# MOOSE USE OF THE MOUNT MCALLISTER BURN IN NORTH-CENTRAL BRITISH COLUMBIA: INFLUENCE OF BURN SEVERITY AND SOIL MOISTURE

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ABSTRACT: The influence of recent wildfires in British Columbia (BC) on moose habitat and its use by moose are understudied, as are prescribed burning strategies that can be used to enhance moose habitat. Our objective was to investigate how 3 classes of fire severity (high, medium, low) interact with 3 soil moisture regimes (hydric, mesic, xeric) in determining how moose use post-fire habitat. In north-central BC, we studied moose use at 2 different spatial levels in the 5-year-old, 26,500 ha Mt. McAllister burn. At the site level, we estimated the density of fecal pellet groups and the percent of plants browsed by moose within plots of varying burn severity and soil moisture. At the landscape level, we investigated use from GPS locations of 7 radio-collared female moose at 3 orders of selection: we compared: 1) randomly distributed locations within the home range to randomly distributed locations throughout the entire burn (2nd order of selection); 2) use locations to randomly distributed potential locations within the home range (3rd order of selection); and daily use locations with potential movement locations (4th order of selection). At the site level, moose used areas of low/medium fire severity and hydric soil moisture. At the landscape level, moose preferred areas of medium fire severity at the daily order, and low/medium fire severity at both the home range and burn orders of selection. Our findings highlight that moose use of post-fire habitat varied by spatial scale and by order of selection and that researchers assessing use of burns by moose should consider multiple levels of investigation. Prescribed burning to enhance moose habitat should focus on low/medium fire severity at sites with mesic soil moisture.

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**Key words:** *Alces alces*, burn, burn severity, forest fire, habitat, habitat management, moose, selection, soil moisture

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Moose (*Alces alces*) are an important component of the predator-prey dynamic in northern British Columbia (BC) as they constitute a large portion of prey biomass, making them an important keystone species (Gillingham and Parker 2008). Moose are also a valued resource for First Nations, for sustenance and ceremonial purposes and an important part of the big-game harvest for resident hunters and guide outfitters (Gorley 2016). Recent surveys performed by the Ministry of Forests, Lands, Natural Resource, Operations and Rural Development (MFLNRORD) estimate the current (2018) moose population in BC at 120,000–205,000, a decline of ~25,000–35,000 since 2014 (MFLNRORD 2018). This decline is concerning to the public, land and resource users, and natural resource managers; as a result, population monitoring is part of the strategic approach in management and decision-making (Kuzyk et al. 2018a, Sittler and McNay 2018). Reasons for the decline are complex, vary regionally, and often interrelated and include altered habitat due to logging and mining, predation, and climate change (Gorley 2016, Kuzyk et al. 2018b, Sittler 2020).

Wildfire is a natural disturbance that alters moose habitat in the short and long-term by resetting vegetative communities to an early successional stage (Johnson and Hale 2002). Wildfires in BC are becoming more frequent, larger, and often more severe, presumably due to increased temperatures, drier conditions, and a record high Build Up Index or the total amount of fuel available for combustion (BCWS 2018). With the exception of moose densities remaining unchanged prior to and after the Plateau Fire in the Cariboo Region (MFLNRORD 2018), there is minimal information about the influence of larger and more severe wildfires on population demographics and habitat use by moose in the Province.

Prescribed fire was used frequently by First Nations as a management tool to clear land for agriculture and manipulate movement of wildlife into desirable hunting locations (Johnson and Hale 2002); more recently, fire is used to improve forage condition for free-ranging cattle (Johnson and Hale 2002, Dixon et al. 2018). The same principle is now applied to enhance availability and abundance of moose forage (Goddard 2011). Many factors influence post-fire revegetation including pre-fire species composition, timing of the fire (i.e., time-since fire and season), fire intensity and frequency, and size of the burn (MacCracken and Viereck 1990).

There has been little consideration of how best to conduct prescribed burns to achieve efficiently the most desirable effects for moose. For example, the site series characteristics of soil moisture and soil nutrient regime influence plant species composition and abundance within a site (Meidinger and Pojar 1991). Pre-fire vegetative composition, site series, and season are interrelated and must be considered together to optimize management objectives. Fire severity is more influenced directly by fire intensity than indirectly by soil moisture (Keeley 2009), although post-fire vegetative regrowth will be influenced by both.

We examined how fire severity interacts with soil moisture to influence habitat use by moose within the Mount McAllister burn in northeastern BC. Using moose fecal pellet and browse data at the site level and GPS locations of collared female moose at the landscape level, we tested a null hypothesis that moose equally use sites of varying burn severity, soil moisture, and browse composition. Our objectives were to determine habitat use response to the interaction between burn severity and soil moisture, and provide related management information about the value of post-fire habitats for moose and the value of prescribed burning.

## STUDY AREA

We studied the Mt. McAllister burn (hence forth “the burn”) because of its varying classes of burn severity and the availability of location data from GPS-collared moose using the burn. Located 56 km west of Chetwynd, BC, the fire started on the southeast-facing slope of Mt. McAllister and was ~26,280.8 ha in size (Fig. 1). According to the British Columbia Wildfire Service, the fire was detected 13 July 2014 by tanker groups actioning nearby fires and was caused by lightning. We assumed that natural vegetative succession was sufficient to produce an abundance of moose forage, and therefore provide useful information about prescribed burn management for moose.

The major drainage is the Peace River, located 30 km north of the burn, with multiple creeks (Dowling Creek, Johnson Creek, McAllister Creek, and Gething Creek) surrounding and running through the burn and

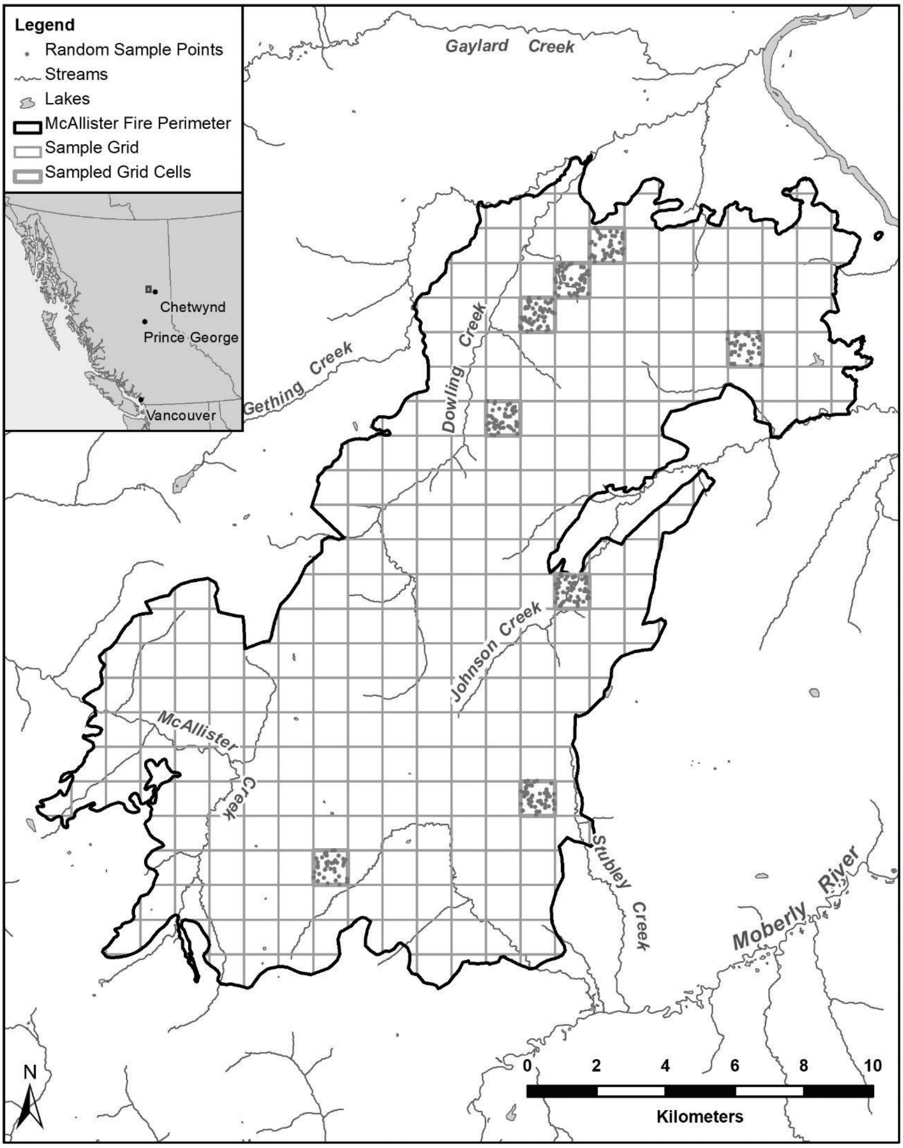

Fig. 1. Mt. McAllister burn study area in north-central British Columbia with 1 km$^2$ sample blocks (grey grid). Sampled blocks are outlined in bold and corresponding sample plots within those blocks are shown as dots.

