

Understanding the effects of wildfire severity on moose habitat characteristics and use in Interior, Alaska

Project Number: 14-3-01-44

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ABSTRACT

Wildfire is the most ubiquitous ecological disturbance in Alaska's boreal forests, and as the primary driver of secondary succession in boreal forests, it directly influences the availability of habitat for many Alaskan wildlife species. However, it remains unknown whether large herbivores, such as moose, preferentially select for burned areas in relation to other habitat features. Furthermore, fire severity is an important control over post-fire succession and production of deciduous species. Fire severity may influence the overall quality of summer and winter habitat for moose, but the relationship between the availability and duration of biomass production and moose habitat use are largely unknown. To examine these relationships, we used data from 15 GPS collared moose in the 20-year-old regenerating Hajdukovich Creek burn in Interior Alaska. We conducted browse assessment surveys that were stratified across fire severity to measure forage production and other habitat characteristics (i.e., plant mortality and architecture class). Next, we used dynamic Brownian bridge movement models (dBBMMs) to determine whether regenerating forests, and fire severity, affect habitat use patterns of moose across their seasonal home ranges and core use areas.

Across moose home ranges, individuals selected for a variety of different habitats types including shrubs, burned areas, and deciduous and coniferous forests. Within the burned areas, moose selected for low-severity sites more often than high- and moderate-severity sites during the winter. In summer, moose selected for high-severity sites. Nearly 200 kg/ha of forage biomass was produced across all sites within the Hajdukovich Creek Burn, but production and availability varied depending on fire severity and browse species. We demonstrate that moose selected areas with high availability of willow biomass (i.e., low-severity sites) more than areas with the most total woody browse biomass (i.e. high-severity sites). Additionally, high-severity sites had the greatest rates of plant mortality and brooming, which may reduce foraging efficiency. These results along with decrease in selection for high-severity sites in winter, suggests that moose are responding to declining habitat conditions. The increase in selection for high-severity sites in summer may be due to cover availability offered by the establishment of a thick deciduous canopy. These results also show that wildfire severity can create an important, yet dynamic, mosaic of habitat for moose.

BACKGROUND AND PURPOSE

Spatial heterogeneity can have important effects on wildlife by influencing patch size and shape, as well as the composition and distribution of habitat types across landscapes (Turner 1989, Li & Reynolds 1994). These changing habitat characteristics can influence predator-prey interactions (Pierce et al. 2000, Kauffman et al. 2007), population dynamics (Dempster & Pollard 1986), community structure (Pacala & Roughgarden 1982), and animal movement and distribution (Kie et al. 2002, Boyce et al. 2003). Both natural (e.g., wind, drought and fire) and anthropogenic disturbances (e.g., agriculture and logging) can be considered sources of large-scale spatial heterogeneity. In forest-dominated landscapes, disturbances, such as fire, produce spatial heterogeneity by opening large patches within the forest matrix (McCarthy 2001).

Wildfire is the most common ecological disturbance in the Alaskan boreal forest, burning 1 to 3 million hectares per year (Chapin et al. 2008). Black spruce (*Picea mariana*) forests are the most common forest type in Interior Alaska. These forests typically follow a post-fire successional trajectory of self-replacement where the dominant pre-fire stand replaces itself shortly after low-severity fires (Van Cleve et al., 1983). However, high-severity fires (i.e., those

that burn through the organic soil layer exposing the mineral soil) can be favorable for seeding deciduous shrubs and trees even in forests historically dominated by black spruce (Johnstone & Kasischke 2005, Johnstone et al. 2010). The poor litter quality of black spruce dominated low-severity sites supports slow rates of decomposition and nutrient turnover, allowing for more gradual growth rates of coniferous species and effectively slowing biomass production (Van Cleve & Viereck 1981). In contrast, deciduous tree species such as trembling aspen (*Populus tremuloides*) and Alaska birch (*Betula neoalaskana*) are able to re-sprout from belowground roots and use carbohydrate reserves to grow rapidly and reestablish a deciduous canopy (Greene and Johnson 1999). Research has found that the lasting effects of fire severity on recruitment and establishment can be seen in forest composition several decades post-burn (Shenoy et al. 2011). Additionally, fire severity is linked to an increase in fire extent across Alaska (Duffy et al. 2007). Thus, fire severity can alter the spatial heterogeneity within boreal forests by influencing the composition, age structure, and size of vegetation patches.

