	4.6	18.2	7.9
S-3	LW	41.4	2.3	6.4	28.7	5.8	0.0	13.1	5.5	5.1	5.6	3.3	24.3	13.8
S-4	SP	115.7	1.7	4.9	28.8	31.8	0.0	10.7	5.9	4.8	2.2	1.7	7.4	13.1
S-4	SU	204.5	1.6	3.5	21.0	40.9	0.0	15.1	6.0	7.3	1.7	2.0	0.8	9.4
S-4	FA	203.1	1.2	2.7	29.8	31.9	0.1	14.5	4.7	7.0	2.2	1.2	4.5	16.1

Table G.1. Continued.

Animal	Season	Range (km^2)	Percentage of land-cover class											Range Burned (km^2)
			CA	LS	CO	RO	NV	SU	RI	AL	BS	BG	NB	
S-4	WI	22.5	1.4	6.0	23.5	10.0	0.0	14.8	2.3	7.5	8.7	5.5	20.3	7.7
S-4	LW	16.9	0.3	2.3	15.5	13.3	0.0	11.2	0.5	9.6	8.5	5.4	33.4	8.0
S-5	SP	199.1	1.9	3.5	30.6	32.3	0.1	9.3	7.8	6.4	2.0	1.9	4.2	16.0
S-5	SU	315.3	2.0	2.8	24.9	40.0	0.3	12.5	6.0	6.2	1.6	1.8	1.8	16.6
S-5	FA	128.6	1.4	3.5	31.9	21.7	0.0	16.7	4.9	8.3	3.1	1.5	7.0	14.9
S-5	WI	23.1	1.7	6.0	20.6	9.8	0.0	15.0	3.1	7.8	8.5	5.4	22.1	8.3
S-5	LW	24.1	1.4	6.1	14.6	8.3	0.0	18.0	1.5	8.7	7.6	4.9	29.1	10.0
S-6	SP	75.1	1.3	4.2	22.8	37.3	0.0	11.8	4.6	7.6	2.7	2.0	5.7	7.8
S-6	SU	203.8	1.2	3.1	20.0	43.2	0.0	14.0	4.4	7.6	1.7	2.1	2.6	13.1
S-6	FA	164.2	1.1	3.3	27.7	31.6	0.0	14.9	5.2	8.0	2.1	1.2	4.8	13.4
S-6	WI	28.4	1.2	4.5	30.6	8.3	0.0	18.1	2.9	7.1	7.1	4.4	15.8	7.8
S-6	LW	25.5	0.7	3.9	16.8	21.7	0.0	12.3	1.3	7.5	6.7	4.5	24.6	9.1
S-7	SP	60.0	0.7	11.2	30.8	17.7	0.0	5.1	4.4	9.8	11.2	5.2	4.0	12.2
S-7	SU	72.4	1.1	15.3	29.7	16.9	0.0	4.6	4.0	9.4	10.7	5.0	3.4	13.8
S-7	FA	75.6	0.8	18.9	29.7	14.9	0.0	5.5	3.6	8.0	11.3	4.2	3.1	14.1
S-7	WI	24.1	0.2	7.0	22.4	23.9	0.0	6.6	3.8	14.3	11.4	6.3	4.0	5.2
S-7	LW	40.2	0.4	7.8	27.6	19.5	0.0	6.8	3.6	11.0	12.0	6.3	4.9	9.4
S-8	SP	29.5	2.5	7.4	38.9	18.2	0.0	1.4	7.2	10.4	5.8	5.1	3.2	4.2
S-8	SU	56.2	3.2	9.1	41.0	13.2	0.0	2.2	9.9	10.1	5.3	4.3	1.7	6.3
S-8	FA	27.9	1.8	9.6	35.1	18.2	0.0	1.9	3.9	12.4	7.5	6.2	3.4	4.8
S-8	WI	17.3	0.0	5.3	28.1	25.9	0.0	2.3	0.3	18.0	6.1	8.6	5.4	3.5
S-8	LW	11.5	0.0	0.6	26.0	35.6	0.0	1.2	0.2	17.7	5.7	4.9	8.3	2.2
S-9	SP	108.4	0.2	3.1	37.0	10.4	0.1	16.9	2.1	14.9	9.4	4.6	1.3	16.6

Table G.1. Continued.

