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BURNING FOR NORTHERN MOUNTAIN UNGULATES: EFFECTS OF PRESCRIBED FIRE

By

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Abstract

Prescribed fire is used as a management tool to enhance ungulate habitats. In northeastern British Columbia, up to 7,800 ha are burned annually. Yet relatively few studies have quantified the role of fire on 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*). In the Muskwa-Kechika Management Area, we examined the response of Stone's sheep and elk to seasonal changes in forage quantity and quality over an elevation gradient in areas recently burned by prescribed fires versus unburned control areas. We monitored vegetation and fecal-pellet transects at a fine scale and used Landsat imagery, survey flights, and telemetry locations at a landscape scale. 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 unburned 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 fires enhanced habitat value for grazing ungulates at least in the short-term. By altering animal distributions, however, use of prescribed fire has the potential to change predator-prey interactions.

Introduction.

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 typically reset after fire. Over time, overlapping fires and their recovery create a mosaic of small younger patches embedded within a matrix of older patches (Turner et al. 1997, Johnson et al. 1998), thereby shaping the heterogeneity of the landscape. The increases in forage quality and quantity in burned areas exert a "magnet effect" (Archibald et al. 2005) for grazing ungulates. Prescribed fires, therefore, are used as a habitat enhancement tool by management agencies to benefit ungulates. In northeastern BC, the Peace-Liard Prescribed Burn Program of the provincial government has been using prescribed burning for over 30 years. Initially the prescribed burns targeted areas to enhance range value for elk (*Cervus elaphus*), but the program has expanded to benefit Stone's sheep (*Ovis dalli stonei*), moose (*Alces alces*) and mountain goats (*Oreamnos americanus*). Up to 7,800 ha are intentionally burned each year in the Peace Region in an effort to enhance wildlife habitat, and have led to a landscape with 41% of all burned area (including from wild fires) resulting from prescribed fire (Lousier et al. 2009). The Peace Region is known for its abundance and diversity of ungulates and their predators.

A recent review and synthesis of past fire history in this part of the province identified knowledge gaps and provided a framework for a research monitoring plan (Lousier et al. 2009). Long-term outcomes of the wildlife/prescribed fire research program were to maintain ecological diversity, and the presence and number of species of large ungulates. To properly evaluate the effectiveness in achieving these long-term outcomes, 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. We approached the first three research needs by documenting resource use by two focal grazers – Stone's sheep and elk – in response to prescribed burning and by monitoring the indirect effects of fire on these species though direct effects on the vegetation. Due to their generalist diet and ease of dispersal, elk in northern BC are expanding (Shackleton 2013), potentially into the small traditional ranges of Stone's sheep. There is concern that the management activities of prescribed burning may promote competition between elk and Stone's sheep, with human-initiated fires changing ecosystem dynamics.