draining into the Peace River; elevation ranges from 502 to 2,309 m. Biogeoclimatic zones within the burn are Engelmann Spruce-Subalpine Fir (ESSFmv2) at higher, Sub-boreal Spruce (SBSwk2) at middle, and Boreal White and Black Spruce (BWBSwk2) at lower elevation (Meidinger and Pojar 1991). Prior to the fire, forests were composed of a mixed overstory canopy of white spruce (*Picea glauca*) and subalpine fir (*Abies lasiocarpa*), and an understory of willow (*Salix* spp.), paper birch (*Betula papyrifera*), and trembling aspen (*Populus tremuloides*). Throughout the study area there were a series of clearcuts of varying age planted with lodgepole pine (*Pinus contorta* subsp. *latifolia*) and white spruce.

The nearby moose population density was estimated as 0.44 moose/km$^2$ in 2018 (Sittler and McNay 2018), a small decline from 0.50 moose/km$^2$ in 2013 (Lirette 2013). Other ungulates that occupy the area in and around the burn include caribou (*Rangifer tarandus*), elk (*Cervus canadensis*), white-tailed deer (*Odocoileus virginianus*), and mule deer (*O. hemionous*) (Shackleton 2013). Potential predators of these ungulates are grey wolf (*Canis lupus*), black bear (*Ursus americanus*), grizzly bear (*U. arctos*), cougar (*Puma concolor*), and wolverine (*Gulo gulo*) (Hatler et al. 2018).

## METHODS

### Site Level

We chose to use random plot-based sampling over investigating individual locations of radio-collared moose (see below) to gain more geographic precision than remote telemetry. To examine the use of burned sites by moose, we generated a layer of potential sample blocks from a 1km$^2$ grid in ArcGIS (Fig. 1). Within that layer we assessed: 1) variation in burn severity using a post-burn image captured by Landsat 8 Operational Land Imager (OLI), and 2) frequency of use by moose using imported locations from GPS-collared cow moose (see below). We identified blocks with a range of burn severity (low, medium, high) and high use by moose for potential sampling; no unburned areas were surveyed or used as controls. We then selected 5 sample blocks that were road and helicopter accessible and that fit within budgetary and logistical constraints of the project. A power-of-test conducted after the first year led us to increase the number of blocks in year 2 to achieve a more robust sample (n = 8, Fig. 1). Within those blocks, we identified 50 sample plots (radius = 3.99 m; Saether and Andersen 1990) distributed randomly and spaced ≥ 20 m apart using the random points in polygons tool in ArcGIS (Fig. 2). The random sample plots were the basis for addressing our objectives at the site level by assessing the response variable (use by moose) and the independent predictor variables (burn severity and soil moisture) within each plot.

We visually classified burn severity (low, medium, high) of each plot using a modified composite Burn Index (Key and Benson 2003) by estimating the presence or absence of leaves, needles, and branches to assess the extent of burning in the upper and lower canopy trees. We also estimated the amount of organic material remaining below the newly distributed leaf litter. To estimate relative soil moisture, we dug a 30 cm radius x 60 cm deep soil pit at plot center to assess soil moisture (hydric, mesic, xeric), texture, and nutrient regime (Weil and Brady 2017).

To estimate use by moose at the site level, we measured the density of fecal pellet groups in each plot and the proportion of plants browsed by moose; both are reliable indicators of habitat use (Mansson et al. 2007, 2011). We searched for pellet groups (≥ 5 individual pellets) in the main 3.99 m plot and within 4 subplots of equal size established in each cardinal direction immediately adjacent to the main plot boundary. Pellet density (groups/m$^2$) equaled the number of pellet groups divided by subplot area. To correct for visibility bias associated with obstructions (e.g., downed trees), we corrected proportionally for the estimated amount of obstructed area.

We measured 4 primary (preferred) forage species in each plot: willow, trembling aspen, subalpine fir, and paper birch (Goddard 2003). We did not measure the amount of shoots browsed on individual plants; rather, plants were classified as browsed or not. To estimate percentage browsed, we visually assessed the proportion of plants browsed and multiplied it by

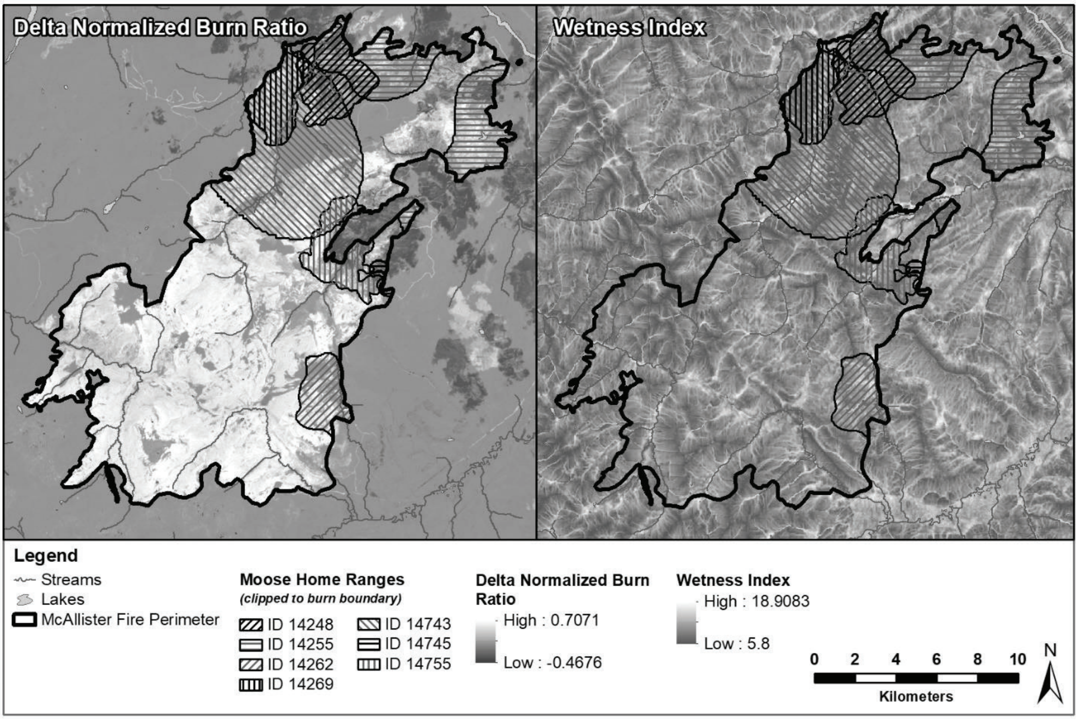

Fig. 2. McAllister burn perimeter with 6 moose home ranges overlapping the burn. The image on the left depicts the delta normalized burn ratio used to determine the level of fire severity, and the image on the right depicts the SAGA wetness index used to determine level of soil moisture.

the proportion available for each preferred forage species:

*Plants browsed (%)*

$$= \sum_{i=1}^{4} \left( PB_i \times PC_i \,| \right) \times 100\% \qquad \text{(Eq. 1)}$$

where *i* was each of 4 preferred browse species, $PB_i$ was a visual estimate of the proportion of total amount of species *i* that showed signs of browsing, and PC*i* was a visual estimate of the proportion of the three-dimensional plot space occupied by species *i*. For example, if there were 10 shrubs in a plot and 5 were browsed, the percentage browsed was 50%.