A fire-mediated shift to a deciduous-dominated forest could affect a broad suite of ecosystem processes, including the production, palatability and duration of important forage and cover species for boreal herbivores such as moose (*Alces alces*). The effects of fire severity on spatial heterogeneity manifested in the distribution of forest cover and vegetation in forest openings may be a key variable influencing habitat use by moose. Throughout the year, moose must balance the costs and benefits associated with accessing forage and finding cover against predation and harsh climatic conditions (Hansson, 1994). The effects of fire severity on woody browse production are especially important during winter when moose maintain a neutral to negative energy balance. Additionally, the high nutrient content of regenerating forage post-fire (McNaughton et al. 1988, Hobbs 1989) may also serve as a strong attractor for moose. Obtaining sufficient nutrition to survive the winter is an important limiting factor (Schwartz et al. 1988, Van Ballenberghe & Ballard 1998). The proportional production and removal of aspen by moose during winter may occur predominantly in high-severity sites (Lord and Kielland 2015), and stem densities of forage species may be positively correlated with fire severity (Lord 2008, Shenoy et al. 2011). Higher production of stems, especially those above browse height in closed forests, results in more shelter against predation and/or harsh climatic conditions (Dussault et al. 2005). Thus, moose may perceive burned areas as habitat mosaics of productive forest openings dispersed within areas of continuous cover. Within burns, moose may respond to severity-dependent differences in vegetation composition, such as increased woody browse production that can be found in high-severity sites.

Despite substantial research on the effects of fire severity on forest recruitment (Johnstone & Kasischke 2005, Shenoy et al. 2011), the duration of browse availability for moose is poorly understood. While numerous studies have found that moose populations respond strongly to the increased production of shrub habitat post-fire (Lutz 1960, Spencer and Hakala 1964, DuBois 2008), these studies did not examine the influence of fire severity. Schwartz and Franzmann (1989) found that moose populations increased 15 years after a burn on the Kenai Peninsula in Alaska, while others have found that moose do not respond within the first 5 years (Gasaway et al. 1989), suggesting that additional factors, such as fire severity, should be examined in relation to preferred moose habitat. Therefore, while research suggests that favorable moose habitat conditions peak between 11 and 30 years following wildfire events (MacCracken & Viereck 1990, Loranger et al., 1991, Maier et al., 2005), it remains unknown, however, whether moose preferentially select for high-severity habitat patches in relation to low/moderate severity patches or other landscape features (e.g., riparian habitat).

The Joint Fire Science Program (JFSP) Graduate Research Innovation program (GRIN) allowed us to evaluate the relative influence of a regenerating burn on moose habitat use, taking into account differences in fire severity within the burn. We used GPS radiotelemetry data from 15 moose to determine whether the regenerating burn affects habitat-use patterns of moose across their home ranges. We examined if fire severity influenced the use of habitat patches within individual core use areas, and performed browse assessment surveys to assess the duration, quality and availability of forage production and removal across fire severities. We hypothesized that moose would prefer habitat in the Hajdukovich Creek Burn compared to areas outside of the burn during both winter and summer. Within the burn, we expected individual moose to exhibit greater preference for high-severity sites versus low-severity sites during both winter and summer due to the abundance and nutritional quality of woody browse in the high severity sites.

STUDY DESCRIPTION AND LOCATION

STUDY AREA

Research was conducted within the 20-year old Hajdukovich Creek Burn (HCB) 25 miles east of Delta Junction, Alaska (Figure 1). In 1994, the fire burned approximately 4,800 hectares of a forest that was dominated by black spruce stands with few mixed stands of aspen and spruce (Johnstone and Kasischke, 2005, Michalek et al., 2000). The HCB is located on the northern side

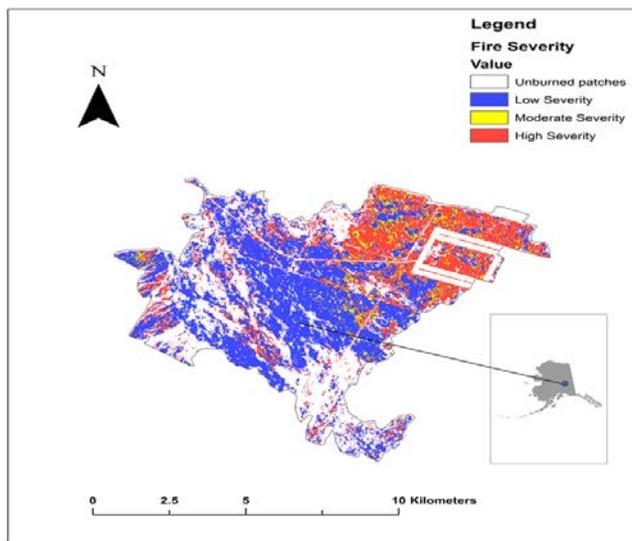


Figure 1: Fire-severity map of HCB located 35 miles southeast of Delta Junction, Alaska. Red pixels denote high-severity, yellow pixels are moderate-severity, and blue pixels denote low severity. There were some areas within the fire perimeter that did not burn. Non-burned areas are in white.

of the Alaska Range and is characterized primarily by flat topography. Agriculture fields border the northern edges of the burn perimeter and riparian corridors including the Gerstle River and Sawmill Creek border the eastern and western edges respectively. Mean snow depth during winter months is 0.43 m (SE=0.01) and does not differ significantly between fire severities ($F=0.0295$, $P=0.97$, Brown unpublished data). Winter temperatures during our study were (10°C - 42°C) while summer temperatures ranged between (0°C - 30°C; Brown unpublished data, 2014). Predators in the study area include wolves (*Canis lupus*), brown bears (*Ursus arctos*), and black bears (*Ursus americanus*).