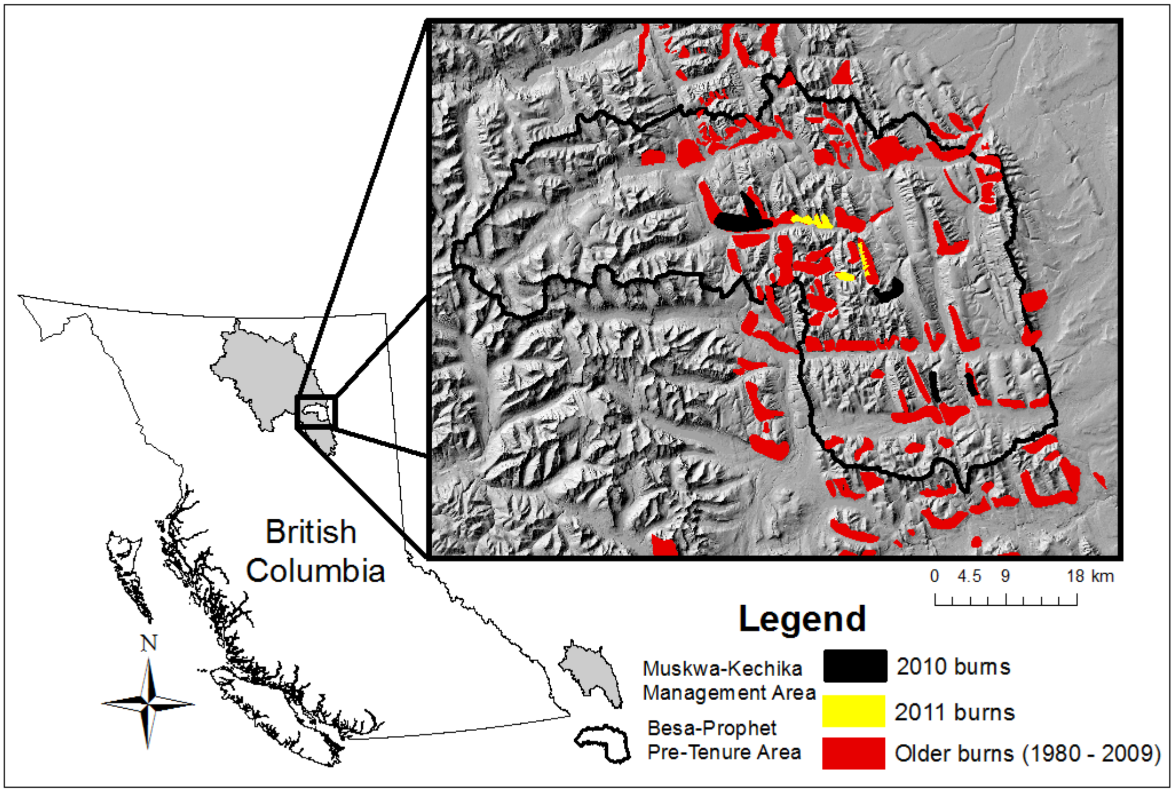

Figure 1. The Besa-Prophet area (inset) surrounding and including the Besa-Prophet Pre-tenure Planning Area in northeastern British Columbia. Locations of seven new prescribed burns implemented for this study are shown by black (2010) and yellow (2011) polygons. Changes in vegetation quantity and quality resulting from fire were monitored in the four 2010 burns. Locations of older prescribed burns (1980 – 2010) in the Besa-Prophet area are shown in red.

Methods

Study area

The Besa-Prophet area (approximately 741,000 ha between 57°11' and 57°15'N; 121°51' and 124°31'W) within the Muskwa-Kechika Management Area of northeastern BC supports one of the most diverse large mammal predator-prey systems in North America. It surrounds and includes the Besa-Prophet Pre-Tenure Planning Area (a zone that requires specific management planning prior to oil and gas exploration and development) and Redfern Keily Provincial Park (Figure 1). Elevations range from ~700–2200 m (tree line between 1450–1600 m; Lay 2005) and encompass three biogeoclimatic zones (Meidinger and Pojar 1991). A unique topography of numerous east-west drainages and south-facing slopes provides excellent wintering habitat for large ungulates: Stone's sheep, elk, moose, caribou (*Rangifer tarandus caribou*), some mountain goats, deer (*Odocoileus* spp.), and bison (*Bison bison*). The large predators are wolves (*Canis lupis*), grizzly bears (*Ursus arctos*), black bears (*Ursus americanus*), wolverines (*Gulo gulo*), coyotes (*Canis latrans*), and a few cougars (*Puma concolor*). Human activities include some snowmobiling and use of all-terrain vehicles, hunting, fishing, hiking, horseback riding, and prescribed burning. The latter contributes to the heterogeneity of the landscape that supports this globally renowned large-mammal assemblage. Since 1980, there have been 138 sites intentionally burned, often repeatedly, in the Besa-Prophet area (Sittler 2013).

Vegetation response to prescribed fire

Seven prescribed fires were implemented at sites associated with four drainages in the Besa-Prophet area between 15 May and 01 June 2010 and 2011 as part of the Peace-Liard Prescribed Burn Program. The resultant burns ranged in size from 150 to 1000 ha on south-facing (Richards, Townsley) and west-facing (Nevis, Luckhurst) sites. At four of the burned areas (referred to as 'burns') implemented in 2010 and at adjacent unburned control areas (referred to as 'unburned areas'), we took measurements prior to burning, the year of burning, and 1 year after burning in winter (late May) and summer (mid-July). On 50-m vegetation transects at high, mid, and low elevations, we measured vegetation cover and height, species diversity, and forage biomass. Mid elevations for each burn and its control were 1300, 1650, 1483, 1530 m for Richards, Townsley, Nevis, and Luckhurst sites, respectively. Mid-elevation transects were 100 m higher than low transects and 100 m lower than high transects. We determined nutritional quality of forage (graminoids and forbs) samples using laboratory analyses of digestibility and protein content. Over the course of this study, we repeated vegetation sampling five times on 24 transects (four sites, each with three transects – high, mid, low elevations – on burns and unburned areas) for a total of 120 transects. We quantified forage quantity and quality after clipping and analyzing samples from 360 plots (three per transect). To document large-scale vegetation response to fire, we compared satellite images (Landsat 5 TM, Landsat 7 +ETM) from the year of the burn and 2 years after the burn. We monitored changes in vegetation biomass (net primary productivity) with the normalized difference vegetation index (NDVI; Hope et al. 2007).

Ungulate response to prescribed fire

As a fine-scale measure of animal use of burned versus unburned areas, we recorded the species of each ungulate fecal pellet group on 100-m transects at the same elevations as the vegetation sampling in winter and summer. We also collected and analyzed data over 2 years from 11 female Stone's sheep and 22 female elk (11 in each year) fitted with global positioning satellite (GPS) collars that were programmed to acquire animal locations at 6-hour intervals. To supplement data from individuals, we conducted monthly distribution flights by fixed-wing aircraft over a 1-year monitoring period. We recorded the distribution of groups of elk and Stone's sheep in relation to prescribed burns at high, mid, and low elevations along a 2-hour route over an area that encompassed all GPS-collared animals as well as 28 burns of varying size and age (newly implemented burns and older burns).