## Collared Moose

We assessed location data (collected once daily at 0900 hr, February 2018 – January 2019) from 42 GPS-collared female moose that were part of a larger project examining limiting factors in the area (Sittler and McNay 2017). We identified animals using the burn by estimating the combined seasonal and annual home ranges of individual moose with a 95% kernel density estimator (Seaman et al. 1999, Healy et al. 2018) in ArcMap (ESRI 2015). Although ranges of 10 moose overlapped the burn, 3 animals with minimal use (< 20% locations) were discarded; sample size was 7 animals with 874 locations (mean = 125/animal; SD = 75; Table 1). Five of 7 used the burn in all seasons and were considered resident; 2 were migratory using the burn only during winter.

## Landscape Level

We considered all area within the fire perimeter as having been burned. We used

Table 1. Summary of moose GPS locations from 2018 to 2019 that overlapped the Mt. McAllister burn. Average percentages are weighted by the home range area within the burn. HRTot represents the total area in ha of moose home range, HRBurn is the total area in ha of moose home range that overlaps the burn perimeter, HRInBurn is the percentage of moose home range in the burn, PtsTot represents the number of GPS locations for each moose, PtsBurn are the GPS locations for each moose within the burn perimeter, and PtsInBurn is the percentage of GPS locations for each moose within the burn.

| Animal | HRTot (ha) | HRBurn (ha) | HRInBurn (%) | PtsTot | PtsBurn | PtsInBurn (%) |
|---|---|---|---|---|---|---|
| 14,248 | 1,228 | 1,201 | 98 | 270 | 270 | 100 |
| 14,255 | 6,343 | 2,531 | 40 | 294 | 128 | 44 |
| 14,262 | 1,160 | 732 | 63 | 263 | 128 | 49 |
| 14,269 | 2,112 | 843 | 40 | 206 | 70 | 34 |
| 14,743 | 11,646 | 4,328 | 37 | 194 | 44 | 23 |
| 14,745 | 232 | 81 | 35 | 257 | 76 | 30 |
| 14,755 | 1,208 | 914 | 76 | 250 | 158 | 63 |
| Total | 23,929 | 10,630 |  | 1,734 | 874 |  |
| Average | 3,418 | 1,519 | 50 | 248 | 125 | 43 |
| SD | 4,141 | 1,445 | 24 | 36 | 75 | 26 |

the GPS location data to determine habitat use by moose within the burn at three standard orders of selection (*sensu* Johnson 1980); hence, referring to this as the landscape-level focus. First, we used second-order selection to compare home ranges within the burn to the entire burn using points within the home range and random points placed every 2 ha; hereafter, burn order. Next, we used third-order selection to compare use locations to available locations within the home range randomly placed every 2 ha; hereafter, home range order. Finally, we assessed habitat use with daily movements; hereafter, fourth-order selection or daily order. Each animal's potential daily movement was estimated following methods of Sittler (2020) by placing a circular buffer around each daily use location in a GIS. A season-specific buffer radius was determined using the 95th-percentile of distances traveled by individuals between consecutive daily locations within each season. We then selected 5 random locations within each buffered use location (4370 points total). Seasons were defined in Sittler (2020) with consideration of normal behavioral changes (Gillingham and Parker 2008, Heard et al. 2013, Scheideman 2019): calving (16 Apr–15 Jun), summer (16 Jun–15 Aug), fall (16 Aug–31 Oct), winter (1 Nov–31 Jan), and late winter (1 Feb–15 Apr).

We characterized all use and random locations for each analysis with estimates of burn severity and soil moisture. To estimate burn severity, we used a delta Normalized Burn Ratio (dNBR; Crocke et al. 2005) calculated from downloaded pre-fire (11 July 2014) and post-fire (28 June 2015) images from EarthExplorer Landsat 8 OLI. We clipped and enhanced both images with a linear enhancement using PCI Geomatica software (PCI, Geomatics version 10.1, Richmond Hill, Ontario, Canada). For each image, we calculated a Normalized Burn Ratio (NBR) for each 1 ha raster pixel using the equation:

$$NBR = (NIR\ (5) - SWIR\ (7)) / (NIR\ (5) + SWIR\ (7)) \quad \text{(Eq. 2)}$$

where NIR is the near infrared band 5 and SWIR is the shortwave infrared band 7 (Crocke et al. 2005). We used QGIS software (QGIS Development Team, version 3.1, Open Source Geospatial Foundation Project) to determine the difference between attributes of the 2 images with the equation:

$$dNBR = NBRpre - NBRpost \qquad \text{(Eq. 3)}$$

where NBRpre is the reflectance values from the pre-fire image and NBRpost is the reflectance values of the post-fire image (Fig. 2).

To estimate potential soil moisture, we used a SAGA (System for Automated Geoscientific Analyses) wetness index based on a modified catchment area calculation in ArcMap (Böhner and Selige 2002) to generate soil moisture values for 1 ha raster pixels (Fig. 2). We classified both dNBR (low, medium, and high fire severity) and SAGA (hydric, mesic and xeric wetness) results by calibrating the modelled values found at each site-level field plot to our field classifications from the same plot. To apply the calibrations, we iteratively applied standard numerical classification methods (ESRI 2006) choosing the method that resulted in the most accurate correlation with our field classifications; accuracy was the number of agreements divided by total samples (Fawcett 2006). In the case of dNBR values, 72% of the cases agreed with our field classifications using cutpoints that were equidistant across the range of observed values (0.21 and 0.43). In the case of SAGA values, 62% of the cases agreed with our field classification, again using equidistant cutpoints (9 and 12). We accepted that accuracy as adequate based on consistency with standards used in other land classification systems in BC (DeLong et al. 2010).

## DATA ANALYSIS

### Site level

Pellet group density and the percentage of plants browsed were not distributed normally and could not be transformed to meet the assumptions of normality. Therefore, to test if soil moisture and fire severity influenced pellet group density and the percentage of plants browsed, we ranked the data and used a multivariate, two-factor analysis of variance; a multivariate extension of the nonparametric Friedman's test (Mottonen et al. 2003). We tested collinearity between the two dependent variables using Pearson's Partial Correlation Coefficient (Zar 2010) and although significant, there was only a weak linear relationship as indicated by the line slope ($r = 0.2$, $P = 0.009$). A post-hoc contrast of the main effects on dependent variables was conducted using the Least Significant Difference test ($P = 0.05$; Zar 2010). Significance of statistical tests were assessed at an alpha of 0.05 and all analyses were conducted using SAS version 9.1 2003 (SAS Institute Inc., Cary, North Carolina, USA).

### Landscape level

To test if fire severity and soil moisture influenced use of the burned habitats by each radio-collared moose, we used logistic regression with a logit link function to fit the binomial result (use or random) to fire severity and soil moisture as main effects. Reference classes for soil moisture and fire severity were set as xeric and high, respectively. Selection coefficients were averaged across individuals and weighted by the inverse square of the standard error, to give more weight to individuals with more precise data (Dickie et al. 2017, DeMars et al. 2019); this was repeated for the 3 orders of habitat selection. Since availability was not independent of use points in the fourth, daily order of selection, we used a conditional logistic regression (Johnson et al. 2006) for that analysis. In logistic regression, selection occurs when the function coefficient (β) is significantly different ($P < 0.05$) from zero. A positive selection (or preference), occurs when the β is significantly greater than zero (95% CI does not overlap 0) and is the likelihood of an animal selecting a given item (fire severity and soil moisture) when offered alternative choices (Beyer et al. 2010). Negative selection (avoidance) occurs when β is significantly less than zero.