Since the fire, forest regeneration in the HCB has been studied extensively. Vegetation composition in high-severity patches is dominated by deciduous trees and shrubs with few coniferous trees, whereas low-severity patches are primarily composed

of black spruce, willow (*Salix* spp.) and few aspen and birch (Shenoy et al. 2011). Fire severity classes were first determined using post-fire satellite imagery and later ground-truthed with field based measurements of soil organic matter combustion (SOM, Michalek et al. 2000). In total,

61% of the burn was classified as low-severity, 6% as moderate severity, and 33% as high-severity, with some areas that did not burn at all (Figure 1).

BIOMASS PRODUCTION AND NUTRITIONAL QUALITY

To estimate forage composition within fire severity classes, we used 20 pre-established sites (Johnstone and Kasischke 2005, Shenoy et al. 2011, Lord and Kielland 2015) that were stratified by burn severity (low, n=6; moderate, n=3; high, n=11) for browse assessment surveys, conducted in March 2013. At each site, we established 30-m diameter circular plots and randomly found three plants of each forage species within each plot. We defined forage species as *Salix* spp. (*Salix scouleriana*, *Salix bebbiana*, *Salix glauca*), *Populus* spp. (*Populus tremuloides*) and *Betula* spp. (*Betula neoalaskana*) that were of foraging height for moose (0.5m–3m; Peek et al. 1976, Risenhoover 1989). While willows were identified to species in the field, they were grouped into *Salix* spp. for final analysis. For each plant, we recorded species, height, percent dead material by volume, and architecture class. Plant architecture classes were categorized by the percentage of lateral branching due to herbivory and were defined as: unbrowsed (< 5%), browsed (5 - 50%), and broomed (> 50%). This definition provided an index for categorizing moose browsing pressure on a plant throughout its life (Seaton 2002). Stem densities can provide a useful estimate of the abundance of forage species, as well as for estimating cover opportunities for moose (i.e., depending on age class, high numbers of stems/m² is equivalent to thicker cover, Dussault et al. 2015). To estimate stem densities, we divided 30-m plots into quadrants, totaled the number of stems in each quadrant, and divided this sum by the area of the plot ($\pi r^2=706.86$ m²). To compare differences in stem densities across fire severities, we used a one-way analysis of variance (ANOVA).

Additionally, we estimated biomass production and removal at each site (Brown et al. 2015). We randomly located 3 plants from each forage species that were of foraging height for moose (0.5 m to 3.0 m): *Salix scouleriana*, *Salix bebbiana*, *Salix glauca*, *Salix arbusculoides*, *Populus tremuloides*, and *Betula neoalaskana*. For each plant, we recorded the diameter of the base of current annual growth (CAG) for 10 twigs per plant as well as the diameter at the point of browsing (DPB) if twigs were browsed. When necessary, more than 3 plants were sampled until 30 twigs per species or all of the twigs available in the plot were measured. Total stem densities were then estimated for each forage species.

Biomass was calculated using the estimated dry weights from mass-diameter regression equations. The formula used for estimating biomass production and removal was:

$$\hat{B}_k = \sum \frac{M_{jk}}{m_{jk}} \sum \frac{N_{ijk}}{n_{ijk}} \sum z_{ijk}$$

Where, B is the site estimate of removal or production biomass in grams. Twigs are denoted by h , plants by i , species by j , and the sites by k . M and m are the total and sampled plants in each plot, respectively, while N and n are the total and sampled twigs, respectively. Individual twig biomass is represented by z (Seaton, 2002). Tukey's adjustments for pairwise comparisons were used to test for differences among severity classes. We used a program developed in R 2.14.1 (R Development Core Team 201) by the Alaska Department of Fish and Game using plot counts, twig diameters, diameter-biomass relationships and production and removal (kg/ha) on the basis of plant, species, and plot (Paragi et al. 2008). Finally, to examine the duration of browse production in the burn, we compared our results to a previous study (Lord and Kielland 2015) that utilized the same sites to estimate biomass production and removal.

