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Resource selection of free-ranging horses influenced by fire in northern Canada

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Abstract: Free-ranging or feral horses (*Equus ferus caballus*) were important to the livelihood of First Nations and indigenous communities in Canada. The early inhabitants of the boreal region of British Columbia (BC) capitalized on naturally occurring wildfires and anthropogenic burning to provide forage for free-ranging horses and manage habitat for wildlife. This form of pyric herbivory, or grazing driven by fire via the attraction to the palatable vegetation in recently burned areas, is an evolutionary disturbance process that occurs globally. However, its application to manage forage availability for free-ranging horses has not been studied in northern Canada. Across Canada, there are varying levels of governance for feral and free-ranging horses depending on the provincial jurisdiction and associated legislation. The BC Range Act (Act) allows range tenure holders to free-range horses that they own for commercial operations on Crown land. Big-game guide outfitters as range tenure holders are provided grazing licences or grazing permits under the Act with an approved range use plan. Guide outfitters and other range tenure holders have incorporated fire ecology as part of their rangeland management in mountainous portions of the boreal forest of northeastern BC to promote mosaics of vegetation height and species composition across the landscape to meet nutritional requirements of their free-ranging horses. Using resource selection function models, we evaluated the influence of pyric herbivory on boreal vegetation and use by horse herds occupying 4 distinct landscapes. We found that horses preferentially selected recently burned areas and areas that burned more frequently when they were available. We also found that horses avoided steep slopes and forest cover types. Fire and the ecological processes associated with it, including pyric herbivory, are important considerations when managing boreal rangelands in northeastern BC. Because historical fire regimes of the boreal region of Canada differ from the arid regions of the United States inhabited by feral horses, the role of pyric herbivory in altering horse distributions in the United States is limited.

Key words: boreal forests, Canada, *Equus ferus caballus*, fire, guide outfitters, horses, pyric herbivory, rangelands

In Canada, free-ranging or feral horse (*Equus ferus caballus*) ecology and management is complex due to the intersection of indigenous people groups, challenging environmental features, variable provincial and national policies and regulations, and regular disturbance regimes such as fire (Blackstock and McCallister 2004). These fire regimes occur variably in space and time, and consequently, free-roaming herbivores including horses and wildlife may distribute across the landscape to access more palatable vegetation (i.e., pyric herbivory) afforded in recently burned areas (Fulendorf et al. 2009, Allred et al. 2011). Today, free-ranging horses still occur in the western forests, central prairies, and eastern coastal regions of Canada, with distinct populations occurring in the provinces of British Columbia (BC), Alberta, Saskatchewan, and Nova Scotia (Notzke 2016). Modern horses have been present in BC for 200 years or more with the current BC horse populations estimated at 54,000–90,000 head including all domestic, free-ranging, and feral horses (Gayton 2010).

Historically, equids have been important to sustaining First Nations and indigenous communities in Canada for the last 200–400 years (Blackstock and McAllister 2004). Native people (hereafter natives) caught and used horses for traditional practices such as hunting and trapping and have bestowed both spiritual and cultural values on the horses (Kincaid and Fletcher 2017). Early explorers reported that natives in Alberta often raided the East Kootenay natives to steal their horses and that horses were hunted and eaten in the Invermere area in the late 1700s and early 1800s (Campbell and Bawtree 1998). As early as 1808, the explorer Simon Fraser traded horses with indigenous tribes in the area of Soda Creek and reported natives with horses between Quesnel and Lytton, BC (Campbell and Bawtree 1998, Gayton 2010). Fur trading brigades used hundreds of horses in the summer with many routes across Canada (Campbell and Bawtree 1998). For example, the Hudson's Bay Company had established large herds near Soda Creek and by 1859; Captain John Palliser noted the "Kootenay Indians kept herds of fine horses… presumably the progeny of animals introduced by Sinclair and his party in 1841" (Gayton 2010).

In 1913, the Forest Branch of BC estimated that 11,000 free-ranging horses were present on rangelands. After 1919, horse grazing authorizations were established for Crown rangeland under the Grazing Act to better manage free-ranging horses (Campbell and Bawtree 1998). Concentrated efforts made to remove unauthorized free-ranging horses from Crown land from 1950–1970 improved range condition (Campbell and Bawtree 1998). As efforts to manage horses developed across Canada, provincially-specific guidelines were established independently and varied in how horses were designated to be feral or free-ranging, and as such how horses could be gathered or managed, and what permits or authority were required.

Contemporary management of Canada's free-ranging horses

Free-ranging horses are still present in several locations in Canada, including small distinct populations on Sable Island, Nova Scotia, and the Bronson Forest near Lloydminster, Saskatchewan (Notzke 2016, Kincaid and Fletcher 2017). Wild or feral horse populations have also been documented in western Canada in the Rocky Mountain foothills of western Alberta (Salter and Hudson 1982) and in the Chilcotin of the interior of BC in the Brittany Triangle sub-population (Cothran and McCrory 2014), where the Xeni Gwet'in First Nation and others have raised awareness of their presence on the landscape (Bhattacharyya et al. 2011).

Management of free-ranging horses is variable, with some situations falling under the jurisdiction of the provincial governments such as in BC and Alberta when found on Crown land, but in other areas horses are federally protected such as the Sable Island horses in Nova Scotia (Bearcroft 1966, Kincaid and Fletcher 2017). Such jurisdictional and legislative variation is evident in the province of Alberta, where horse capture permits can be obtained under the Stray Animals Act (AESRD 2014*a*, AESRD 2014*b*) and according to the Horse Capture Regulation (Alberta Regulation 59/1994 with amendments up to and including Alberta Regulation 123/2017; Province of Alberta 2018).

In BC, policies only address horses through the mechanism of ownership of livestock so far as governing horses that are owned by ranchers, guide outfitters, First Nations, and indigenous communities. In addition to truly feral horses in Canada, free-ranging horses that are privately owned are also present on the landscape and provide insight into horse ecology and distribution. However, at the national administrative level, these free-ranging equids are recognized for their cultural importance nationally through the National

Figure 1. Free-ranging horses (*Equus ferus caballus*) on native rangeland after the hunting season in northeastern British Columbia, Canada (*photo courtesy of S. Leverkus*).