## RESULTS

### Site Level

We surveyed a total of 167 vegetation plots and 835 pellet plots on 29 June – 3 July 2018 and 15–24 June 2019. The highest proportion of plots (36%; 56 of 157) was distributed in areas of low fire severity and mesic soil moisture; the lowest proportion (2%) was in areas of high fire severity and xeric soil moisture (Fig. 3). A total of 251 pellet groups were counted with their locations proportional to plot distribution across the classes of fire severity and soil moisture except in two situations: 1) at sites with high fire severity and xeric soil moisture where the proportion of pellet groups was low compared to the proportion of plots; and 2) at sites with low fire severity and hydric soil moisture where the proportion was high compared to the proportion of plots (Fig. 3).

Overall, the proportion of available forage for moose did not appear to vary across classes of fire severity and soil moisture, with mean forage availability ranging from 60 to 80% (Fig. 4). A total of 44 species were identified with willow having the highest proportion of plants browsed. The proportional distribution of plants browsed was less similar to the availability of plots than the proportional distribution of pellet groups, but illustrated a similar trend – lower

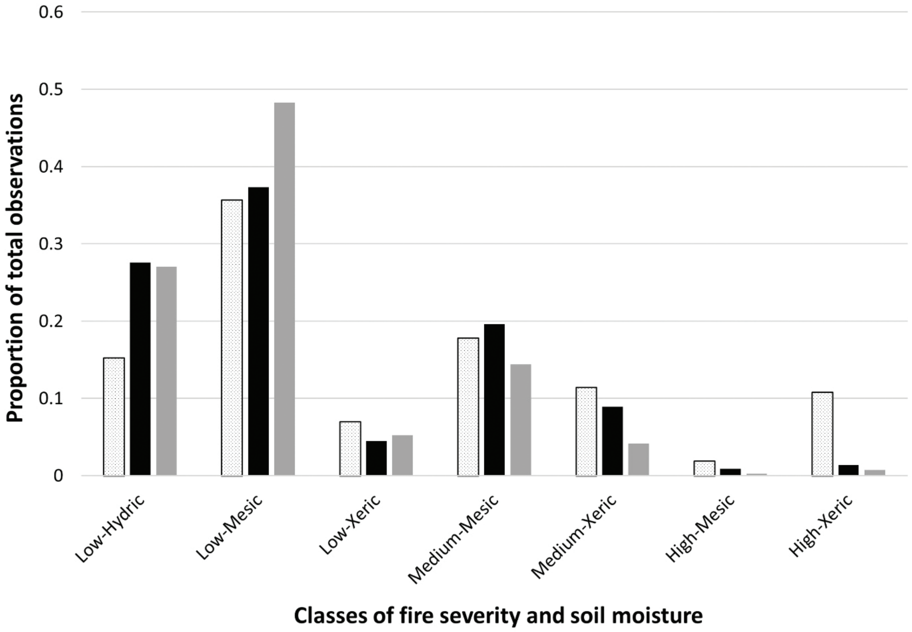

Fig. 3. The proportion of total sample plots (availability – white bars), moose pellet groups (use – filled dark bars), and percent of plants browsed (use – filled grey bars) within combined classes of fire severity (low, medium, high) and soil moisture (hydric, mesic, xeric).

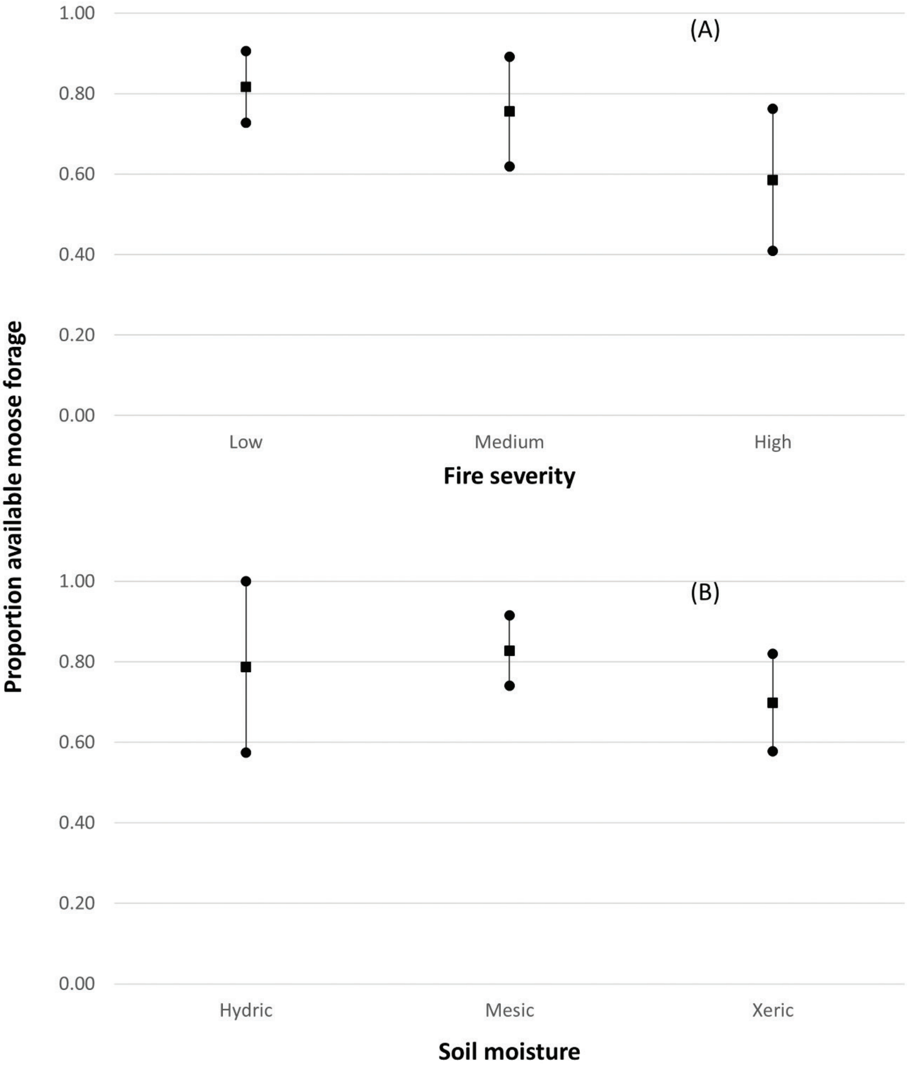

Fig. 4. The mean proportion and 95% confidence intervals of available moose forage (squares) in (A) fire severity classes (Low, Medium, High) and (B) soil moisture classes (Hydric, Mesic, Xeric) within the Mt. McAllister Burn, 2018–2019.

proportions in high fire severity and mesic and xeric soil moisture and higher proportions in low fire severity and hydric and mesic soil moisture.

Pellet group density and the percent of plants browsed varied significantly with fire severity ($F_{4,\ 302} = 4.13$, $P = 0.003$); but not with soil moisture ($F_{4,\ 302} = 2.14$, $P = 0.076$). More pellet groups were found at low and medium than high fire severity sites ($P < 0.05$; Fig. 5A); no difference was found between sites of low and medium fire severity ($P > 0.05$). Despite the lack of significance within the multivariate model, pellet group density varied significantly among the soil moisture classifications ($P < 0.05$; Fig. 5B).