Animal	Season	Range (km^2)	Percentage of land-cover class											Range Burned (km^2)
			CA	LS	CO	RO	NV	SU	RI	AL	BS	BG	NB	
S-9	SU	96.6	0.0	3.7	25.2	14.1	0.0	23.3	0.7	19.1	8.5	4.0	1.5	13.5
S-9	FA	69.0	0.1	4.2	24.8	17.0	0.0	18.8	0.4	20.0	6.9	4.7	3.1	10.2
S-9	WI	32.7	0.1	4.0	24.4	20.0	0.0	14.5	0.4	17.7	6.9	5.2	6.9	6.2
S-9	LW	22.2	0.0	2.5	27.7	22.6	0.0	13.2	0.6	14.0	6.9	4.2	8.3	4.3
S-10	SP	208.4	1.9	3.3	28.5	31.0	0.0	13.2	7.3	6.8	2.1	2.1	3.8	16.7
S-10	SU	318.3	1.8	2.7	21.0	46.2	0.2	12.3	5.4	5.6	1.6	1.7	1.5	15.6
S-10	FA	152.8	1.4	2.9	24.3	33.6	0.0	15.7	4.5	8.0	2.8	1.4	5.4	14.7
S-10	WI	28.9	2.0	8.1	24.9	8.0	0.0	14.8	5.0	7.2	7.1	4.4	18.7	8.7
S-10	LW	42.1	1.0	3.6	17.5	36.9	0.0	10.2	1.9	9.2	5.9	3.8	10.1	8.3
S-11	SP	20.9	2.0	6.8	37.1	21.4	0.0	1.1	5.4	9.9	6.8	4.8	4.6	3.4
S-11	SU	22.2	1.1	8.5	31.6	20.0	0.0	1.9	4.2	13.4	8.2	7.3	3.9	4.3
S-11	FA	27.2	1.2	9.2	27.0	23.8	0.0	2.3	3.1	15.4	8.3	6.3	3.5	4.9
S-11	WI	20.8	2.3	9.6	27.9	21.3	0.0	2.7	0.5	16.6	7.7	6.8	4.6	4.0
S-11	LW	10.7	0.3	1.0	18.9	37.9	0.0	1.5	1.3	18.9	7.1	6.2	6.9	2.2

Table G.2. Seasonal range sizes (km^2) of 22 GPS-collared female elk and the percentages of land-cover classes within each animal's seasonal range in the Besa-Prophet area of northern British Columbia. Seasons are: SP = spring, SU = summer, FA = fall, WI = winter, LW = late winter. Land-cover classes are: CA = *Carex*, LS = Low shrub, CO = Conifer, RO = Rock, NV = Non-vegetative, SU = Subalpine, RI = Riparian, AL = Alpine, BS = Burn shrub, BG = Burn grass, NB = New burn). The area of range burned represents the area of the seasonal range in the 3 burn classes (Burn shrub, Burn grass, New burn). Seasonal ranges for each individual were based on the animal's movement potential.