Horse of Canada Act of 2002. Bhattacharyya et al. (2011) suggested the difference in terms between wild and feral are a distraction from the priority discussion of how horses interact with the landscape, and because we are primarily interested in equid responses to complex landscapes, we henceforth refer to them as free-ranging horses.

Crown lands (i.e., public land) are managed by a number of BC government agencies. The BC Livestock Act (Province of British Columbia 2018*b*) and Forest and Range Practices Act (Province of British Columbia 2018*a*) outline the process for capturing animals at large to include free-ranging horses specifically if it is determined that damage is occurring. The Range Act provides for range tenure holders to graze free-ranging horses on Crown land if the holders have an approved range management plan and the horses are branded as per the BC Livestock Identification Act (Province of British Columbia 2018*c*). As such, free-ranging horses are now an important component of the landscape as guide outfitters in northeastern BC use horses for back-country commercial services (such as big-game hunting and other recreation) and are also licenced to graze these horses on Crown land. At the end of the hunting season, tenured horses are released to roam on rangelands through the winter to the following summer, allowing them to select resources alongside other native grazing and browsing ungulates (Figure 1).

Challenging environmental and disturbance features in Canada

Another feature distinguishing Canadian horse ecology and management from the United States is associated with more northern latitudes where the availability of grasses and forbs for horses is limited in the winter (Cornelissen and Vulink 2015), making forage site selection and availability important survival mechanisms (Figure 2). Horses prefer grasses when available and thus require open grass-dominated areas for foraging (Duncan 1983, Haber 1988, Beever et al. 2008, Vince 2011, Girard et al. 2013*a*, Scasta et al. 2016) along with other areas with features providing cover (Beever et al. 2008, Vince 2011, Girard et al. 2013*a*). From a thermal regulation perspective, south-facing slopes that are warmer with higher radiant heat and less snow in the winter provide critical winter grazing and browsing for animals due to the more exposed and productive graminoid-dominated communities (Luckhurst 1973).

The vegetation of the boreal region of western Canada, where free-ranging horses

Figure 2. Canadian horse (*Equus ferus caballus*) ecology and management differs from the United States because the more northern latitudes limit the season of growth and availability of grasses and forbs for horses, making site selection and availability important survival mechanisms. Note the global positioning system (GPS) radio-collar on the horse in the center of the photograph. As part of this study, big game guide outfitters deployed GPS radio-collars on select horses in their free-ranging herds after the hunting seasons to track the movement patterns and resource selection of the horses through the non-hunting season (*photo courtesy of S. Leverkus*).

roam extensive landscapes, has historically been influenced by naturally occurring fires (Seip and Bunnell 1985*a*, Peck and Peek 1991, Gottesfeld 1994, Sittler 2013). First Nations and other indigenous communities historically incorporated fire in their management of the lands, primarily targeting south-facing slopes, resulting in a spatial and temporal diverse cultural and vegetation landscape (Lewis 1978, Parminter 1983, Lewis and Ferguson 1988, Peck and Peek 1991, Leverkus et al. 2017). Cultural interactions between anthropogenic ignitions and horses were documented by Fort Nelson First Nation and Shifting Mosaics Consulting (2015) within the Fort Nelson First Nation community, such as: "I was born and raised at Kahntah, and my earliest memory of burning was when I was ten or twelve years old…They burned in the evening in the early spring for horses, and in August they would cut down the new growth. Deer would eat the new growth too," and "…we usually burned to maintain river/mountain corridors…to maintain land for horses, and for safety—to open visual corridors so you're not in a hole peeking through the bush" (Fort Nelson First Nation and Shifting Mosaics Consulting 2015).

Managing Canada's boreal forest for multiple-species with fire

Broad landscapes such as Canada's boreal forest are occupied by diverse guilds of flora and fauna that need variation in vegetation structure, composition, and spatial distribution to meet the varying resource requirements of each individual species that is often referred to as landscape heterogeneity (Rowe and Scotter 1973, Fuhlendorf et al. 2012, Leverkus et al. 2017). Such heterogeneous landscapes provide opportunities for individual species to select optimal habitat resources, whereas some species may require open areas but others may require closed-canopy forests (Rowe and Scotter 1973, Fisher and Wilkinson 2005, Leverkus et al. 2017). In a closed-canopy environment such as what is found throughout the boreal forest, open areas are characterized as relatively free of obstructions to sight or movement and are dominated by grass, bare ground, rock, soil, or low shrubs, lacking vertical structure and dense tree canopy cover (Leverkus 2015, Leverkus et al. 2017). In northwest Canada, these open features result from disturbances such as fire, geomorphological events (landslides and flooding), and anthropogenic development of the landscape. In particular, fire across the boreal forest has resulted in a shifting mosaic of varying degrees of openness since the last Ice Age, with recent fire providing the most open areas accessible for ungulate selection and use (Rowe and Scotter 1973, Goldammer and Furyaev 1996, Stocks et al. 2003, Leverkus et al. 2017).

Across this landscape, combined anthropogenic and natural fire has resulted in overlapping fire boundaries, making it virtually impossible to determine the extent to which any specific fire has burned (Parminter 1983). The season of fire historically begins with the application of prescribed fire in May followed by lightning fires, which start to peak in ignitions in June and July (Parminter 1983). However, the ecological disturbance of fire does not operate singularly. Pyric herbivory, grazing driven by fire or the fire-grazing interaction, is an evolutionary disturbance process that occurs globally but has not been studied in northern Canada. This interaction is a function of herbivores preferentially selecting recently burned landscapes (Pearson et al. 1995, Moe and Wegge 1997, Kramer et al. 2003, Klop et al. 2007, Murphy and Bowman 2007, Onodi et al. 2008, Allred et al. 2011). This preferential selection leads to focal grazing in recently burned patches, which keeps fuel loads low in these areas compared to other areas. From a management perspective, the primary process of maintaining and enhancing forage quantity, quality, and accessibility is through prescribed fire. This is where free-ranging horses and fire interact. As licenced range tenure holders under the BC Range Act, guide outfitters hold grazing licences or permits that are directed by provincially legislated range use plans (defined and stipulated by the BC Forest and Range Practices Act and the BC Range Planning and Practices Regulation). In BC, the Northern Guides Association and members of the Guide Outfitters Association of BC and Northeast BC Wildlife Fund have a long history of rangeland management in the province pertaining to forage for horses and habitat for wildlife and managing fire.