Consistent with pellet group density, there was no difference ($P > 0.05$) between percentage of plants browsed on sites with

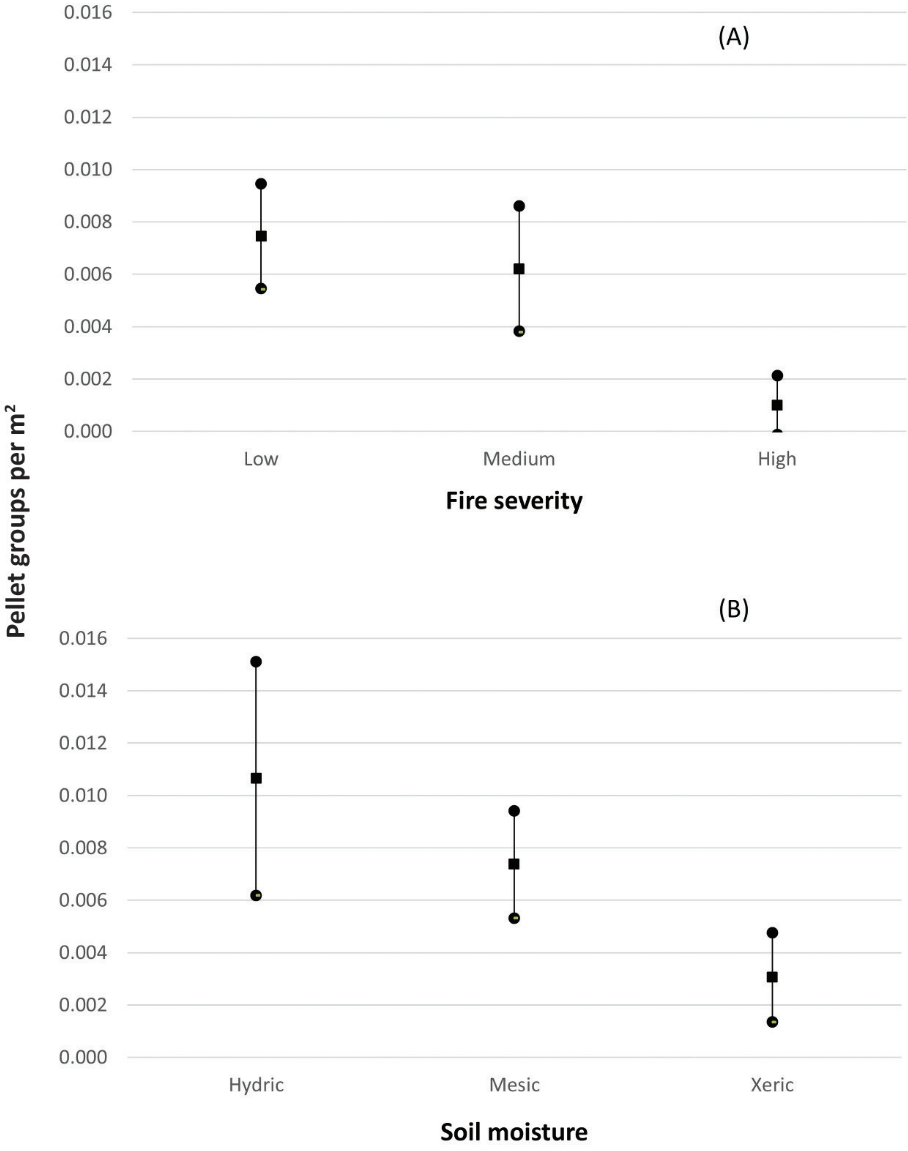

Fig. 5. The mean pellet group density (pellets/m$^2$, squares) and 95% confidence intervals in (A) fire severity classes (Low, Medium, High) and (B) soil moisture classes (Hydric, Mesic, Xeric) within the Mt. McAllister burn, 2018–2019.

low and medium fire severity, but lower browsing occurred on high fire severity sites ($P < 0.05$; Fig. 6A). Similarly, there was no significant difference between the percentage of plants browsed on hydric and mesic sites ($P > 0.05$), but a significant difference between hydric and mesic sites and xeric sites ($P < 0.05$), (Fig. 6B). Likewise, the percentage of plants browsed on hydric and mesic sites was similar ($P > 0.05$), whereas a lower percentage ($P < 0.05$) was found on xeric sites (Fig. 6B).

## Landscape Level

A total of 874 locations from the 7 moose were identified within the burn accounting

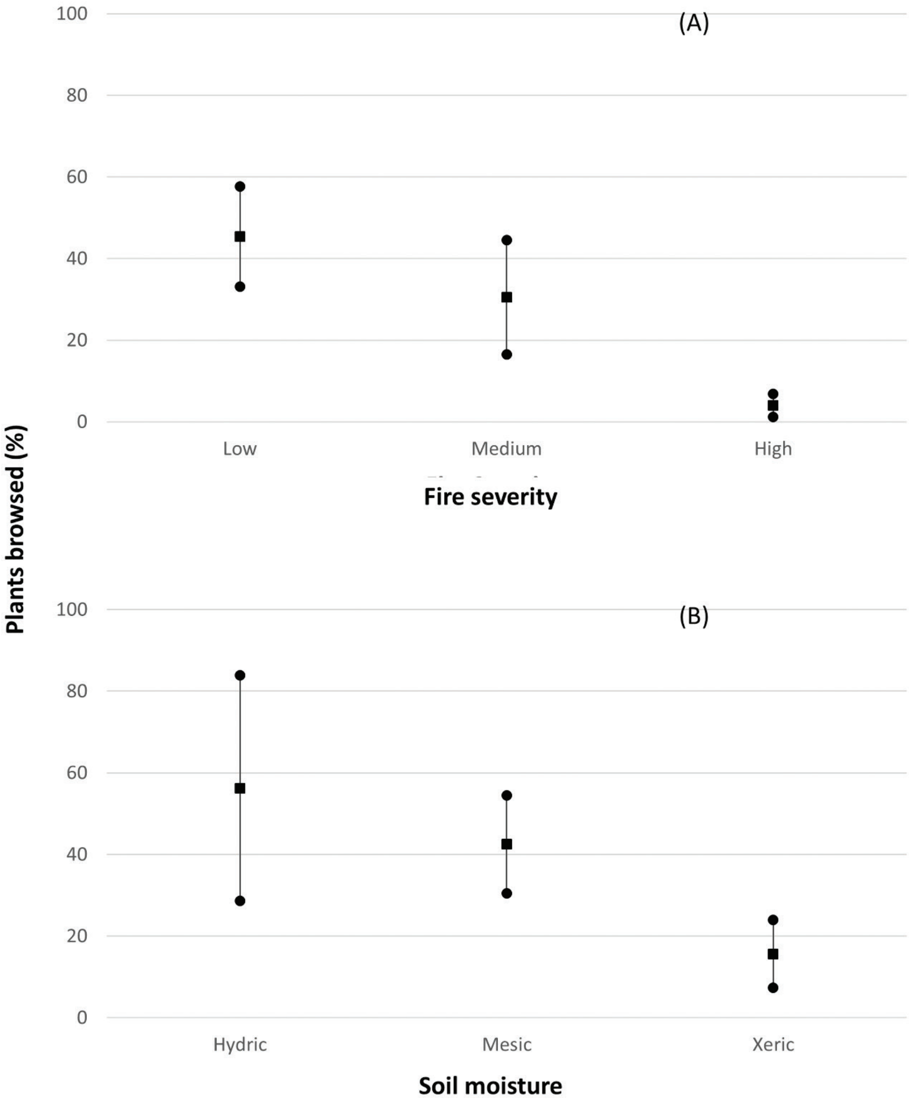

Fig. 6. The mean percent and 95% confidence intervals of plants browsed in (A) fire severity classes (Low, Medium, High) and (B) soil moisture classes (Hydric, Mesic, Xeric) within the Mt. McAllister burn, 2018–2019.

for 10,630 ha overlap of a total of 23,949 ha encompassing their entire home ranges. Home range size varied by nearly 2 orders of magnitude (~200–12,000 ha), averaging ~3,500 ha. The average overlap was 50% (range = 37–98%; Table 1).