Additionally, at four sites (n=2 low-severity, n=2 high-severity), we sampled twigs from 5 randomly selected individual plants from each of the following species: *Salix scouleriana*, *Salix bebbiana*, *Populus tremuloides*, and *Betula neolaskana*. Due to the low percentage of moderate severity patches across the entire burn, we only sampled at low and high severity sites. All samples were within foraging height for moose and we used average species DPB to select twig size. All samples were kept frozen until they were freeze-dried in the lab. Freeze-dried twig samples were ground in a Wiley mill over a 20-mesh (1mm) screen and stored in airtight containers prior to chemical analysis. Nitrogen concentration (N) was determined on a Truspec C-N Analyzer. Crude protein (CP) concentrations were calculated by assuming that the mean protein in food was 16% N (Robbins 1993). Tannin-protein precipitation capacity was determined with bovine serum albumin (BSA) using the method of Martin & Martin (1983). Sequential fiber analysis was conducted on all forages according to the methods of Van Soest yielding neutral detergent fiber and acid detergent fiber concentrations. We determined the N concentration of ADF (ADFN) by preparing separate samples of each forage and then analyzing for N using the Truspec C-N Analyzer. All samples are reported on a dry matter basis. Finally, digestible protein concentration was calculated using the equation of Spalinger et al. (2010):

$$DP = 5.73CP - 2.43 - 8.28PPC - 2.88ADFN - 11.12(ADFN-0.793) (PPC-0.140)$$

where DP is digestible protein as a percentage of dry matter, CP is crude protein as a percentage of dry matter (6.25 X N concentration), PPC is protein precipitation capacity ($\mu\text{g}/\mu\text{g}$), ADFN is a percentage of dry matter. We analyzed our data with an ANOVA model where dependent variable = fire severity + species + fire severity*species. The dependent variables were nitrogen concentration (N), protein precipitation capacity (PPC), and digestible protein (DP).

ESTIMATING HOME RANGE and CORE AREAS

In October 2012, 15 adult male moose were captured by darting them in the HCB from a helicopter. We fitted the captured moose with GPS radio collars (TDW-4780, Telonics, Mesa, Arizona) equipped with ARGOS connectivity and programmed to collect one location every hour from August 16th to October 15th, and once every 2 hours for the rest of the year. The increase in GPS fixes during the late-summer is due to external research efforts. Location data were downloaded weekly between October 2012 and November 2014 and resulted in 220,000 locations. One animal died in December 2012 and was excluded from all analyses. Two additional mortalities occurred in spring 2013 and these two moose were only included in the winter 2012 analysis.

We used dynamic Brownian bridge movement models (dBBMM; Kranstauber et al. 2012) to estimate the utilization distribution (UD) for each individual moose based on the movement data collected from the radio collars. The UD's were calculated for the winter season (November 1–April 1) and summer seasons (May 1–September 1). Traditional Brownian bridge movement models (BBMM) are continuous-time stochastic movement models that predict the probability of being in an area by incorporating the distance and elapsed time between consecutive locations, the location error, and an estimate of the animal's mobility, referred to as the Brownian motion variance (σ^2_m ; Horne et al. 2007). The BBMM assumes a constant σ^2_m along the entire movement path. However, animal movement is often composed of a series of behaviorally unique movements that can change over time (e.g., diurnal versus nocturnal movement patterns). Moose movement, in particular, can change daily between foraging,

bedded, or traveling behaviors (Moen et al. 1996) and seasonally during rut (Miquelle 1990). A BBMM assumes a constant σ_m^2 along the entire movement path, whereas the dBBMM allows the σ_m^2 to vary along a path corresponding to changes in the animal's behavior over time (Kranstauber et al. 2012). We chose to use dBBMM because this model incorporates the animal's movement path as well as the time between locations. Moreover, the dBBMM allows for a more precise estimate of the UD by introducing changing behavioral states into the estimate of the σ_m^2 .

We calculated UDs using the `Brownian.bridge.dyn` function (move package) in R. Moose home range boundaries were defined by 95% isopleth values. Core use areas were defined by isopleths that divided intensively used areas from peripheral home range areas (VanderWal and Rodgers 2012). To calculate core use areas we fit an exponential regression to a plot of UD area against UD volume (i.e., isopleth value) and determined the point at which the slope of the line fitted was equal to 1 (VanderWal and Rodgers 2012, Feierabend and Kielland 2014). This point represents a limit where the home range area begins to increase at a greater rate than the probability of use and the corresponding UD volume defines the boundary of the core area.

HABITAT USE ANALYSIS

Each pixel within the home range and core use areas were assigned a UD value denoting the probability that the individual was located within that pixel during a given period relative to other pixels within the home range or core use area. The sum of these pixels associated with a habitat type (e.g., evergreen forest) was equal to the total probability of occurrence within that habitat type (Marzluff et al. 2004). To estimate selection for a particular habitat type, we divided the total probability of occurrence by its availability for each individual, referred to as 'concentration of use' (Neatherlin and Marzluff 2004, Bjørneraas et al. 2012). Concentration of use is an index measuring habitat use relative to its availability. This index is similar to other use/availability selection coefficients (e.g., Manly et al. 2002). However, this approach: 1) uses the animal, not the location (i.e., GPS fix) as the experimental unit, 2) is not affected by the unit sum constraint (Aebischer et al. 1993), and 3) incorporates variation of use within habitat types instead of assigning space "used" versus "unused" (Neatherlin and Marzluff 2004).