Data analyses

We used transects as the sampling unit for all our analyses of vegetation and pellet counts. Data collected in three plots along each transect within a sampling period were averaged before analysis. To assess the influence of prescribed burning on vegetation quantity (forage biomass, forage cover, shrub cover), forage quality (crude protein, digestibility), plant species diversity and richness, and ungulate pellet counts, we used mixed-model regressions that tested the effects of treatment (burned versus unburned), elevation (high, mid, low) and site (Richards, Townsley, Nevis, Luckhurst). Because vegetation structure and composition differed seasonally, we tested post-burn effects in summer and winter separately.

We developed resource selection models to quantify characteristics that best described habitat selection (Burnham and Anderson 2002) by the GPS-collared Stone’s sheep and elk, specifically to better understand the influence of prescribed burns. For all GPS locations, we used a Geographical Information System (GIS) to query the elevation, slope, aspect, terrain ruggedness, and land cover. Land cover was described by 11 classes (Lay 2005, Sittler 2013), which included three burn classes. The ‘Burn shrub’ class was typically older burns containing deciduous shrubs (<2 m), ‘Burn grass’ referred to recent burns with open grass meadows most often found on south-facing slopes, and ‘New burns’ were the seven new (2010 and 2011) burns aged 1 and 2 years. We developed models for each collared individual, and then averaged those models within species in spring, summer, fall, early winter and late winter.

We also quantified relative importance of the land-cover classes, with emphasis on the burn classes. Importance was calculated as relative use (based on GPS locations) multiplied by availability (five randomly sampled points per GPS fix), scaled to 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 selection models because of their abundance on the landscape (Stewart et al. 2002). We used descriptive statistics to examine the differential use of topography (elevation, slope, ruggedness) and distance to a burn.

Results & Discussion

The effects of prescribed fire on forage quantity and quality varied with site, season, and elevation (Table 1). We were unable to detect a difference in the total amount of forage biomass on the vegetation transects 1 year after burning compared to unburned areas. The rate of forage growth, however, was higher on burns than unburned areas, suggesting that the expected increase in biomass following burning may not have peaked. By the second summer following burning, satellite imagery (NDVI) confirmed that plant biomass on burns was higher. There was always more forage on south-facing sites (Richards, Townsley) than west-facing sites (Nevis, Luckhurst). In terms of forage quality, digestibility increased following burning in both summer and winter, and was highest 1 year after burning. Crude protein was higher in the new growth on burns in late winter after the fire, but returned to pre-burn levels by 1 year after burning. The availability of high-quality forage for

Table 1. Summary of vegetation response to 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.

Vegetation characteristic	Response to prescribed burning
Forage quantity	
Biomass	Scale-dependent. Differences between burns and unburned areas were not detected at the scale of the 50-m transect by 1 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 burns than unburned areas. Forage biomass was always higher on south-aspect sites than west-aspect sites.
Green-up	Forage green-up was earlier on burned sites than unburned sites and was less hindered by litter.
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 rebounded almost to unburned levels by 1 year after burning.
Forage quality	
Crude protein	Crude protein increased in the new growth on burns, but declined to pre-burn levels by 1 year after burning.
Digestibility	Forage digestibility increased on burns, was highest 1 year after burning, and was higher on burns than unburned areas.
Available forage (quantity × quality)	Available digestible protein and digestible dry matter per unit area were higher on south-aspect sites than west-aspect sites. Because of variation among sites and across elevation gradients, there was no statistical difference between burns and unburned areas the year of burning and 1 year after burning.

ungulates (quantity × quality) was higher on south-aspect sites than west-facing sites.

With the reduction in shrubs following prescribed fire, herbaceous cover increased (Table 1). Fire reduced species diversity in the year of the burn, but by 1 year after burning, species diversity increased to almost that of unburned areas. There was no introduction of invasive species (Sittler 2013), which can out-compete native plants and have detrimental effects on forage quality in winter for ungulates (Kohl et al. 2012).

Stone's sheep and elk were the two species that used burned slopes most, based on pellet counts and animal distribution flights. Table 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). Burns had more use by these two species than unburned areas at both scales.

Table 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 burns in fall, winter and late winter. Burns were most important in winter and late winter. The proportional use of burns, averaged across individuals, was highest in late winter when 46% of Stone's sheep locations were on 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 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 burns, averaged across individuals, was highest in late winter when 80% of elk locations were 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 areas. Larger groups were observed in winter than summer.

Stone's sheep used higher elevations most, whereas elk use was distributed across elevations. For Stone's sheep, use of burns was highest at the end of the first winter (late May) after burning and in the following summer. Among sites, use was highest post-burn on Luckhurst, which had the highest burn severity and consequently the lowest shrub and forage cover as well as the lowest availability of digestible forage. This site, however, had the highest crude protein values because new forage emerged sooner at the end of winter. Stone's sheep are able to selectively forage on the most nutritious parts of plants even in low-biomass areas (Seip et al 1985a, 1985b), unlike elk that require much larger amounts of forage. Highest use of burns by elk was on the south-facing sites (Richards, Townsley) with the highest forage biomass.