Animal	Season	Range (km^2)	Percentage of land-cover class											Range Burned (km^2)
			CA	LS	CO	RO	NV	SU	RI	AL	BS	BG	NB	
E-1	SP	14.9	0.7	5.7	20.1	10.0	0.7	21.1	5.9	8.3	16.5	11.0	0.0	4.1
E-1	SU	210.0	1.7	4.5	41.9	5.1	0.3	15.9	7.3	8.1	6.2	3.2	5.7	31.7
E-1	FA	78.3	2.2	3.3	45.3	4.4	0.4	11.0	8.6	4.7	4.4	1.9	13.8	15.7
E-1	WI	4.1	0.0	9.2	64.1	1.2	0.0	7.1	2.0	0.0	15.2	1.3	0.0	0.7
E-1	LW	20.0	0.9	6.3	35.5	2.1	1.0	5.2	9.1	1.8	23.3	14.7	0.0	7.6
E-2	SP	24.5	2.3	9.1	20.2	2.2	0.8	13.2	18.5	3.5	19.1	11.1	0.0	7.4
E-2	SU	66.3	1.1	4.1	30.0	2.0	0.1	31.2	12.0	8.2	8.4	2.8	0.0	7.4
E-2	FA	97.0	1.4	4.3	42.5	4.1	0.6	13.8	12.0	3.4	11.6	6.3	0.0	17.4
E-2	WI	40.8	1.0	7.2	20.7	5.4	0.0	33.4	5.6	9.5	13.0	4.1	0.0	7.0
E-2	LW	28.3	1.9	9.0	25.0	2.0	0.3	17.4	14.7	4.2	15.9	9.6	0.0	7.2
E-3	SP	39.8	3.8	5.4	30.2	4.0	0.4	4.0	12.2	1.9	5.2	3.5	29.6	15.2
E-3	SU	169.2	2.9	5.7	29.6	19.0	0.2	9.5	9.6	7.2	4.1	4.9	7.3	27.4
E-3	FA	27.4	2.0	2.3	29.6	5.8	0.0	5.8	7.2	3.8	6.9	2.5	33.9	11.9
E-3	WI	13.9	0.2	0.3	20.3	4.0	0.0	8.2	2.3	5.8	7.6	3.3	48.0	8.2
E-3	LW	7.9	0.0	0.1	22.8	3.4	0.0	1.7	2.6	0.6	8.0	5.1	55.7	5.4
E-4	SP	243.3	4.6	8.7	24.9	4.6	0.5	4.1	14.5	2.7	4.5	3.8	27.1	86.1
E-4	SU	55.4	0.7	5.0	34.1	22.4	0.0	20.6	2.5	9.8	2.6	1.7	0.7	2.8
E-4	FA													
E-4	WI													
E-4	LW	31.4	4.6	8.7	24.9	4.6	0.5	4.1	14.5	2.7	4.5	3.8	27.1	11.1
E-5	SP	77.5	3.1	7.1	45.0	3.4	0.4	6.3	11.4	2.7	5.1	2.9	12.5	15.9
E-5	SU	229.1	2.2	3.1	29.3	31.0	1.3	13.6	6.3	4.1	2.8	1.4	5.1	21.2

Table G.2. Continued.