We compared use of burned areas relative to other habitat types across individual seasonal home ranges by defining availability as the proportion of habitat types inside the 95% boundary. To examine use of fire severity patches within burns, we defined availability as the proportion of habitat types inside the 40% (winter) and 64% (summer) core use areas. We then divided the sum of all UD values associated with a particular habitat by the availability. We scaled the concentration of use index to a value between 0 and 1 within each individual home range and core area (Bjørneraas et al. 2012).

To test whether moose preferred habitat within the HCB, we compared the concentration of use across all habitat types between individual home ranges. Habitat types consisted of evergreen forest, deciduous forest, shrubs, mixed forest, open water, agriculture, and the HCB burn classes. We merged National Land Cover Data (NLCD 2001) with HCB data (Mikalek et al. 2002) to produce a map of relevant habitat types for the study area. The burn class represented area within the HCB perimeter. Next, we compared the concentration of use across all fire severity types between individual core use areas. Fire severity types consisted of and high, moderate, and low severities, and unburned patches. The unburned class was composed of pixels that were within the HCB boundary but were not consumed by fire. We utilized Mikalek

et al's (2002) fire severity classifications for this analysis. In this case, availability was the proportion of fire severity classes within individual core use areas.

We used linear mixed effects models using the lme4 package in R with individual moose ID as a random effect to examine whether moose preferred some habitat types or fire severity classes to others by comparing mean concentration of use of different habitat/severity types between home range and core use areas. We added individual moose as a random factor to account for within-individual dependency among the observations. Proportionate data was square root arcsine transformed to normalize variance prior to analyses. To compare concentration of use among all habitat types within moose home ranges, we used a mixed model one-way analysis of variance (ANOVA).

KEY FINDINGS

BIOMASS PRODUCTION AND NUTRITIONAL QUALITY

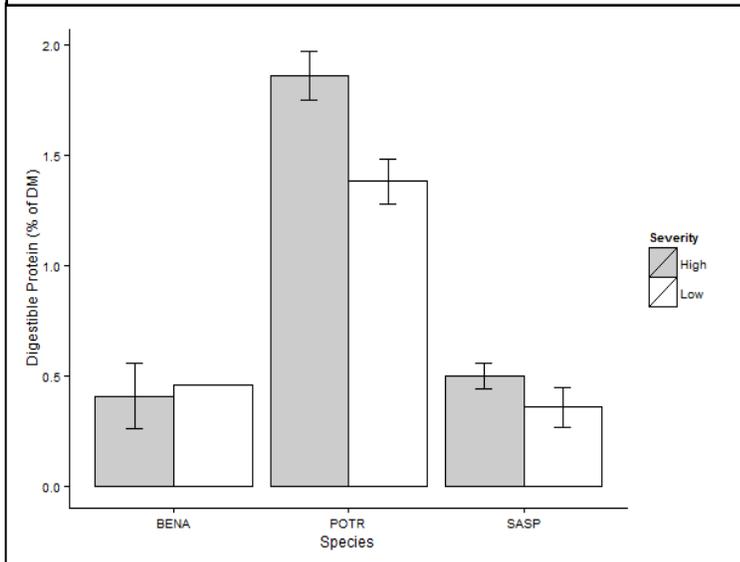
The number of deciduous stems within the HCB varied significantly across fire severity classes ($F=4.62$, $p=0.03$). The stem density was 1.19 (SE=0.18) stems/m² across all high severity sites, 0.66 (SE=0.04) stems/m² in moderate severity and 0.43 (SE=0.12) stems/m² in low severity sites. *Salix* spp. were the most abundant forage species across all sites; however, spruce was the most abundant tree species in low severity sites. Although high-severity sites have greater stem densities, they had the highest percentage of brooming (54%, SE=4%) contrasted to low (38%, SE=7%) and moderate (42%, SE=7%) severity sites. Additionally, moderate (60%, SE=1%) and high (38%, SE=6%) severity sites had the highest rates of percent dead material by volume compared to low-severity sites (22%, 3%). High-severity sites also had the most number of mature trees that had grown out of moose browsing height (0.28 trees/m², SE= 0.04 stems/m²) related to moderate (0.08 stems/m², SE= 0.04 stems/m²) and low-severity sites (0.06 stems/m², 0.04 stems/m²). Lastly, high severity sites also have high rates of plant mortality (38%, SE=6%) and 54% (SE=4%) of plants sampled showed signs of intensive browsing in the past (i.e. broomed). Low-severity sites had the lowest mortality rates 22% (SE=3%) and proportion of broomed plants 38% (7%).

Browse production estimates varied by fire severity class. High-severity sites produced a mean of 267.57 (SE=26.29) kg/ha and low-severity sites produced a mean of 172.06 (SE=15.97). The proportion of annual browse production that was consumed by moose (offtake) varied across fire severities. Offtake was highest in moderate-severity sites at 33% (SE = 7%), lower in high-severity sites (27%, SE = 6%), and lowest in low-severity sites (11%, SE = 4%). However, there was a significant difference in forage offtake only between high-severity and low-severity sites ($t = 2.2$, $p = 0.05$). Whereas the average forage production has increased slightly (5%) since 2007 (Lord 2008), the proportional removal across all sites has declined significantly from 33% in 2007 (Lord 2008) to 23% in 2013. This decline is especially apparent in high-severity sites where proportional removal has declined by half since 2007 (Lord 2008). Additionally, production of aspen and *Salix* spp. has declined substantially in both high and moderate severity sites since 2007. However, in low-severity sites, aspen and *Salix* production has increased nearly three-fold.