Study objectives

Although similar in some aspects to the feral horse issue in the United States (McKnight 1959, Notzke 2016), the management and ecology of horses in Canada is unique for many reasons, including social structures, habitat, weather and climate, and disturbance regimes. While fire and grazing have been studied in the region (Rowe and Scotter 1973, Lewis and Ferguson 1988, Sittler 2013), there has been minimal investigation to evaluate the fire-grazing interaction and subsequent resource selection of free-ranging horses. Understanding free-ranging horse grazing patterns in these complex landscapes as they relate to time since fire and habitat features is important because pyric herbivory is not generally included as a practice in natural resource management plans (Leverkus 2015, Leverkus et al. 2017) and there has been a lack of information about how horses use such landscapes. Beyond the basic animal ecology implications of such quantification of horse use of this complex landscape, understanding if the practice of prescribed fire is important to horses in northeastern BC is an additional step to developing applied ecosystem management strategies for large ungulates and the potential role of pyric herbivory. Given the unique boreal forest plant community, free-ranging horses, and anthropogenic fire, northeastern BC represents a large intact landscape that provides a novel opportunity to evaluate the resource selection of horses in the context of a forested landscape that is fire-prone (Leverkus 2015). Therefore, our objective was to evaluate resource selection of 4 free-ranging horse herds in BC relative to the biophysical environment that includes heterogeneous vegetation features and spatiotemporally variable fire. We postulated that time since fire and open habitat features will be strong and significant explanatory variables for horse resource selection.

Study area

British Columbia is the westernmost province in Canada and is the third largest province, occupying approximately 10% of Canada's land surface (Canadian Encyclopedia 2013). The study area is located within northeastern BC, comprised of 3 biogeoclimatic zones: boreal white (*Picea glauca*) and black spruce (*Picea mariana*), spruce-willow-birch, and alpine tundra (Parminter 1983). Within the biogeoclimatic zones, number of fires and time since fires drives the vegetation composition. Prescribed fire for wildlife habitat has converted trembling aspen (*Populus tremuloides*) and white spruce forests to open trembling aspen and shrub and herbaceous communities (Parminter 1983). Retreating glaciers have left a thin mantle of glacial drift and boulders over the region with specific deposits including lacustrine, morainal, and glaciofluvial deposits (Peck and Peek 1991). The climate characteristics of the study area include short summers with long, cold winters with annual precipitation averages of 44.6 cm (Peck and Peek 1991). Elevation ranges from <800 m to >2000 m with annual precipitation averaging 44.6 cm (Peck and Peek 1991).

We identified 4 horse herds in 2 watersheds in northeastern BC with varying fire histories

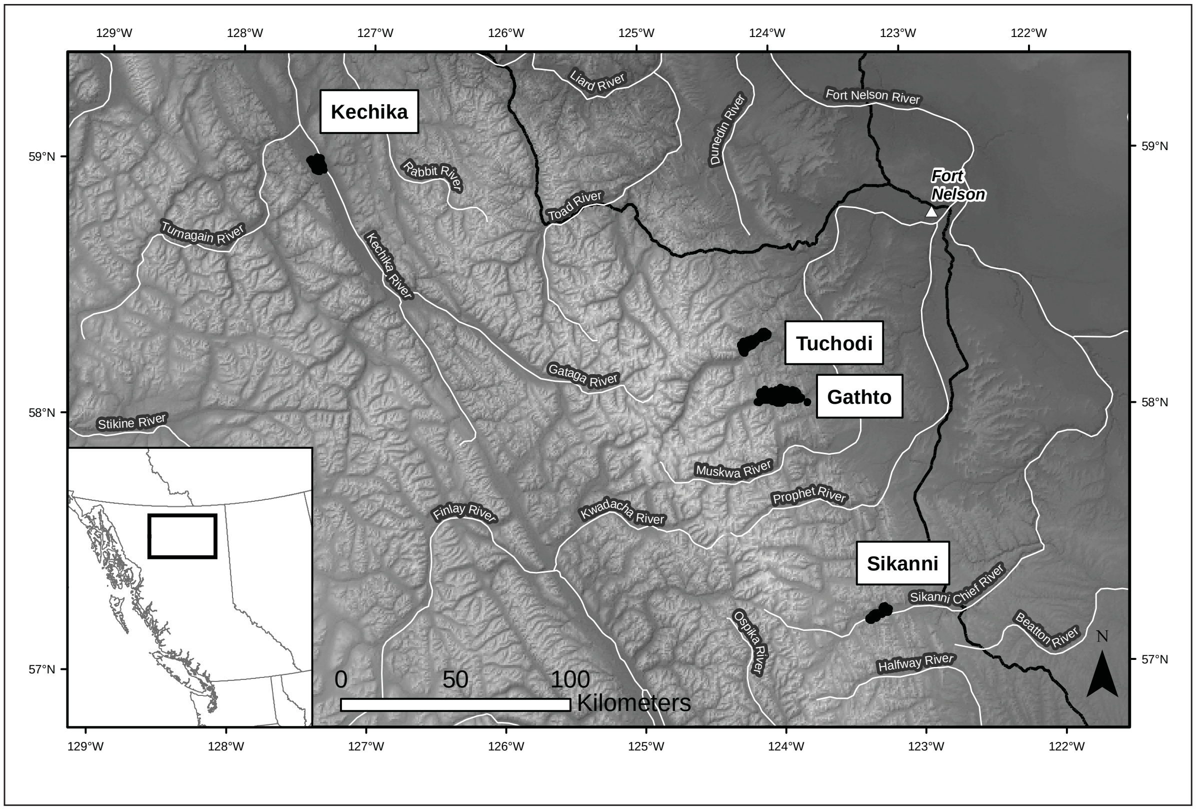

Figure 3. Global positioning system (GPS) locations (black points) from 4 horse (*Equus ferus caballus*) herds (Kechika, Tuchodi, Gathto, and Sikanni) located in northeastern British Columbia, Canada were spatially analyzed from 2010–2012 using minimum convex polygons (MCP), kernel density estimates (KDEs), and resource selection function (RSF) models.