Throughout the year, both species always selected for south aspects and usually selected to be close to a burn. Stone's sheep selected to be on the New burn, Burn grass, or Burn shrub classes in fall, winter and late winter. Elk selected to be on burns in every season, with highest selection for the Burn shrub class

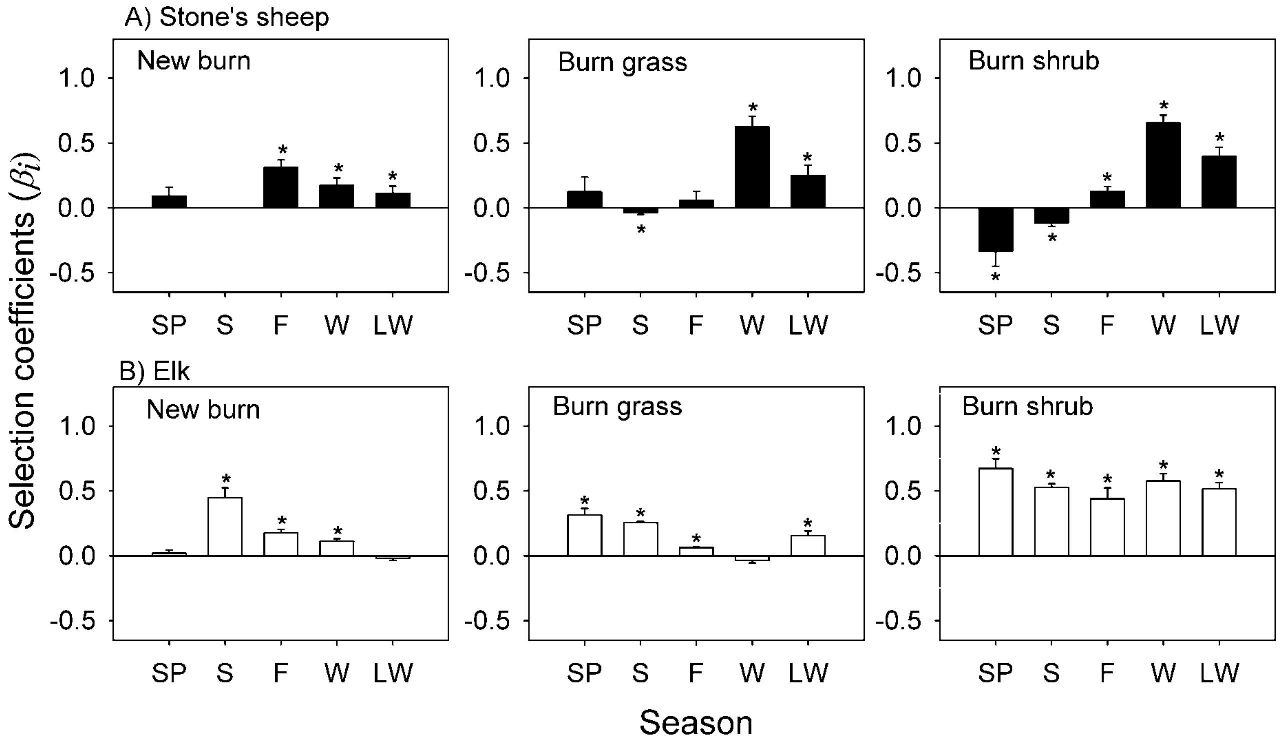

Figure 2. Selection coefficients ($\beta_i \pm$ SE) for the three burned land-cover classes (New burn, Burn grass, Burn shrub) from the best global resource selection models by season for GPS-collared female Stone's sheep (A) and elk (B) in the Besa-Prophet area of northern British Columbia. Positive β_i indicates selection for burns; negative β_i indicates selection against burns. SP = spring, S = summer, F = fall, W = winter, and LW = late winter. * indicates seasonal β_i is different from zero based on 95% confidence intervals.

(Figure 2). Stone's sheep most often used younger burns (<3 years old), whereas elk commonly used burns of all ages (1-28 years).

Even with this selection for burns and being close to a burn, most locations of collared Stone's sheep were in rocky areas, in contrast to elk that rarely used them. The relative importance (use × availability scaled to 1.0) of these two land-cover classes is shown in Figure 3. Prescribed burns were most important to Stone's sheep in winter and late winter. Rocky areas were always important, especially during seasons when burns were least important (Figure 3A). Prescribed burns were more important than other cover classes in every season for elk and rocky areas were not of high importance (Figure 3B).