At the burn order of selection, moose used areas of low fire severity-mesic/hydric soil moisture more than it was available (Fig. 7A); use and availability were proportional in areas of medium fire severity-mesic soil moisture (Fig. 7A). At the home range order of selection, use and availability were proportional, except in the low fire severity-hydric soil moisture areas where use was lower than availability (Fig. 7B). The proportion of use and available locations was similar in low/medium fire severity and mesic soil moisture classes, but higher than all other main effect classifications (Fig. 7B); a

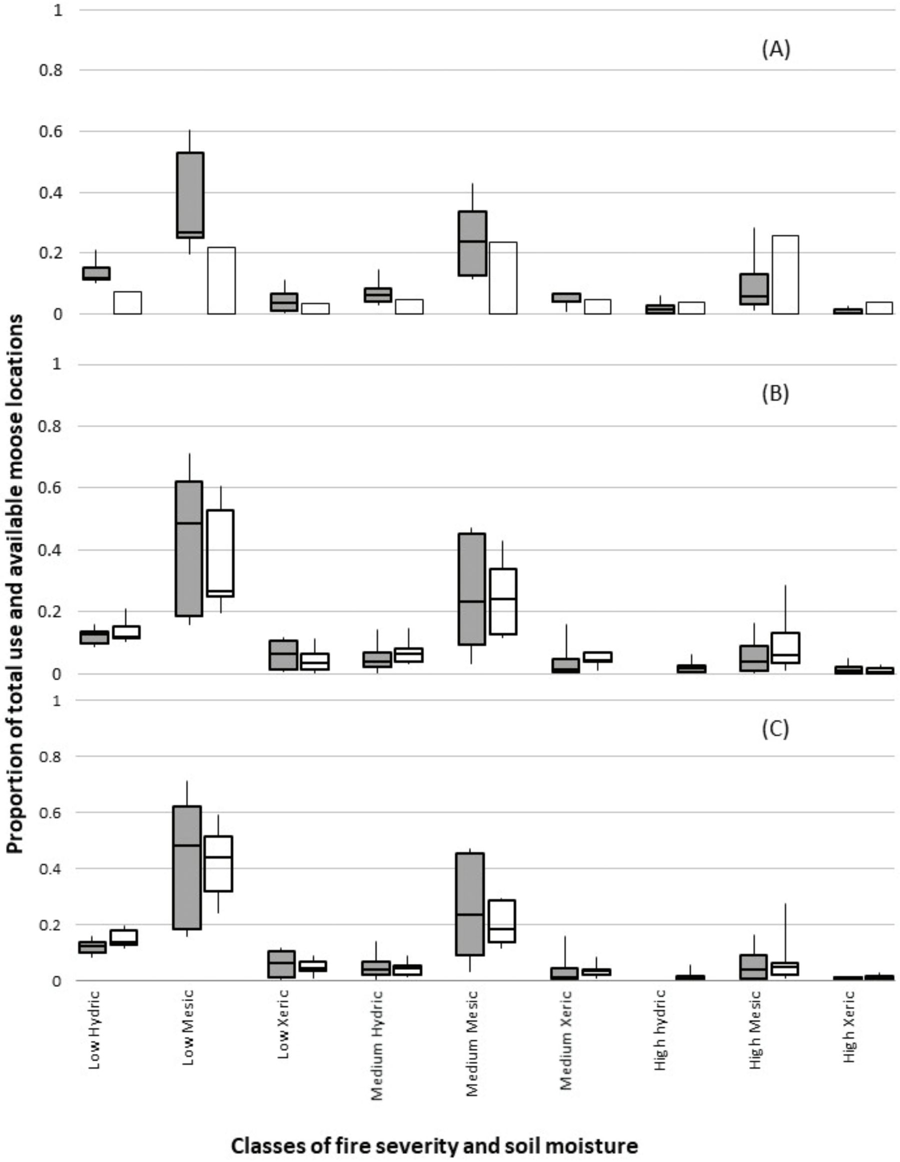

Fig. 7. Box (first and third quartiles with median as a line) and whisker (minimum and maximum) plots for the proportion of use (filled) and available (open) moose location classes of fire severity and soil moisture at three levels: (A) daily movements, (B) within collared moose home ranges, and (C) home ranges within the Mt. McAllister burn, 2018–2019. Note that calculation of available within the burn (C) is a total area.

similar trend was found at the daily order of selection (Fig. 7C). All areas of high fire severity had proportionally less use than available locations.

Although selection models based on the main effects fit the data ($P < 0.05$), model $R^2$ was low (≤ 0.20; Appendix A). The selection models did not converge for one moose at the burn and home range orders (second and third order) due to its small home range within the burn. Fire severity and soil moisture were significant in all models at the burn order (second order). At the daily order (fourth order), moisture was significant in 2 models and burn was significant in all (Appendix A).

Compared to the reference class of high fire severity, sites with low fire severity were selected for at the burn and home range orders, but neither for nor against at the daily order; moose avoided areas classified as high fire severity at all orders (Fig. 8B, Table 2). Compared to the reference class of xeric soil moisture, sites with hydric soil moisture were selected against at the home range and daily orders, but selected for at the burn order (Fig. 8B, Table 2). At the burn order, mesic soil moisture was neither selected for nor rather than or against, but was selected at the home range and daily orders (Fig. 8B, Table 2). Moose were equivocal in their selection of xeric sites at the home range and daily orders, but avoided these sites at the burn order (Fig. 8B, Table 2).

## DISCUSSION

### Site Level

Relative to pellet groups and the percent of plants browsed, moose used areas of low to medium fire severity more than areas burned at high severity. Higher use of low and medium fire severity habitats is largely due to patterns of post-fire vegetation succession (Kielland and Brown 2015), and these sites are generally characterized with higher browse availability than unburned sites (MacCracken and Viereck 1990). Although others detected a relationship between post-burn browse availability and relative fire severity (MacCracken and Vierek 1990, Bailey and Whitham 2002), we did not find that relationship. We recommend that other studies examining these relationships include measurements of unburned sites.

Moose also used areas that were generally wetter based on measurements of pellet group density and percentage of plants browsed. Although wetter sites may not have proportionally more forage, they mostly contained willows and aspens that are preferred forage of moose (Meidinger and Pojar 1991) and may have strongly influenced habitat use. Although not correlated, it appeared that wetter sites were burned less severely and would have likely incurred less damage to above- (stems and shoots) and below- (roots) ground plant parts.

Habitats with a combination of low to medium fire severity and wetter soil moisture tend to provide moose cover as well as forage. Joly et al. (2016) found that the density and basal area of standing live trees were greater on sites of low burn severity than drier and/or more severely burned sites. Therefore, cover would likely be less common on sites with xeric soil moisture and high fire severity, especially in the relatively young McAllister burn. In Alaska, northwest of our study area, greater use of high fire severity sites was documented on older burns during summer months when forage biomass increases and provides cover for moose (Kielland and Brown 2015). There is a general consensus that moose prefer older burns – >11 years old – and that forage production is highest in burns between 11 and 30 years old (Kelsall et al. 1977, Maier et al. 2005, Joly et al. 2016, Julianus 2016). It is not surprising that we found little use of high fire severity areas given the young age of the McAllister burn, which we expect to change as secondary succession progresses.

### Landscape Level

Habitat use and selection by moose varied by fire severity class with a decreasing trend in selection for low and medium fire severity at a finer resolution of selection (i.e., from home range to daily movements). We also found that fire severity, more than soil moisture, influenced where home ranges were and where moose were within their home ranges.