resulting from both wildfire and prescribed fire (Figure 3). The Kechika horse herd, owned by Scoop Lake Outfitters, is located in the Kechika watershed with an area of 1,965,538 ha, of which 439,683 ha has burned by wildfire (413,050 ha) and prescribed fire (26,633 ha) over the past century (Leverkus et al. 2017). The Tuchodi (owned by Tuchodi River Outfitters), Gathto (owned by Big 9 Outfitters/High and Wild Wilderness Safaris), and Sikanni (owned by Sikanni River Outfitters) horse herds are located in the Fort Nelson watershed with an area of 1,295,040 ha, of which 206,721 ha has burned by both wildfire (113,910 ha) and prescribed fire (92,811 ha) in the past century (Leverkus 2015, Leverkus et al. 2017). Less than 7% of the burnable landscape in the Kechika watershed and <11% of the burnable landscape in the Fort Nelson watershed has burned within the past 25 years (Leverkus et al. 2017).

Methods

Telemetry data from 4 horse herds were acquired through Lotek Wireless Inc. (Newmarket Ontario, Canada L3Y 7B5) global positioning systems (GPS) deployed on 13 male horses between the ages of 5 and 12, as 4 replications in 4 different locations in the boreal cordillera: the Kechika (n = 5), the Tuchodi (n = 4), the Gathto (n = 3), and the Sikanni (n = 1) river valleys, from October 2010 to July 2012 (Figure 3). The Lotek 3300L GPS collars were programmed to record 24 GPS locations per day, once every hour (Collins et al. 2014). All horses were born in the mountains on native rangeland and were free-ranging from October to July in the non-hunting season. The ranging status of the horses during the hunting season is minimized by their use as work horses. Data were not collected during this time period.

We compared horse distribution to available conditions to determine use/avoidance of features across the landscape as a function of time since fire, number of times burned, presence of fire, 7 cover types (bare/rock, forest, aspen parkland, water, snow/ice, clouds, and grass), anthropogenic features, slope, and aspect. We established 3 random points for each observed location to provide estimates of available conditions (Allred et al. 2011), such as cover type.

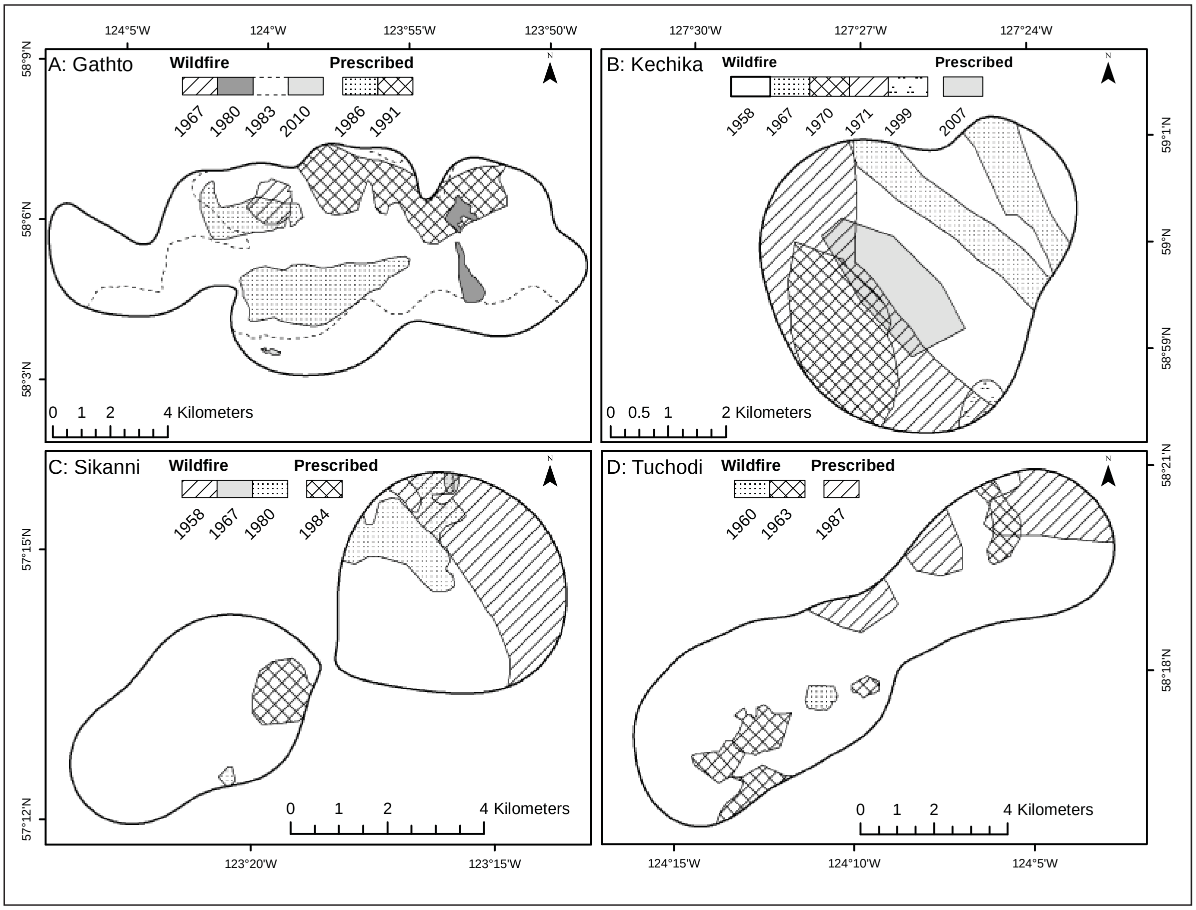

Figure 4. The fire history (wildfire and prescribed fire) from 1922–2012 of the area selected by 4 horse (*Equus ferus caballus*) herds in the Kechika, Tuchodi, Gathto, and Sikanni valleys within the 95% isopleth (black exterior line) was spatially analyzed to determine fire frequency and time since fire in northeastern British Columbia, Canada. Note the same prescribed fire unit was burned every year from 2007–2012 in the Kechika.