The highest probability of overlap in the selection and use of burns by Stone's sheep and elk was in winter and late winter, but the two species partitioned the landscape through their differential use of elevation and topography. Stone's sheep always used steeper slopes and higher elevations than elk, and selected for rugged terrain. When elk used steep slopes, they were typically at lower elevations (Figure 4). When elk occasionally used more rugged terrain, they also were at

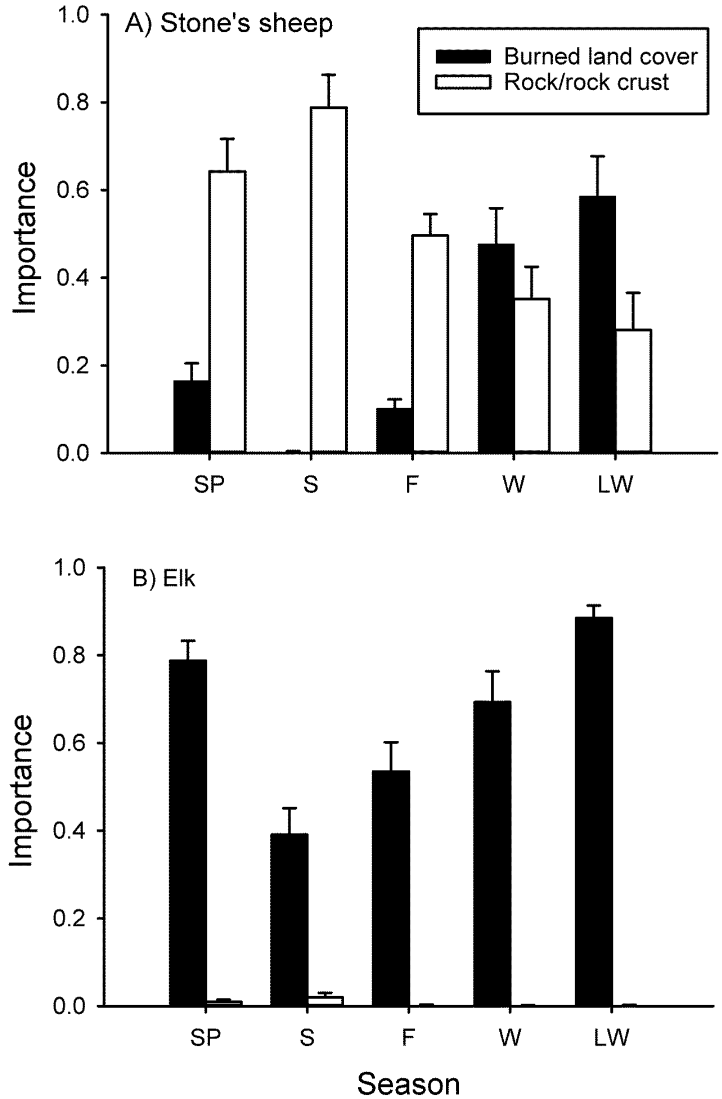

Figure 3. Seasonal importance (use × availability scaled to 1.0, $\overline{X}$ ± SE) of burned land-cover classes (New burn, Burn grass, Burn shrub) and Rock/rock crust land cover for GPS-collared female Stone's sheep and elk in the Besa-Prophet area in northern British Columbia between 2010–2012. Averages from each individual in each season were used to calculate means and standard errors. SP = spring, S = summer, F = fall, W = winter, and LW = late winter

lower elevation than Stone's sheep. Most ungulates must balance the need to meet nutritional requirements through forage with the risk of predation. Availability of escape terrain, consisting of solid-rock features or talus slopes is a well-recognized component of wild sheep habitat (Bleich et al. 1997, Rachlow and Bowyer 1998). Stone's sheep use rocky areas to reduce the risk of predation. In the food-risk trade-off, food becomes increasingly important from fall through late winter (Walker et al. 2007) and Stone's sheep take advantage of the forage on prescribed burns (Figure 3A). In spring during lambing, risk outranks food. As summer progresses, lambs become less vulnerable and the importance of food increases. Stone's sheep show strong site fidelity and philopatry to their seasonal ranges (Seip and Bunnell 1985b).

Elk also show site fidelity to particular ranges (Craighead et al. 1972, Edge et al. 1986). We expected that elk would travel long distances to use new burns, but this was not the case. Several collared individuals spent all year on older burns, even when they had access to new burns nearby. The predator avoidance strategies of elk rely on the ability to detect danger at a distance, giving them time to retreat to safer terrain when needed (White et al. 2009). Prescribed burns increase visibility, and the Burn shrub areas provide excellent foraging opportunities for elk as well as some cover. For both elk and Stone's sheep, grouping behaviour (outside of the calving/lambing period) also serves as an anti-predation strategy because larger groups increase the ability to detect predators. We observed largest groups of both species on burns in winter.