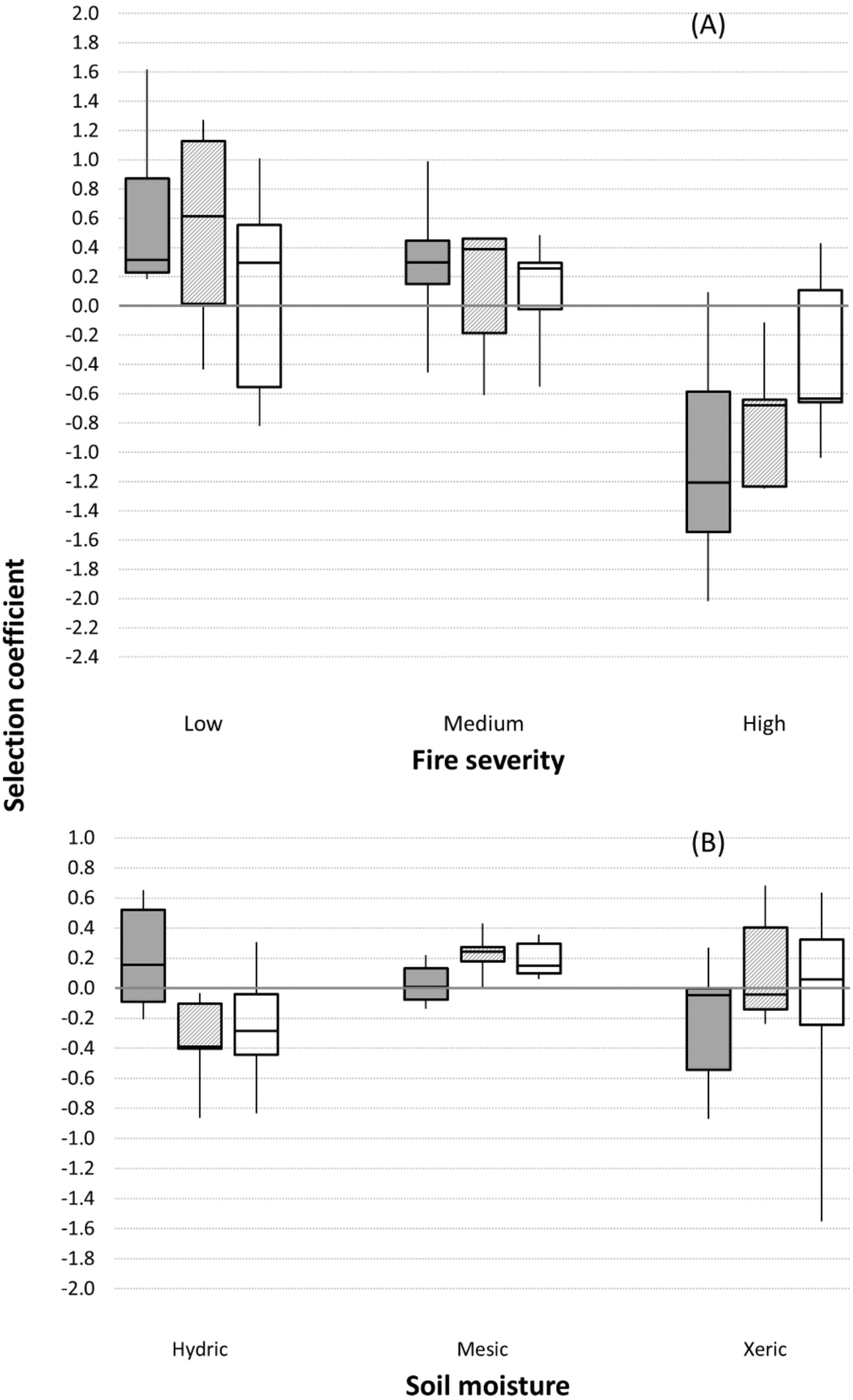

Fig. 8. Box and whisker plots (first and third quartiles (box) with median (line) and minimum and maximum (whiskers)) for selection coefficients showing the relative preference (values > 0) or avoidance (values < 0) by radio-collared moose for (A) fire severity classes (Low, Medium, High) and (B) soil moisture classes (Hydric, Mesic, Xeric) at three levels: daily movements (filled), within collared moose home ranges (hashed), and home ranges within the Mt. McAllister burn (open), 2018–2019.

Table 2. Moose selection coefficients and 95% lower and upper confidence intervals (LCI < > average < > UCI) for classes of fire severity (Low, Moderate, High) and soil moisture (Hydric, Mesic, Xeric) at three different orders of selection (Burn, Home range, Daily). Individual radio-collared moose were modelled separately using logistic regression and then averaged for population-level estimates. The number of individual moose was Burn = 6, Home range = 5, and Daily = 6. Selection for or against a factor was defined as confidence intervals that did not overlap zero.

| Factor | Selection order | Factor classes | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| Fire severity | Burn | 0.446 < > 0.684 < > 0.921 | 0.159 < > 0.349 < > 0.539 | −1.346 < > −1.033 < > −0.719 |
| | Home range | 0.267 < > 0.586 < > 0.906 | −0.052 < > 0.16 < > 0.372 | −0.955 < > −0.746 < > −0.538 |
| | Daily | −0.149 < > 0.154 < > 0.457 | 0.013 < > 0.164 < > 0.315 | −0.561 < > −0.318 < > −0.075 |
| | | Hydric | Mesic | Xeric |
| Soil moisture | Burn | 0.058 < > 0.204 < > 0.35 | −0.028 < > 0.028 < > 0.083 | −0.407 < > −0.231 < > −0.056 |
| | Home range | −0.498 < > −0.357 < > −0.216 | 0.157 < > 0.225 < > 0.292 | −0.037 < > 0.133 < > 0.302 |
| | Daily | −0.413 < > −0.258 < > −0.102 | 0.14 < > 0.19 < > 0.24 | −0.092 < > 0.068 < > 0.227 |

Although we cannot infer that these statistical relationships result in behavioural responses by moose, we did find that all home ranges were located in areas of low fire severity, and moose selectively foraged in areas of low fire severity. At the daily order of selection, they avoided areas of low fire severity suggesting that at a finer selection order, moose used a variety of habitats to fulfill different life requisites. Joly et al. (2016) found that female moose preferred burned habitats and areas with higher solar radiation; more specifically, that maternal females selectively used more forested than riparian areas to minimize predation risk.

Moose in the burn ranged in areas that were wetter and avoided more xeric conditions. It is not uncommon to find moose in more hydric habitats, as wetlands and lakes are important habitat features providing important life requisites including forage abundance and thermal cover (Wall et al. 2010). When comparing the 3 orders of selection, an increasing trend in use of mesic sites was noted when moving to a finer order (from 2nd to 4th order). At the daily movement order, moose preferred mesic more than hydric soil moisture, and showed no selection for xeric sites.

Moose use a variety of habitats to fulfill various requirements for growth, reproduction, and survival. Daily use within their home ranges was influenced by burn severity and soil moisture, but use is also influenced by multiple factors including sex, pregnancy status, season, winter severity, and other biotic and abiotic factors (Kielland and Brown 2015, Joly et al. 2016). We recognize that our results were biased to winter somewhat and by the single daily location at 0900 hr, and that broader and more frequent locations would likely expand and elucidate patterns of burn use undetected in our study.

We found an inconsistency at the daily movement order between the site and landscape orders. At the site level, moose showed higher use of hydric sites but selected against hydric sites at the daily movement order. In addition, moose also used areas of low fire severity at the site level, yet showed no preference for low fire severity habitats at the daily movement order. Possible explanations for these inconsistencies are that we had a low sample size of moose at the landscape level and were presumably sampling most moose at the site level. Again, data sets including higher location fix rates may help to identify finer moose movements and habitat use patterns (Beyer et al. 2010) that are known to change throughout the day (Poole and Stuart-Smith 2006). In addition, habitat selection is manifested in individual home range size which reflects the spatial availability of resources and ultimately the selection patterns we observed (Herfindal et al. 2009). It is possible that moose with smaller home ranges were using portions of the burn which offered better resources, emphasizing why moose behavior and habitat use should be examined at multiple levels of a spatial scale (Schaefer and Messier 1995, Potochnik and McGill 2012).

### Conclusions and Management Implications

In conclusion, we determined that fire severity, more than soil moisture, influenced habitat use by moose in the recent Mt. McCallister burn. Yet, that influence appeared scale dependent as moose used areas of low fire severity at the course levels of investigation and areas of medium fire severity at the fine levels of investigation, similar to previous research (Mansson et al. 2007). It could be that moose use areas of low fire severity for abundant forage and cover, and more moderately burned (medium fire severity) areas to access forage that provides increased or specific nutritional benefits (Lautenschlager et al. 1997). We suggest that prescribed fires with low and medium fire severity in areas with potential for abundant forage and forest cover would increase habitat value for moose. Such an approach could help restore habitat elements important for moose populations and could be reintroduced into routine forest management where feasible (Gorley 2016). Our results indicate that fire severity and soil moisture influence moose use of burns and provide a framework for improving prescribed fire monitoring protocols aimed specifically at wildlife habitat enhancement (Scasta et al. 2018).