Animal	Season	Range (km^2)	Percentage of land-cover class											Range Burned (km^2)
			CA	LS	CO	RO	NV	SU	RI	AL	BS	BG	NB	
E-5	FA	27.0	2.9	4.7	17.6	5.1	0.0	10.6	8.6	5.6	4.5	3.6	36.9	12.1
E-5	WI	32.9	3.0	8.0	23.7	6.5	0.0	9.0	7.9	5.2	5.7	3.8	27.1	12.0
E-5	LW	32.0	3.0	8.1	23.1	7.3	0.0	5.4	7.9	4.2	6.4	4.3	30.3	13.1
E-6	SP	142.0	2.3	4.6	45.8	5.3	0.3	14.4	8.7	4.9	3.8	2.1	7.9	19.6
E-6	SU	65.7	1.8	4.9	36.4	4.5	0.0	14.2	5.9	7.4	4.5	2.4	18.0	16.4
E-6	FA	41.7	2.1	4.1	31.3	4.1	0.0	13.0	7.5	5.6	3.5	2.8	25.9	13.5
E-6	WI	37.5	2.5	6.6	30.6	4.7	0.0	8.8	8.5	4.3	4.3	2.9	26.8	12.8
E-6	LW	61.7	3.7	8.2	34.2	4.6	0.3	5.7	10.7	2.9	5.5	5.1	19.2	18.4
E-7	SP	93.1	2.3	2.7	49.5	11.0	0.2	3.8	9.9	7.1	7.5	5.9	0.0	12.5
E-7	SU	106.2	1.1	11.7	36.1	11.2	0.1	7.4	5.1	9.9	10.3	6.3	0.8	18.5
E-7	FA	65.5	1.4	6.1	41.9	9.2	0.2	6.2	7.1	8.1	12.0	7.2	0.6	13.0
E-7	WI	19.0	1.5	2.1	30.2	9.1	0.0	10.5	3.5	12.6	19.6	11.0	0.0	5.8
E-7	LW	11.9	3.0	0.9	38.3	3.9	0.1	2.5	8.8	0.8	25.4	16.3	0.0	4.9
E-8	SP	58.1	2.0	2.9	50.7	8.8	0.2	3.2	9.4	6.1	10.1	6.8	0.0	9.8
E-8	SU	47.9	1.8	3.0	45.5	8.4	0.2	4.9	8.1	7.9	11.8	8.4	0.0	9.7
E-8	FA	26.4	2.1	2.2	44.1	7.2	0.3	4.1	8.8	8.0	15.9	7.4	0.0	6.1
E-8	WI	24.1	1.1	2.7	35.4	9.4	0.2	6.4	6.2	9.6	17.7	11.3	0.0	7.0
E-8	LW	10.1	2.1	0.8	42.3	7.3	0.2	2.9	11.3	3.1	21.4	8.6	0.0	3.0
E-9	SP	221.4	1.4	3.3	42.0	10.6	0.3	10.3	7.1	11.1	7.9	5.5	0.4	30.5
E-9	SU	81.6	2.6	3.1	46.4	4.4	0.7	5.6	13.1	3.8	11.5	8.8	0.0	16.5
E-9	FA	23.1	0.6	2.1	43.2	4.1	0.9	9.3	7.0	8.2	16.8	7.9	0.0	5.7
E-9	WI	26.4	1.3	2.0	41.0	3.3	0.5	7.6	7.1	6.1	21.6	9.4	0.0	8.2
E-9	LW	6.3	0.5	0.3	38.3	3.4	1.0	0.0	14.7	0.1	26.7	15.0	0.0	2.6
E-10	SP	60.9	2.0	4.2	34.0	14.6	0.1	8.4	8.0	10.5	9.3	6.8	2.0	11.1
E-10	SU	338.4	1.1	3.4	40.2	10.5	0.2	13.6	5.7	12.2	7.3	4.9	0.8	44.0
E-10	FA	218.7	1.4	3.8	38.0	11.0	0.3	13.0	6.4	11.5	8.5	5.7	0.6	32.1

Table G.2. Continued.