For analyses of vegetation selection, we focused on 2 spatial extents: broad scale and fine scale. The broad study area was intended to address the selection of a home range within broad landscapes while the fine scale extent was intended to address vegetation selection within the home range. The broad study area was determined through a combination of natural barriers and buffers on a Minimum Convex Polygon (MCP) to ensure a conservative estimate of where horses could easily select space. We determined the fine scale extent using the 95% kernel isopleth from the Kernel Density Estimate (KDE) as derived through Hawthorne's tools using ArcGIS9.3 and ArcGIS10.1 (Anderson et al. 2005, Leggett 2006, Compton et al. 2007, Laver and Kelly 2008, Girard et al. 2013*a*). We generated KDEs with a bivariate normal kernel and single parameter smoothing factor of 1000. The raster cell size used was 100 with 1,000,000 scaling factor. We used the 95% kernel isopleth to analyze selection and use on a fine scale (Figure 4; Worton 1989, Anderson et al. 2005, Kie et al. 2010).

We analyzed selection of cover type at the 4 locations using a combination of archived Landsat imagery from the U.S. Geological Survey (USGS) at 30 x 30-m resolution and cover type data at 20 x 20-m resolution from 2000 from the Canadian Council on Geomatics Geobase/Geogratis (Government of Canada 2009). Cover type data from 2010 were analyzed for the Tuchodi, Gathto, and Kechika and 2011 for the Sikanni.

Our multivariate analysis using isocluster unsupervised classification yielded 20 classes, which were re-classified into 7 broad cover types including: bare/rock, forest, aspen parkland, water, snow/ice, clouds (in the higher elevations, there was significant image interruption from clouds and scanlines), and grass. Isocluster unsupervised classification is a geographic information system (GIS) supported process that

Table 1. Estimated resource selection function coefficients for Kechika, Tuchodi, Gathto, and Sikanni horse (*Equus ferus caballus*) herds in northeastern British Columbia, Canada, from 2010–2012. Model parameters included presence within a fire, number of times burned, time since fire (years), cover type (bare, forest, grass, aspen [*Populus tremuloides* Michx.] parkland, water), northness and eastness (°; both derivatives of aspect), and slope (%). Standardized variables are shown for coefficient comparison. Standard error (SE) and significance (*P*) are included.

Resource variable	Kechika	SE	*P*	Tuchodi	SE	*P*	Gathto	SE	*P*	Sikanni	SE	*P*
Fire	-0.0587	0.0411	0.15	0.2479	0.0303	<0.01	1.0680	0.0290	<0.01	1.1472	0.1060	<0.01
Number of times burned	5.2473	0.0701	<0.01	-0.4948	0.0273	<0.01	0.6799	0.0220	<0.01	-0.4220	0.0857	<0.01
Time since fire	0.8272	0.0533	<0.01	0.3246	0.0159	<0.01	-0.4579	0.0206	<0.01	-0.6648	0.0573	<0.01
Bare	-0.1423	0.0386	<0.01	0.1171	0.0125	<0.01	-0.3273	0.0217	<0.01	0.6051	0.0324	<0.01
Forest	-0.4888	0.0318	<0.01	-0.5604	0.0133	<0.01	-1.1594	0.0234	<0.01	-0.5025	0.0428	<0.01
Grass	0.3968	0.0259	<0.01	0.2063	0.0101	<0.01	0.4897	0.0158	<0.01	0.5977	0.0460	<0.01
Aspen parkland	-0.1750	0.0258	<0.01	0.8102	0.0141	<0.01	0.3844	0.0204	<0.01			
Water	-0.4428	0.0414	<0.01	-0.1712	0.0133	<0.01	-0.1173	0.0123	<0.01	-0.5238	0.0777	<0.01
Eastness	-0.0243	0.0179	0.17	-0.1819	0.0082	<0.01	-0.0368	0.0112	<0.01	0.1001	0.0234	<0.01
Northness	-0.0996	0.0178	<0.01	0.0240	0.0081	<0.01	-0.0599	0.0112	<0.01	-0.0239	0.0235	0.31
Slope	-2.1581	0.0439	<0.01	-0.9343	0.0112	<0.01	-1.0370	0.0160	<0.01	-2.4823	0.0590	<0.01

Table 2. The research sites (named by the valley systems where they occur) located in northeastern British Columbia, Canada, from 2010–2012 with the broad area (ha) representing the home range and the fine scale area (ha) representing the site selection within the home range. Additional details include the number of individuals sampled, range of data collection, number of locations received per day, total number of animal months and total number of locations used for spatial analysis whereby the global positioning system collars were deployed on the horses (*Equus ferus caballus*) and data were collected. Number of fires and their respective areas across the broad scale are shown in hectares.

Site	Broad (ha)	95% (ha)	*n*	Sampling duration	# day	Months	Locations	Fires	Fire area (ha)
Kechika	268,059	2,223	5	10/2010–07/2012	24	45	25,829	58	223,357
Tuchodi	383,209	5,038	4	10/2010–07/2012	24	36	27,260	171	94,002
Gathto	383,209	9,462	3	10/2010–07/2012	24	27	21,767	171	94,002
Sikanni	27,636	3,230	1	11/2011–07/2012	24	8	4,387	49	9,939

analyzes spatial data and groups together similar classes of vegetation. Where interruption from clouds and scanlines occurred, we rectified the issue through reclassification using cover type data combination from Landsat 4/5 and Geogratis (Government of Canada 2009). Some rivers within the 4 study sites were classified as bare/rock in our analysis because of the transparency of the water. Digital Elevation Models (DEMs) were developed and analyzed for aspect and slope using data from the Government of BC geographic database (Government of Canada 2009, Leverkus 2015). The most current data on wildfires and prescribed fires in BC from 1922–2012 were spatially analyzed as per Leverkus (2015) and included time since fire (years), times burned, and presence in burned areas (Figure 4).