PPC, CP, and DP concentrations varied strongly across species within the burn. PPC were highest in *Salix* sp. that were located in high-severity sites (0.067 µg/ µg, SE=). CP concentrations were highest in *Populus tremuloides* (7.8%, SE=0.11) also located in high-severity sites. The overall digestible protein concentrations were greater in *Populus tremuloides*

(1.86%, SE=.11) than in *Betula neoalaskana* and *Salix* sp. (Figure 4). We did not see significant differences in CP or PCA concentrations across severities; however, *Populus tremuloides* DP

Figure 2: Digestible protein concentrations of *Betula neoalaskana* (BENA), *Populus tremuloides* (POTR), and *Salix* sp. (SASP) within high- and low- severities. Mean (95% CI) a percentage of dry matter.



was significantly greater in high-severity sites versus low-severity sites ($p=0.025$).

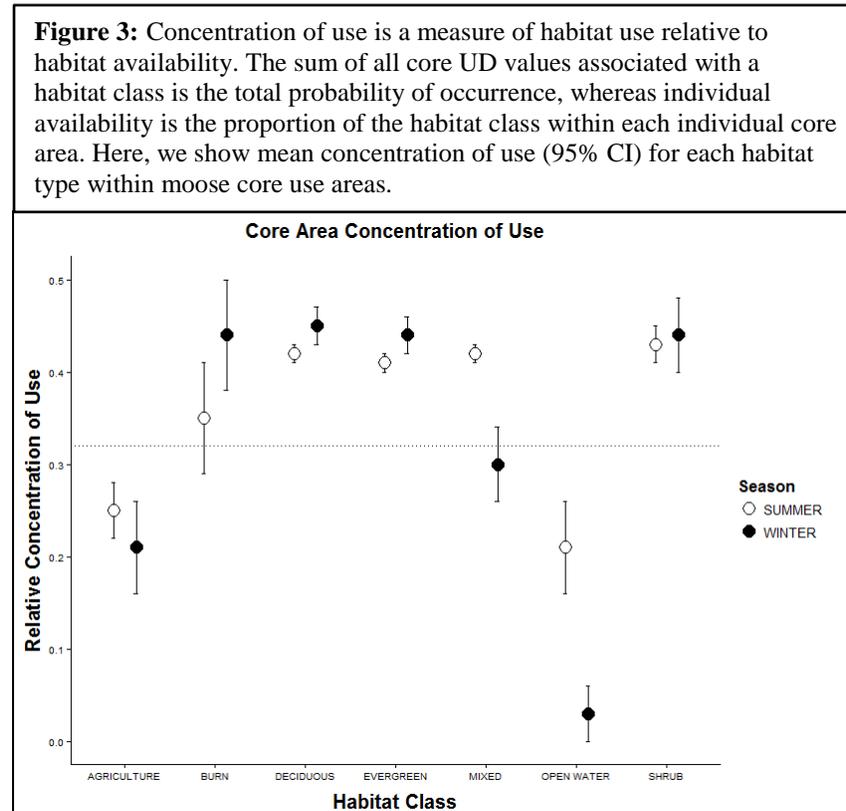
We estimated 50 UD_s (26 winter, 24 summer) from radio-collared moose throughout our study. Core use isopleths ranged between the winter 31%–47% ($X=40%$, $SD=4%$) and summer season 61%–67% ($X=64%$, $SD=2%$). During the winter season, mean home range size was 20.5 km² ($SE=2.3$) and mean core area size was 1.2 km² ($SE=0.1$ km²). In the summer months, mean home range size was 32.3 km² ($SE=1.9$) and mean core area size was 6.3 km² ($SE=0.4$ km²). Since we found no significant difference in core area size among years (2012–2014), data were pooled across years

to analyze seasonal habitat use. During the winter, habitat availability across individual home ranges was greatest in the HCB (winter=66%, $SE=0.07$) followed by unburned deciduous (winter=44%, $SE=0.03$) and evergreen forest types (38%, $SE=0.03$). In the summer, habitat within the evergreen (56%, $SE=0.03$) and HCB (53%, $SE=0.07$) was most available. Within individual core areas, moose selected the burn more during winter than summer months (Figure 3). Moose showed pronounced selection for burned habitat along with unburned shrub, deciduous and evergreen patches (Figure 3), however, mean selection did not differ significantly from deciduous ($F=2.21$, $p=0.10$), evergreen ($F=1.27$, $p=0.27$), or shrub habitat ($F=0.06$, $p=0.81$). During summer, moose also selected for burned patches but again there was no significant difference between deciduous, evergreen, shrub and mixed forest patches ($F=1.54$, $p=0.19$).