Animal	Season	Range (km^2)	Percentage of land-cover class											Range Burned (km^2)
			CA	LS	CO	RO	NV	SU	RI	AL	BS	BG	NB	
E-10	WI	69.2	1.5	4.6	34.8	14.4	0.1	8.5	4.8	11.4	10.3	7.8	1.7	13.7
E-10	LW	38.0	2.2	3.5	38.0	8.3	0.2	4.9	7.0	6.2	15.6	11.0	3.1	11.3
E-11	SP	52.4	3.3	2.6	51.3	10.0	0.2	2.8	13.9	5.4	4.9	5.6	0.0	5.6
E-11	SU	50.2	1.4	2.1	44.9	6.5	0.4	7.2	8.7	5.8	13.8	9.2	0.0	11.5
E-11	FA	18.7	0.2	1.8	37.1	4.7	0.7	9.6	7.7	8.1	19.2	11.0	0.0	5.6
E-11	WI	18.3	0.8	1.3	36.4	5.1	0.4	8.2	6.6	7.2	22.6	11.4	0.0	6.2
E-11	LW	3.7	2.0	1.7	30.9	3.6	0.2	0.4	2.8	0.4	34.2	23.8	0.0	2.1
E-12	SP	91.4	2.7	5.2	45.1	4.3	0.3	8.4	9.0	3.7	5.4	2.7	13.1	19.3
E-12	SU	289.0	1.5	3.3	41.0	9.7	0.1	19.2	7.1	8.1	3.8	2.0	4.2	28.9
E-12	FA	42.7	1.6	2.1	33.3	7.1	0.0	10.8	4.1	7.3	6.2	3.1	24.3	14.4
E-12	WI	28.2	1.8	1.9	21.7	8.0	0.0	7.7	5.3	5.6	5.4	3.9	38.4	13.5
E-12	LW	51.5	3.2	5.8	30.5	6.5	0.3	6.7	9.5	4.7	6.3	3.5	23.0	16.8
E-13	SP	91.4	2.4	5.1	41.7	4.1	0.3	14.8	8.6	5.3	3.6	2.1	12.0	16.2
E-13	SU	149.0	1.9	3.8	36.9	9.9	0.2	20.9	6.9	9.0	2.8	1.3	6.4	15.6
E-13	FA	56.6	1.3	4.6	33.1	8.2	0.0	23.3	4.4	8.9	3.0	1.9	11.2	9.2
E-13	WI	29.2	2.7	5.7	21.2	4.9	0.0	10.5	9.2	5.3	4.4	3.6	32.5	11.8
E-13	LW	22.2	3.1	5.7	13.0	9.4	0.0	8.5	5.8	5.5	7.2	5.1	36.8	10.9
E-14	SP	98.2	1.2	19.3	30.3	8.7	0.1	10.9	5.2	8.6	10.1	5.0	0.6	15.4
E-14	SU	102.7	0.5	19.4	21.7	9.4	0.0	19.3	1.3	15.2	9.3	3.3	0.6	13.6
E-14	FA	132.1	2.8	19.0	26.3	7.1	0.2	11.9	3.4	10.3	13.3	5.3	0.5	25.2
E-14	WI	38.2	1.7	15.4	30.3	5.8	0.7	11.1	4.2	10.0	13.9	7.0	0.0	8.0
E-14	LW	43.6	2.0	13.9	34.6	5.2	0.1	5.9	7.9	5.6	15.4	9.5	0.0	10.8
E-15	SP	50.9	3.5	7.5	35.2	4.6	0.3	7.5	11.1	4.0	4.9	3.1	18.3	13.4
E-15	SU	125.4	2.4	4.5	45.9	4.7	0.3	12.7	8.5	5.4	3.9	2.2	9.5	19.4
E-15	FA	57.3	3.0	6.3	37.3	4.3	0.3	8.4	9.8	3.4	4.9	2.8	19.5	15.6
E-15	WI	25.2	3.6	8.7	18.3	5.9	0.0	4.5	9.5	2.8	6.0	4.4	36.3	11.8

Table G.2. Continued.