We developed resource selection function (RSF; Boyce et al. 2002) models for the 4 herds that included presence or absence of horses within features in the landscape with discrete boundaries. These features included burned areas, anthropogenic features (base camp locations and supplemental feeding locations), and cover type classes across the broad scale. We also quantified horse selection of the landscape by slope, aspect, time since fire (wildfire and prescribed fire), and number of times burned (wildfire and prescribed fire; Boyce et al. 2002, Duchesne et al. 2010, Allred et al. 2011, Girard et al. 2013*a*, Buchanan et al. 2014, Ehlers et al. 2014). Features were buffered by 5 m to account for potential inaccuracy in the GPS collar fix locations and edges of landscape features.

The resource selection variables were standardized as per Gelman and Hill (2007) and Allred et al. (2011). Aspect data were transformed to northing and easting (Allred et al. 2011). Multiple logistic regression with binomial distribution was performed using generalized linear models (GLMs) to estimate the RSF on the standardized variables (Bates and Maechler 2010). The RSF coefficients indicate direction of selection as either positive or negative. We ran 2 RSF models. The initial RSF model was an additive process starting with cover type. We progressively added fire and anthropogenic features such as supplemental feeding locations (salt licks, graining sites) and base camp locations. While horses preferentially select for anthropogenic features across the landscape (base camps and areas where salt and grain are distributed), these are minimal areas occupying less than a couple of hectares across the broad landscape; therefore, we then ran RSF models without anthropogenic features. This allowed us to gain an understanding of the selection for or against certain cover types and fire variables.

Results

Fire (i.e., number of times burned, time since fire, and burned areas), certain habitat features, and slope were all drivers influencing horse site selection across all 4 herds (Table 1). Our modeling incorporated 25,829 (Kechika), 27,260 (Tuchodi), 21,767 (Gathto), to 4,387 (Sikanni) horse locations obtained in BC from October 2010 to July 2012 (Table 2). The geographic extents of each scale vary from the broad scale in the Kechika (268,059 ha) to the fine scale extent using the 95% kernel isopleth in the Kechika (2, 223 ha; Table 2).

Resource selection coefficients indicated that the response to time since fire varied among the herds. Horses in the Gathto ($P < 0.05$; Gatho = -0.46) and Sikanni ($P < 0.05$; Sikanni = -0.66) selected recently burned areas. As time since fire increased, the probability of horses being present decreased. However, the Kechika ($P < 0.05$; Kechika = 0.83) and Tuchodi ($P < 0.05$; Tuchodi = 0.32) herds selected for time since fire.

Horses from the Kechika and Gathto herds selected for number of fires with the Kechika herd having 5 times the preference over all the other herds. There were more recent fires and number of fires available on the landscape in the Kechika herd distribution area. Horses in the Tuchodi and Sikanni selected against number of times burned (Table 1). This suggests a decreased probability of horse presence as the number of times an area burned increased.

Based on RSF coefficients, horses selected for lower slopes ($P < 0.05$; Kechika = -2.52, Tuchodi = -0.93, Gathto = -1.04, Sikanni = -2.48; Table 1). Horses across all 4 herds avoided steeper slopes with the strongest avoidance by the Sikanni and Kechika herds (Table 1). While all 4 horse herds were free to roam across broad landscapes in northeastern BC (Figure 3), they selected areas represented by the 95% isopleth (Table 2).

Forest and aspen parkland were the primary cover types across the region. The surrounding areas of the fine scale sites were often composed of a landscape that may have experienced multiple fires since 1922 and earlier (Figure 4). Within the areas selected by horses, 12 fires burned in the Kechika (6,799 ha), 13 fires burned in the Tuchodi (1,368 ha), 11 fires burned in the Gathto (9,542 ha), and 10 fires burned in the Sikanni (7,528 ha) since 1922 (Figures 5 and 6).

Resource selection coefficients were consistent with the hypothesis that horses selected for specific cover types (Table 1). Horses had highest use of aspen parkland and grass of all cover types (Table 3). Horses spent 68–98% of their time in open cover types (aspen parkland and grass), which represent 43–71% of the area, respectively (Table 3). Horses avoided forest cover type ($P < 0.05$; Kechika = -0.49, Tuchodi = -0.56, Gathto = -1.16, Sikanni = -0.50). Specifically, horses spent 2– 13% of their time in closed canopy forest cover type that represented 17–52% of the landscape.

Discussion

Our results showed that the free-ranging horses in our study were strongly attracted to areas managed by recent fire (times burned, time since fire, and burned areas) and open cover type. Specifically, time since fire and number of fires drive the availability, access