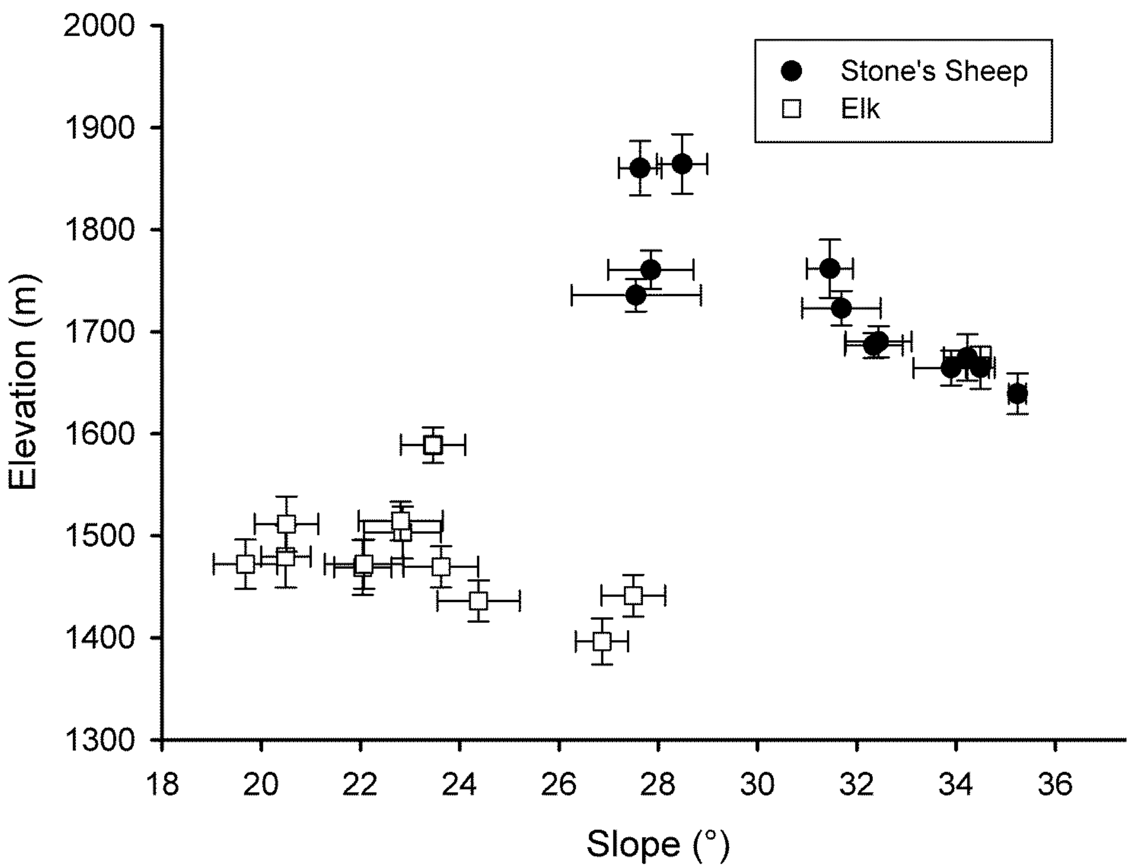

Figure 4. Niche partitioning of elevation and slope ($\bar{x}$ ± SE) by GPS-collared female Stone's sheep and elk in the Besa-Prophet area of northern British Columbia. Individual averages were calculated monthly and averaged across individuals to obtain means and standard errors.

Conclusions & Recommendations

Our findings provide insights into the short-term vegetation dynamics and ungulate response to prescribed fire in a mountainous region of the northern Rockies. They also provide a baseline for long-term monitoring of the effectiveness and impacts of prescribed burning in northeastern BC.

Winter range and season for prescribed burning

Stone's sheep in the Besa-Prophet area showed the highest use and selection for burns in winter and late winter. This is consistent with other studies for Stone's sheep (Walker et al. 2007) and bighorn sheep (*Ovis canadensis*; Greene et al. 2012). Prescribed burning to enhance Stone's sheep populations should place conserving and enhancing winter and late winter range as the highest priority. Peck and Peek (1991) observed highest use of burns by elk in drainages north of the Besa-Prophet area during winter, and in our study, elk used burns in every season. Even without higher protein levels in late-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*a*).

Prescribed burning that targets winter range should be conducted in spring. Spring burning results 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). Although there has been some success from fall fires to increase habitat value (Merrill et al. 1980), 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). Fall fires also are typically larger and more intense (Holl et al. 2012).

Frequency of burning – based on forage quality and quantity

The length of time that burned areas remain beneficial to grazing ungulates is unknown. When Stone's sheep used burns, they were most often younger burns with increased nutritional quality. Forage quality, however, deteriorates with time (Van Dyke 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 and fewer lungworm parasites 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). Therefore, 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 showed less preference for the age of a burn. Other studies though have shown that forage biomass increases and persists for a longer time than forage quality (Singer and Harter 1996, Sachro et al. 2005), which may be of most benefit to elk.

Thus, there is a need for long-term monitoring of plant response to fire in the Besa-Prophet area. The permanent transects on the four burns and four unburned areas (at Richards, Townsley, Nevis, and Luckhurst sites) should continue to be revisited to monitor longer term changes in vegetation. Also, there are 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. The locations of permanent transects and range exclosures that we installed to measure long-tern impacts of herbivore use are given in Sittler (2013).

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 known to produce high quantities of forage. The Richards burn provided the highest forage biomass and the large area enabled largest congregations of animals. Even though both Stone’s sheep and elk used this burn in winter and late winter, they partitioned their use of it spatially. Implementing large burns from the valley bottom to the alpine would enable both species to benefit from the burn, and at current population densities, minimize the potential for competition.