When examining use within the burn during the winter season, moose selected for low-severity patches more than high ($F=3.90$, $p=0.05$) and moderate ($F=32.61$, $p=0.0008$) severity patches (Figure 4). Concentration of use did not differ between low-severity and unburned patches ($F=0.015$, $p=0.902$). However, during summer, moose selected high-severity patches significantly more than low-severity patches ($F=4.39$, $p=0.04$) and moderate severity patches ($F=5.35$, $p=0.02$). Just as in winter, moose concentration of use did not significantly differ between high-severity patches and unburned patches ($F=0.024$, $p=0.877$).

MANAGEMENT IMPLICATIONS

The findings from this study will be useful when prioritizing areas for wildlife management. As wildfire characteristics, such as severity, continue to change under a warming



climate, managers can expect to see changes to plant species composition, soil-plant interactions, fire return interval, and wildlife distribution. Fire-related changes to the community composition of forest stands would likely affect the types of ecosystems that human communities rely on for hunting and trapping. Moose constitute the largest non-fish subsistence resource in Interior Alaska (Nelson et al. 2008), making fire-related habitat shifts especially important given that stable populations of moose act as a key ecosystem service in this region. A conversion of black spruce stands to aspen following a severe fire can

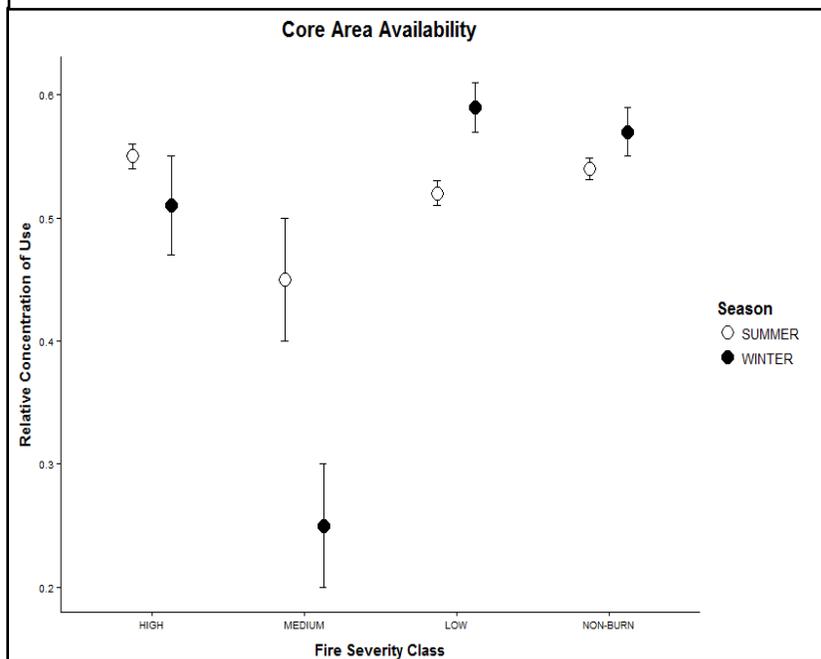
offer opportunities for moose hunters in interior Alaska, but it will require attention to ensuring access into new burned areas (Brown et al. 2015). Alternatively, other wildlife species, such as caribou may actively avoid recently burned areas (Rupp et al. 2006). Like moose, forage availability appears to be the key driver controlling fire effects on caribou (Klein 1982, Joly et al. 2003). However, caribou require late-successional vegetation such as lichens in mature spruce forests instead of the early successional deciduous forests that moose use. Future research should incorporate the effects of fire on the full assemblage of Alaskan boreal wildlife communities

It is clear that managing fire to benefit wildlife will create new and often challenging management decisions. For example, fire suppression decisions will likely hinge on proximity to human infrastructure and may limit future access into areas for subsistence. Collaborative communication between fire and wildlife managers will be very important to the overall success of these strategies. Another key challenge for managers will be prioritizing areas that offer important ecosystem services. This can be especially difficult when operating under finite resources, i.e., limited budgets and staff. Monitoring a few important variables following a fire event, e.g., biomass production, can provide information that will aid in the prioritization process. Understanding the habitat variables that are driving wildlife population dynamics following a wildfire event will become especially important when setting long-term management goals. In a time of rapid change across northern ecosystems, wildlife management must incorporate both adaptive and holistic approaches to managing fluctuating wildlife populations as resource conditions change.