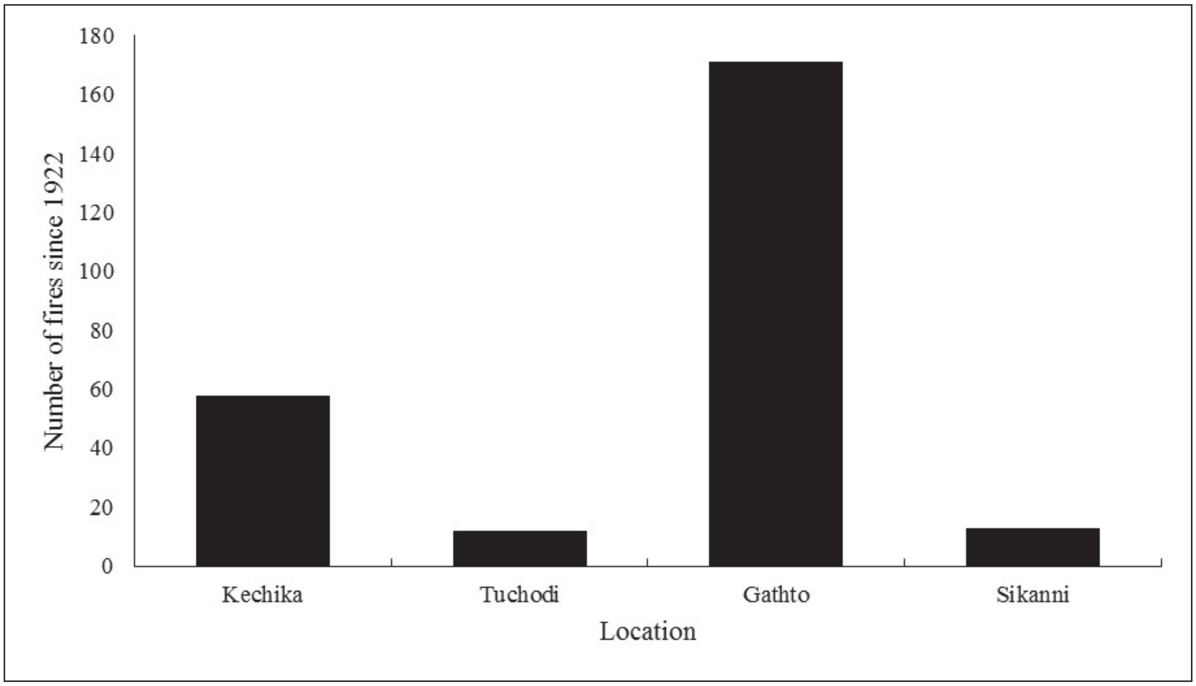

Figure 5. The number of fires (wildfire and prescribed fire) from 1922–2012 across the selected areas derived from the 95% isopleth of each horse (*Equus ferus caballus*) herd (Kechika, Tuchodi, Gathto and Sikanni) in northeastern British Columbia, Canada was analyzed using Microsoft Excel and ESRI ArcGIS.

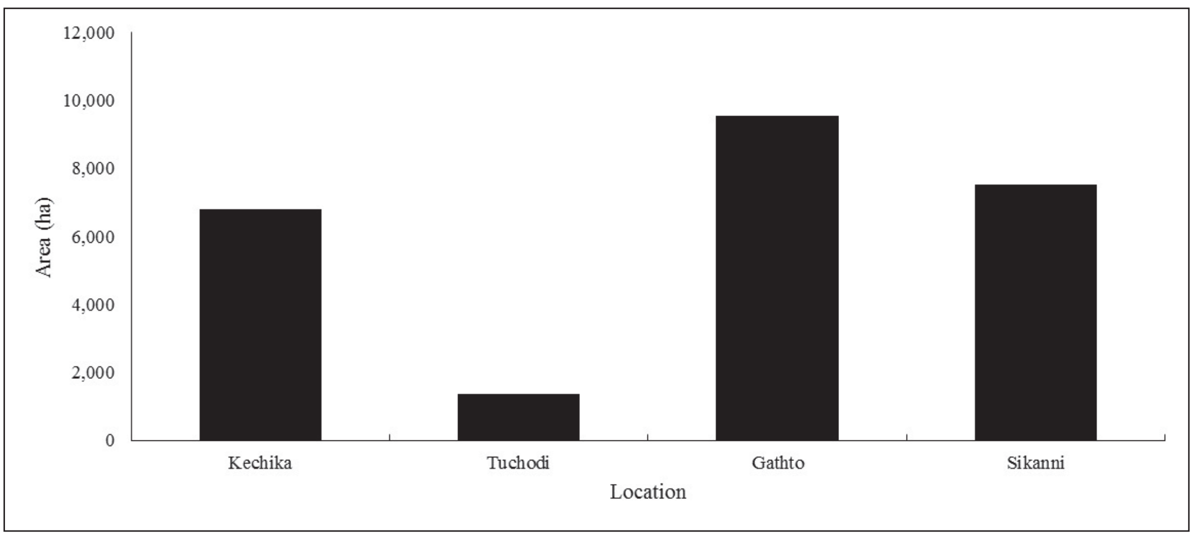

Figure 6. The total recorded area burned from 1922–2012 across the selected areas derived from the 95% isopleth of each horse (*Equus ferus caballus*) herd (Kechika, Tuchodi, Gathto and Sikanni) in northeastern British Columbia, Canada was analyzed using Microsoft Excel and ESRI ArcGIS.

to, and quality of grazing areas for horses on rangelands in the boreal forest (Figure 6). In BC, vegetation structure, composition, and distribution are influenced by time since disturbance in the region (Rowe and Scotter 1973). Across the Kechika and Fort Nelson watersheds, vegetation and cover type were influenced by areas burned by fires coupled with herbivory. Thus, in this boreal forest, rangeland vegetation composition, structure, and richness were driven by fire frequency and affected how free-ranging horses used the landscape. The number of times an area burns within the boreal forest may increase the accessibility to an area through larger openings with less vertical structure. Fire in these landscapes optimized the proportion of grass and aspen parkland features, which attracted horses. Conversely, our results showed that horses avoided forest cover type, which was consistent with the findings of Girard et al. (2013*b*) who found that horse use was positively related to distance to forest edge.

The fire-grazing interaction was important for horses on northern rangelands where steep slopes and exposed rock prevent access and distribution across the landscape. This was consistent with the findings of Girard et al. (2013*b*) for free-ranging horses in Alberta that selected against terrain ruggedness as well as Hull et al. (2014), who documented that both giant pandas (*Ailuropoda melanoleuca*) and horses selected for low slopes with high solar radiation in China. Aspect and water had minimal influences on horse distribution across the landscape. This may be due to the seasonality of snow and open-water abundance and availability and the ability to meet nutritional requirements.

Although the forage quality and quantity between a closed-canopy aspen parkland and a closed-canopy conifer forest may differ (Leverkus 2015, Leverkus et al. 2017), there was limited imagery available to analyze these specific differences. Both forest types had experienced a longer time since fire in comparison to the aspen parkland class. Forest canopy cover may limit forage abundance and access to forage, suggesting that resource selection could be influenced by the presence or absence of a forest canopy.