Smaller fires result in lower amounts of burned habitat, but increase heterogeneity on the landscape. As demonstrated by high use of the Luckhurst burn, small 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 the desired result of reducing shrubs and increasing forage quality, prescribed burning on west-aspects should be implemented late in spring to obtain high burn 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, 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 because of heavy snow accumulation. These areas provide less benefit to ungulates and if the objective is to enhance ungulate habitats, burning north-aspect slopes would be inefficient.

Dynamics of the large-mammal assemblage

There is a need for long-term monitoring of animal response to fire in the Besa-Prophet area. The findings of our study suggest that there is not currently a conflict for space or forage between Stone's sheep and elk, as they appear to partition their use of the landscape based on elevation, slope, and ruggedness. However, we have not quantified the longer-term demographic effects of fire or changing predator-prey dynamics. Additional studies should focus on population estimates and distributions of target ungulates, primarily elk, moose, and Stone's sheep. Continued increases in the elk population could increase the potential for competition with Stone's sheep if elk move into the traditional areas of Stone's sheep in response to the early seral habitats created by fire, and the potential for apparent competition (by facilitating the increase of shared predators) even if elk do not alter their distribution. There is some seasonal overlap between elk and moose in the Besa-Prophet area (Gillingham and Parker 2008) and if the elk population continues to expand, it could potentially come at a cost, not only to Stone's sheep but also to moose. Caribou in the Besa-Prophet area appear to avoid burned areas in all seasons (Gustine and Parker 2008), but because they are a far-ranging species potentially affected by any disturbance on the landscape, their populations should also be monitored in light of changes in predator-prey dynamics. Just south of the Besa-Prophet area, the Sikanni Valley is the northern boundary of the largest free-ranging herd of plains bison (*B. b. bison*) in BC. 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. If the bison population expands northwards, it may impact native grasses as well as compete spatially with moose, elk, and Stone's sheep.

Management actions of prescribed fire typically alter ungulate distributions. The benefits of fire are likely facilitating numerical and spatial expansion of elk, which now provide the largest biomass of prey in the Besa-Prophet ecosystem. Predator populations are 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 or changing predation opportunities.

References

Archibald, S., W.J. Bond, W.D. Stock, and H.K. Fairbanks. 2005. Shaping the landscape: Fire-grazer interactions in an African savanna. *Ecological Applications* 15: 96-109.

Backmeyer, R., D. Culling, and B. Culling. 1992. *Peace Sub-Region Prescribed Burning Program Evaluation.* Prepared for British Columbia Ministry of Environment, Fort St. John, BC. 88 pp.

Bleich, V.C., R.T. Bowyer, and J.D. Wehausen. 1997. Sexual segregation in mountain sheep: resources or predation? *Wildlife Monographs* 134: 3–50.

Burnham, K.P., and D.R. Anderson. 2002. *Model Selection and Inference: A Practical Information-Theoretic Approach*. 2nd ed. Springer-Verlag, New York, NY, USA.

Craighead, J.J., G. Atwell, and B.W. O'Gara. 1972. Elk migrations in and near Yellowstone National Park. *Wildlife Monographs* 29: 3–48.

Edge, W.D., C.L. Marcum, S.L. Olson, and J.F. Lehmkuhl. 1986. Nonmigratory cow elk herd ranges as management units. *Journal of Wildlife Management* 50: 660–663.

Gillingham, M.P., and K.L. Parker. 2008. Differential habitat selection by moose and elk in the Besa-Prophet Area of Northern British Columbia. *Alces* 44: 41–63.

Greene, L., M. Hebblewhite, and T.R. Stephenson. 2012. Short-term vegetation response to wildfire in the eastern Sierra Nevada: Implications for recovering an endangered ungulate. *Journal of Arid Environments* 87: 118–128.

Gustine, D.D., and K.L. Parker. 2008. Variation in seasonal selection of resources by woodland caribou in northern British Columbia, Canada. *Canadian Journal of Zoology* 86: 812–825.

Hatten, J., D. Zabowski, A. Ogden, W. Theis, and B. Choi. 2012. Role of season and interval of prescribed burning on pondersa pine growth in relation to soil inorganic N and P and moisture. *Forest Ecology and Management* 269: 106–115.

Hobbs, N.T., and R. Spowart. 1984. Effects of prescribed fire on nutrition of mountain sheep and mule deer during winter and spring. *Journal of Wildlife Management* 48: 551–560.

Holl, S.A., V.C. Bleich, B.W. Callenberger, and B. Bahro. 2012. Simulated effects of two fire regimes on bighorn sheep: the San Gabriel Mountains, California, USA. *Fire Ecology* 8: 88–10.

Hope, A., C. Tague, and R. Clark. 2007. Characterizing post-fire vegetation recovery of California chaparral using TM/ETM+ time series data. *International Journal of Remote Sensing* 28: 1339–1354.

Johnson, E.A., K. Miyanishi, and J.M.H. Weir. 1998. Wildfires in the western Canadian boreal forest: landscape patterns and ecosystem management. *Journal of Vegetation Science* 9: 603–610.