RELATIONSHIP TO OTHER WORK

Research in the HCB found that increasing severity has shifted black spruce stands towards deciduous dominated stands (Johnstone et al. 2010, Shenoy et al. 2011). Concurrently, Lord and Kielland(2015) found that proportional production and removal of aspen by moose was

Figure 4: Fire severity classes were first determined by post-fire satellite imagery and ground-truthed with field based comparisons of the degree of SOM (Michalek et al. 2000). The *NON-BURN* variable refers to areas within the burn perimeter that were not consumed by fire. The sum of all core UD values associated with a fire severity class is the total probability of occurrence. Whereas, individual availability is the proportion of the fire severity class within each individual core area. Here, we show mean concentration of use (95% CI) for each habitat type



positively correlated with severity within the HCB. However, it was unknown the extent to which moose utilized the burn throughout the year. We found that the HCB was the most abundant habitat class across individual moose home range and core use areas. At the home range scale, moose selected for the HCB as well as several other habitat features (e.g., shrub, deciduous) during both winter and summer seasons. Moose selected core use areas with increasing availability of willow biomass (i.e., low-severity sites) more than areas that have the most available woody browse biomass or higher concentrations of digestible protein (i.e. high-severity sites) during the

winter season. Alternatively, in summer, moose selected for high-severity sites more than low and moderate-severities. The increase in selection for high-severity sites in summer may be due to cover (both thermal relief and predator avoidance) provided by deciduous tree and shrub species.

Additionally, in 2007, proportional removal rates by moose in high-severity sites of the HCB were some of the highest recorded in the state (Lord 2008). However, it was unknown whether moose would still be using burn habitat 20 years post-fire. By comparing biomass production estimates between 2007 and 2013, we gained considerable insight into the longevity of habitat availability that is likely an important driver of moose habitat use. Low-severity sites, in particular, have been slower to regenerate since time of fire due to cooler soils with low-nutrient levels. However from 2007 to 2013, willow biomass production increased in these low severity sites and moose seem to be responding to changing successional conditions by utilizing habitat in low-severity sites during the winter. In our study area, biomass production and removal estimates across high-severity sites peaked at around 2007, or about 13 years post-burn. Since

then, high-severity sites have experienced a slight decrease in biomass production. However, these sites also have high levels of plant mortality, increased rates of brooming, and the most mature trees, which may result in significant decrease in proportional removal. These results indicate that winter habitat quality, in the form of browse availability, is starting to decline 20 years post-burn across high-severity sites, but may still be increasing in low-severity sites. These results suggest that burns with a mosaic of fire severities, can influence the longevity of habitat availability for moose. Our results also indicate that moose are still utilizing burn habitat 20-years post burn.

The seasonal shift of habitat use patterns within the burn suggests that fire severity patches can offer different resources depending on the time of year. During summer, moose select for high-severity sites over moderate and low-severity sites (Figure 4). High-severity sites have the greatest number of stems/m². Despite the high rates of brooming and plant mortality, these sites are comprised of a more abundant understory layer providing both summer forage as well as shade. During summer months, ambient air temperatures above 57° F are stressful for moose and as a result, moose may seek out vegetative cover during hot days (Renecker and Hudson 1986, Dussault et al. 2004). Moose may also seek vegetative cover to minimize risk of predation. Predation by wolves and bears is a strong limiting factor to moose recruitment in parts of Interior Alaska (Gasaway et al. 1992). In burned landscapes where predator densities are high, moose habitat use may be influenced by the risk of predation. However, in areas where predator densities are suppressed with low to moderate calf mortality (e.g., HCB), forage availability during the winter becomes the major limiting factor of moose survival (Boertje et al. 2009). Our results indicate that differences in fire severity within a burn can produce a dynamic, spatially heterogeneous landscape that can influence seasonal moose habitat use.

FUTURE WORK

Future directions for this project involve the processing of harvest data to investigate the effects fire may have on moose hunting in our study area. We will compare harvest tickets from moose hunted within or close proximity to the burn to other non-burned areas in SWGMU 20D. Additionally, future research on wildfire-moose interactions could investigate further the effects of fire on moose populations. Here, we show that moose are using the burn throughout the year, but we do not know if this is translating into more moose on the landscape. It would be interesting to look into the effects of fire on body condition (e.g. rump fat thickness) and whether this translates to an increase in fecundity. Furthermore, I think the nutritional work from this project can be expanded. We captured a brief snapshot of browse quality within the burn. It would be interesting to study the effects of fire severity overtime on browse quality as forest stands regenerate after a burn.

DELIVERABLE CROSSWALK

Deliverable Type	Description	Delivery Dates	Status
Professional Meetings	North American Moose Conference, Girdwood, AK (April 2014); Ecological Society of America, Baltimore, MD (August 2015).	2014-2015	Complete
Data sharing	Moose GPS location data, fire severity/vegetation data, to Alaska Department of Fish and Game, SNAP, UAF	Fall 2015	Complete
Webinar	Present Webinar highlighting key results Scheduled for November 16, 2015 www.frames.gov/partner-sites/afsc/home/	November 2015	In Prep
Report	Report on key results and management suggestions to state agencies (ADF&G and Department of Natural Resources).	December 2015	Complete
Ph.D. dissertation	I will complete my PhD program in the effects of wildfire on moose habitat use, nutrition, and harvest.	Spring 2016	In Prep

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