Kaczensky et al. (2008) demonstrated that Przewalski's horses select for productive plant communities, similar to those available to free-ranging horses in northern Canada where recent fires have occurred and canopy coverage was altered. Similar results have been demonstrated by Lord and Luckhurst (1974), where 60% of thinhorn stone's sheep (*Ovis dalli stonei*) winter forage was dependent on the hairy wild rye (*Elymus innovates*) plant community, a feature that is dominant following fire on northern rangelands and selected for by horses and other ungulates. Resource selection by other species for more recently burned areas occurs during the winter months, particularly when forage is limited (Seip and Bunnell 1985*a*, Seip and Bunnell 1985*b*). This could also be attributed to fire, as structurally open rangeland sites have less snow accumulation and lower snow depths than forested areas due to a greater wind and thermal influence, which is essential for ungulate utilization of northern rangelands in winter (Elliott 1983).

Rangelands in the boreal forest are similar to other rangeland systems in that herbivores were attracted to fire (Allred et al. 2011, Fuhlendorf et al. 2009). Focused grazing occurs on recently burned patches and lowers fuel loads in these areas compared to other areas. However, a single fire in an area may not be sufficient to meet the desired effects. Pyric herbivory is not clearly recognized in range management practices and policies, which continue to encourage uniform distribution of livestock (Province of British Columbia 2006) without taking into account the need for variability in vertical structure and composition of vegetation across the landscape (Allred et al. 2014, Hovick et al. 2015).

Rangeland management in BC centers around the deviation from potential natural community (Province of British Columbia 2006), which does not allow for disturbance processes to be considered as positive influences on the landscape. Furthermore, this removes the human context from the landscape that has been documented as an important ecosystem driver (Lewis and Ferguson 1988, Gottesfeld 1994, Pyne 2007).

Range tenure holders are both authorized to graze their horses on Crown land and responsible for rangeland management, ensuring appropriate livestock distribution, forage availability, and conservation of other values such as preventing the introduction and spread of invasive plants and their propagules. However, free-ranging horses introduced by non-tenured users of the same landscape are not held accountable to this same standard, therefore causing potential impacts on rangelands by consuming forage that was intended and managed for tenured use, introducing invasive plants and their propagules through hay and other feed transported from non-local sources, among other factors including animal health challenges such as equine infectious anemia (Gayton 2010).

Most prescribed fires across this landscape were not randomly distributed, yet they provided grazing yards and corridors, providing nutrition for multiple species (Rowe and Scotter 1973, Lewis and Ferguson 1988). It was difficult to separate the effects of the variables slope and fire because guide outfitters

Table 3. Horse (*Equus ferus caballus*) global positioning system locations per herd were analyzed using Resource Selection Function (RSF) models for percent of locations spent within each resource variable of cover type (bare, forest, aspen [*Populus tremuloides* Michx.] parkland, water, snow/ice, and grass) and anthropogenic features (base camps and supplemental feeding locations) across the finer scale extent derived from the 95% isopleth from 2010–2012 in northeastern British Columbia, Canada. The cover type classes of cloud, shadow, and edge of image were removed as they represented <1% of the area.

Study area	RSF variable	Area (ha)	% of area	# locations	% locations
Kechika	Total landcover	2,223	100	25,353	100
	Bare	2	0.1	18	0.1
	Forest	376	16.9	535	2.1
	Aspen	938	42.2	11,537	45.5
	Water	656	29.5	92	0.4
	Snow/ice	2	0.1	0	0.0
	Grass	248	11.1	13,171	52.0
	Anthropogenic	64	2.9	1,151	4.5
Tuchodi	Total landcover	5,039	100	26,924	100
	Bare	404	8.0	1,396	5.2
	Forest	1,294	25.7	3,011	11.2
	Aspen	2,568	51.0	19,484	72.4
	Water	33	0.6	35	0.1
	Snow/ice	70	1.4	13	0.0
	Grass	667	13.2	2,986	11.1
	Anthropogenic	17	0.3	1,494	5.5
Gathto	Total landcover	9,462	100	20,861	100
	Bare	418	4.4	323	1.5
	Forest	2,246	23.7	620	3.0
	Aspen	4,699	49.7	14,098	67.6
	Water	34	0.4	77	0.4
	Snow/ice	0	0.0	0	0.0
	Grass	2,057	21.7	5,743	27.5
	Anthropogenic	0	0.0	0	0.0
Sikanni	Total landcover	3,230	100	4,377	100
	Bare	49	1.5	868	19.8
	Forest	1,678	51.9	546	12.5
	Water	71	2.2	2	0.0
	Grass	1,393	43.1	2,961	67.6
	Anthropogenic	17	0.5	1,903	43.5

did not randomly burn, and it is likely that they burned lower slopes. Rangeland management is not production based for livestock in this region, but rather for survival of horses through the winter with secondary benefits for other species occupying the same area and the provision of forage and browse throughout the year. The historical practice by guide outfitters and range tenure holders appears to be appropriate because horses were attracted to fire-derived habitats (or patches) on the landscape. However, the lack of fire-derived habitats on these watersheds results in concentrated use and focused selection on grass and aspen parkland by grazing and browsing herbivores. Continual spatio-temporal distribution of fire across these watersheds will be needed for herbivores to remain on the landscape (van Wilgen et al. 2007).

Management implications

Our study suggested that open cover types dominated by grasses within a mosaic of forest cover types were more likely to be used more frequently than they were available by free-ranging horses. If the desire is to continue permitting grazing animals in remote locations, or maintaining unmanaged free-ranging horse populations in similar ecosystems, appropriate resources must be made available for them. Long-term rangeland maintenance based on historical disturbance regimes and current landscape objectives will be required. This can be achieved through the Landscape Disturbance Matrix with continued application of prescribed fire to increase open rangeland conditions and to promote pyric herbivory. Because the diet of horses primarily consisted of sedges and grasses available in grassland meadows and aspen parklands, processes such as fire that produce such vegetation were critical for horse herds we studied. Time since fire and number of fires drive the availability and quality of grazing for horses on rangelands in the boreal forest. Because the historical fire regimes of the boreal area we studied differ from the arid regions of the United States currently occupied by feral horses, the role of fire in altering horse distribution in these arid regions is limited.

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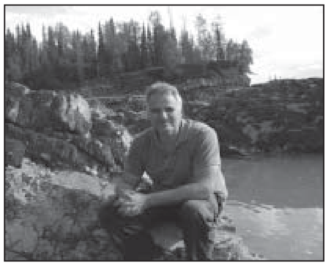

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