Jourdonnais, C.S., and D.J. Bedunah. 1990. Prescribed fire and cattle grazing on an elk winter range in Montana. *Wildlife Society Bulletin* 18: 232–240.

Kohl, M.T., M. Hebblewhite, S.M. Cleveland, and R.M. Callaway. 2012. Forage value of invasive species to the diet of Rocky Mountain elk. *Rangelands* 34: 24–28.

Lay, R.J. 2005. *Use of Landsat TM and ETM+ to Describe Intra-Season Change in Vegetation with Consideration for Wildlife Management.* Thesis. University of Northern British Columbia, Prince George, BC.

Lousier, J.D., J. Voller, R.S. McNay, R. Sulyma, and V. Brumovsky. 2009. Response of wildlife to prescribed fire in the Peace Region of British Columbia: A problem analysis. *Wildlife Infometrics Inc. Report* No. 316. Wildlife Infometrics Inc., Mackenzie, BC. 90 pp.

Meidinger, D., and J. Pojar. 1991. *Ecosystems of British Columbia*. Special Report No. 6. British Columbia Ministry of Forests, Victoria, BC. 330 pp.

Merrill, E.H., H.F. Mayland, and J.M. Peek. 1980. Effects of fall wildfire on herbaceous vegetation on xeric sites in the Selway-Bitteroot Wilderness, Idaho. *Society for Range Management* 33: 363–367.

Milakovic, B. 2008. *Defining the Predator Landscape of Northeastern British Columbia*. Dissertation. University of Northern British Columbia, Prince George, BC. 251 pp.

Owensby, C.E., and K.L. Anderson. 1967. Yield response to time of burning in Kansas Flint Hills. *Journal of Range Management* 20: 12–16.

Peck, R.V., and J.M. Peek. 1991. Elk, *Cervus elaphus*, habitat use related to prescribed fire, Tuchodi River, British Columbia. *Canadian Field Naturalist* 105: 354–362.

Peek, J.M., R.A. Riggs, and J.L. Lauer. 1979. Evaluation of fall burning on bighorn sheep winter range. *Journal of Range Management* 32: 430–432.

Rachlow, J.L., and R.T. Bowyer. 1998 Habitat selection by Dall's sheep (*Ovis dalli*): maternal trade-offs. *Journal of Zoology* 245: 457–465.

Sachro, L., W. Strong, and C. Gates. 2005. Prescribed burning effects on summer elk forage availability in the subalpine zone, Banff National Park, Canada. *Journal of Environmental Management* 77: 183–193.

Seip, D.R., and F.L. Bunnell. 1985*a*. Foraging behaviour and food habits of Stone's sheep. *Canadian Journal of Zoology* 63: 1638–1646.

Seip, D.R., and F.L. Bunnell. 1985*b*. Nutrition of Stone's sheep on burned and unburned ranges. *Journal of Wildlife Management* 49: 397–405.

Shackleton, D. 2013. *Hoofed Mammals of British Columbia*. 2nd ed. Royal British Columbia Museum, Vancouver, BC, Canada.

Singer, F.J., and M.K. Harter. 1996. Comparative effects of elk herbivory and 1988 fires on northern Yellowstone National Park grasslands. *Ecological Applications* 6: 185–199.

Sittler, K.L. 2013. *Influence of Prescribed Fire on Stone's Sheep and Rocky Mountain Elk: Forage Characteristics and Resource Separation*. Thesis. University of Northern British Columbia, Prince George, BC. 182 pp.

Stewart, K., R.T. Bowyer, J. Kie, N. Cimon, and B. Johnson. 2002. Temporospatial distribution of elk, mule deer, and cattle: resource partitioning and competitive displacement. *Journal of Mammalogy* 83: 229–244.

Stewart, K.M., R.T. Bowyer, J.G. Kie, and M.A. Hurley. 2010. Spatial distribution of mule deer and North American elk: resource partitioning in a sage-steppe environment. *American Midland Naturalist* 163: 400–412.

Turner, M.G., W.H. Romme, R.H. Gardener, and W.W. Hargrove. 1997. Effects of fire size and pattern on early succession in Yellowstone National Park. *Ecological Monographs* 67: 411–433.

Van Dyke, F., and J. Darragh. 2007. Response of elk to changes in plant production and nutrition following prescribed burning. *Journal of Wildlife Management* 71: 23–29.

Walker, A.B.D., K.L. Parker, M.P. Gillingham, D.D. Gustine, and R.J. Lay. 2007. Habitat selection by female Stone's sheep in relation to vegetation, topography, and risk of predation. *Ecoscience* 14: 55–70.

White, P. J., R. . Garrott, S. Cherry, F.G.R. Watson, C.N. Gower, M.S. Becker, and E. Meredith. 2009. Changes in elk resource selection and distribution with the reestablishment of wolf predation risk. Pages 451–476 *in* R.A. Garrott, P.J. White, and F.G.R. Watson, editors. *The Ecology of Large Mammals in Central Yellowstone: Sixteen Years of Integrated Field Studies.* Academic Press, San Diego, CA, USA.

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