Wildfire is a natural landscape disturbance with long-term influence on moose habitat and population dynamics. Because wildfires are becoming larger and more unpredictable due to climate change and past forest management practices (BCWS 2018), it is critical to recognize related consequences for moose. Wildfire management plans, prescribed burning, and strategic fire suppression efforts should consider the impact of fire severity and soil moisture on short- and long-term influences of moose habitat when possible (Gorley 2016).

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Appendix A. Model fitting information[1], and resulting equations, for models of the probability of use of a site by individual radio-collared moose (Animal) given the state of main effects for soil moisture (Moist) and fire severity (Dnbr).

| Animal | Preference | Use | Random | Con | AIC | LR | Pr Moist | Pr Dnbr | RSq | C | Equation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14,248 | burn | 611 | 13,140 | Y | 4395 | 0.0001 | 0.0040 | 0.0001 | 0.1434 | 0.767 | Logit = −3.86 − 0.21(ClMoist1) − 0.06(ClMoist2) + 1.71(ClDnbr1) +0.30(ClDnbr2) |
| 14,255 | burn | 1239 | 13,140 | Y | 7724 | 0.0001 | 0.0011 | 0.0001 | 0.1113 | 0.708 | Logit = −2.91 − 0.15(ClMoist1) + 0.15(ClMoist2) + 1.13(ClDnbr1) +0.42(ClDnbr2) |
| 14,262 | burn | 362 | 13,140 | Y | 3276 | 0.0001 | 0.0001 | 0.0001 | 0.0232 | 0.618 | Logit = −3.86 + 0.65(ClMoist1) + 0.22(ClMoist2) + 0.26(ClDnbr1) − 0.41(ClDnbr2) |
| 14,269 | burn | 416 | 13,140 | Y | 3451 | 0.0001 | 0.0001 | 0.0001 | 0.0842 | 0.718 | Logit = −4.01 + 0.63(ClMoist1) + 0.07(ClMoist2) + 0.38(ClDnbr1) + 1.07(ClDnbr2) |
| 14,743 | burn | 2186 | 13,140 | Y | 12,027 | 0.0001 | 0.0101 | 0.0001 | 0.0620 | 0.629 | Logit = −1.93 + 0.10(ClMoist1) − 0.08(ClMoist2) + 0.37(ClDnbr1) + 0.54(ClDnbr2) |
| 14,745 | burn | 43 | 13,140 | N | 533 | 0.0001 | 0.6605 | 0.0008 | 0.0967 | 0.756 | Logit = −10.42 + 0.13(ClMoist1) + 0.21(ClMoist2) + 5.46(ClDnbr1) + 3.98(ClDnbr2) |
| 14,755 | burn | 482 | 13,140 | Y | 4131 | 0.0001 | 0.0105 | 0.0001 | 0.0130 | 0.585 | Logit = −3.29 + 0.21(ClMoist1) − 0.14(ClMoist2) + 0.24(ClDnbr1) + 0.18(ClDnbr2) |
| 14,248 | home range | 270 | 611 | Y | 1041 | 0.0001 | 0.1006 | 0.0001 | 0.0853 | 0.613 | Logit = −1.96 − 0.10(ClMoist1) + 0.24(ClMoist2) + 1.21(ClDnbr1) − 0.57(ClDnbr2) |
| 14,255 | home range | 128 | 1239 | Y | 849 | 0.0236 | 0.0824 | 0.1423 | 0.0178 | 0.569 | Logit = −2.86 − 0.40(ClMoist1) − 0.001(ClMoist2) + 0.68(ClDnbr1) + 0.52(ClDnbr2) |
| 14,262 | home range | 128 | 362 | Y | 555 | 0.0011 | 0.3814 | 0.0004 | 0.0534 | 0.622 | Logit = −1.23 − 0.03(ClMoist1) + 0.37(ClMoist2) + 0.07(ClDnbr1) + 0.53(ClDnbr2) |
| 14,269 | home range | 70 | 416 | Y | 410 | 0.9439 | 0.8241 | 0.8658 | 0.0028 | 0.526 | Logit = −1.88 − 0.10(ClMoist1) + 0.09(ClMoist2) − 0.01(ClDnbr1) + 0.12(ClDnbr2) |
| 14,743 | home range | 44 | 2186 | Y | 429 | 0.0075 | 0.0619 | 0.0643 | 0.0353 | 0.644 | Logit = −4.18 − 0.86(ClMoist1) + 0.18(ClMoist2) − 0.39(ClDnbr1) + 0.45(ClDnbr2) |
| 14,745 | home range | 76 | 43 | N | 160 | 0.2152 | 0.64 | 0.4126 | 0.0651 | 0.595 | Logit = 4.93 − 0.38(ClMoist1) − 0.002(ClMoist2) − 4.26(ClDnbr1) − 5.03(ClDnbr2) |
| 14,755 | home range | 158 | 482 | Y | 633 | 0.0001 | 0.0056 | 0.0001 | 0.1988 | 0.733 | Logit = − 2.03 − 0.39(ClMoist1) + 0.43(ClMoist2) + 1.36(ClDnbr1) − 0.14(ClDnbr2) |
| 14,248 | daily | 270 | 1350 | Y | 935 | 0.0001 | 0.3531 | 0.0001 | 0.0600 |  | Logit = − 0.18(ClMoist1) + 0.10(ClMoist2) + 1.09(ClDnbr1) − 0.51(ClDnbr2) |

| Animal | Preference | Use | Random | Con | AIC | LR | Pr Moist | Pr Dnbr | RSq | C | Equation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14,255 | daily | 128 | 640 | Y | 458 | 0.0736 | 0.0747 | 0.3215 | 0.0246 | | Logit = − 0.46(ClMoist1) + 0.06(ClMoist2) + 0.45(ClDnbr1) − 0.55(ClDnbr2) |
| 14,262 | daily | 128 | 640 | Y | 449 | 0.0015 | 0.2755 | 0.0014 | 0.0503 | | Logit = 0.01(ClMoist1) + 0.32(ClMoist2) + 0.26(ClDnbr1) − 0.35(ClDnbr2) |
| 14,269 | daily | 70 | 350 | Y | 241 | 0.0012 | 0.4883 | 0.0006 | 0.0935 | | Logit = 0.31(ClMoist1) + 0.10(ClMoist2) − 0.78(ClDnbr1) + 0.28(ClDnbr2) |
| 14,743 | daily | 44 | 220 | Y | 150 | 0.0034 | 0.1293 | 0.0161 | 0.1289 | | Logit = − 0.83(ClMoist1) + 0.20(ClMoist2) − 0.77(ClDnbr1) + 0.36(ClDnbr2) |
| 14,745 | daily | 76 | 380 | Y | 273 | 0.1134 | 0.2917 | 0.0709 | 0.0361 | | Logit = −0.42(ClMoist1) + 0.03(ClMoist2) + 0.54(ClDnbr1) − 0.28(ClDnbr2) |
| 14,755 | daily | 158 | 790 | Y | 551 | 0.0001 | 0.0100 | 0.0008 | 0.0542 | | Logit = − 0.42(ClMoist1) + 0.03(ClMoist2) + 0.54(ClDnbr1) − 0.28(ClDnbr2) |

1 – Where: Con is whether the likelihood estimation converged (Y) or not (N), AIC is Akaike Information Criterion, LR is the likelihood ratio, Pr Moist is probability of a greater Chi-square for the main effect of soil moisture, Pr Dnbr is the probability of a greater Chi-square for the main effect of fire severity, RSq is the $R^2$ model value, C is the area under the receiver operating characteristic curve. The probability of a site being used given the state of main effects is $1 / (1 + e^{logit})$ where the logit value is found by each model equation.