Animal	Season	Range (km²)	Percentage of land-cover class											Range Burned (km²)
			CA	LS	CO	RO	NV	SU	RI	AL	BS	BG	NB	
E-15	LW	28.3	2.6	8.1	27.6	5.3	0.0	6.5	8.2	4.3	4.6	3.6	29.2	10.6
E-16	SP	40.6	4.7	3.0	48.1	8.7	0.1	2.5	15.2	6.9	4.7	5.9	0.0	4.3
E-16	SU	56.6	4.1	3.0	50.7	8.2	0.1	2.6	15.5	5.0	4.6	6.3	0.0	6.2
E-16	FA	35.4	3.8	2.6	49.8	10.8	0.2	2.4	15.2	2.6	5.9	6.8	0.0	4.5
E-16	WI	36.1	2.1	3.0	36.5	10.7	0.2	7.3	9.1	7.9	13.2	9.4	0.4	8.3
E-16	LW	37.9	3.6	1.3	49.6	11.5	0.2	2.0	15.4	2.5	5.9	6.5	1.4	5.2
E-17	SP	113.4	2.4	7.3	36.7	3.3	0.4	17.1	14.6	5.4	8.5	4.3	0.0	14.5
E-17	SU	290.7	2.6	5.0	35.4	14.9	2.6	14.5	9.9	7.9	5.1	2.1	0.0	20.9
E-17	FA	175.1	2.4	6.4	38.3	5.0	0.3	17.3	11.0	8.9	6.8	3.6	0.0	18.2
E-17	WI	20.8	0.1	7.6	29.6	4.1	0.0	17.5	1.6	9.3	18.0	12.3	0.0	6.3
E-17	LW	33.7	1.9	6.4	26.6	3.4	1.2	13.5	12.3	6.5	17.1	11.0	0.0	9.5
E-18	SP	50.9	1.9	5.0	29.9	2.7	0.0	19.4	6.3	4.8	6.5	3.6	19.7	15.2
E-18	SU	111.7	1.2	4.3	15.6	3.8	0.0	36.4	4.9	14.7	7.0	2.3	9.8	21.3
E-18	FA	50.3	1.0	5.2	14.3	1.7	0.0	43.3	4.6	16.6	11.0	2.4	0.0	6.7
E-18	WI	58.0	0.1	3.8	18.0	2.5	0.0	46.2	1.1	16.2	9.6	2.5	0.0	7.1
E-18	LW	47.1	1.9	4.7	31.7	4.1	0.0	12.4	6.2	5.5	7.1	3.0	23.2	15.7
E-19	SP	47.6	3.9	5.7	18.4	14.1	0.4	9.4	12.7	3.9	4.7	9.4	17.4	15.0
E-19	SU	129.5	2.2	5.6	26.5	14.4	0.2	16.2	9.6	8.5	3.5	5.0	8.4	21.9
E-19	FA	41.6	2.6	6.8	33.6	5.6	0.0	7.7	8.2	3.9	5.0	3.2	23.5	13.2
E-19	WI	26.2	3.4	9.1	20.3	5.6	0.0	4.9	7.7	4.0	5.3	4.1	35.5	11.7
E-19	LW	24.4	3.2	6.2	14.4	5.9	0.0	5.5	7.6	3.3	5.4	4.6	44.0	13.2
E-20	SP	94.4	1.3	14.5	37.5	8.8	0.1	6.4	5.6	6.5	12.1	6.0	1.2	18.2
E-20	SU	94.9	0.7	17.9	24.9	11.2	0.0	13.5	2.3	12.5	11.0	4.7	1.1	16.1
E-20	FA	110.5	1.2	14.3	37.2	10.5	0.1	7.7	4.3	7.6	11.2	5.0	0.9	18.9
E-20	WI	54.0	0.8	20.9	29.4	8.7	0.0	7.2	3.3	7.7	14.9	6.0	1.2	11.9
E-20	LW	28.6	1.5	18.2	29.3	5.4	0.1	6.0	7.9	6.4	15.2	9.8	0.2	7.2

Table G.2. Continued.

Animal	Season	Range (km^2)	Percentage of land-cover class											Range Burned (km^2)
			CA	LS	CO	RO	NV	SU	RI	AL	BS	BG	NB	
E-21	SP	206.3	2.2	5.2	47.8	7.0	0.2	11.5	7.7	3.7	5.1	3.6	6.0	30.2
E-21	SU	264.7	1.6	5.0	35.7	19.1	0.2	15.3	5.7	6.5	3.8	2.6	4.5	28.7
E-21	FA	47.7	1.9	5.1	33.8	4.4	0.0	11.2	6.9	4.3	5.0	3.3	24.0	15.4
E-21	WI	30.9	2.9	7.9	20.8	5.1	0.0	10.2	8.3	5.0	5.3	3.5	30.9	12.3
E-21	LW	34.3	4.5	8.8	22.5	6.2	0.4	7.7	9.3	4.8	6.0	4.1	25.7	12.3
E-22	SP	74.8	2.7	2.4	52.3	9.8	0.2	2.2	10.8	5.2	8.2	6.3	0.0	10.9
E-22	SU	47.6	1.9	3.3	52.3	8.4	0.2	2.1	8.8	5.3	10.3	7.4	0.0	8.4
E-22	FA	35.2	2.2	1.9	47.2	6.7	0.3	2.7	11.4	4.8	12.9	9.9	0.0	8.1
E-22	WI	24.9	2.1	3.5	41.5	9.2	0.1	6.6	7.9	7.4	10.6	11.1	0.0	5.4
E-22	LW	22.5	2.9	2.2	48.2	4.9	0.4	1.8	13.5	1.1	13.4	11.6	0.0	5.6