CONSERVATION OF BIODIVERSITY IN NORTHERN CANADA THROUGH ECOLOGICAL PROCESSES AND CULTURAL LANDSCAPES

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Abstract: Disturbance processes are critical to ecosystem function and resilience. Across a landscape, fire varies in space and time, which results in a shifting mosaic of patches with different fire return intervals and vertical structure, promoting habitat heterogeneity and biodiversity. The spatiotemporal distribution of fire across the boreal landscape is critical for many species. The number of fires and number of times a particular area has burned results in differences in vertical structure, species composition and openness. This patchwork mosaic of the Boreal forest has historically been a result of anthropogenic fire and lightning since the last Ice Age. Prescribed fire was traditionally used by First Nations in the region and has been continued by guide outfitters in mountainous portions of the Boreal forest of northeastern British Columbia. In recent years, energy development in the region has resulted in a static mosaic of disturbance in the Boreal forest resulting in a series of linear and non-linear development disturbances. The cultural landscape of open vegetation cover across the Boreal is a result of anthropogenic disturbance (prescribed fire and energy development) and wildfire. We studied nearly one century of fire data (wildfire and prescribed fire) across three scales to determine the fire history of northeastern British Columbia. We found that most north-facing slopes experience infrequent fire while some south-facing slopes in certain watersheds have a higher fire frequency from anthropogenic burning. Within the region, we also studied the distribution of endangered native herbivores, wood bison (*Bison bison athabascae*), and domestic herbivores, horses (*Equus callabus*). We used six herds of animals occupying six distinct landscapes to evaluate the role of fire and energy development on boreal vegetation use by free-ranging herbivores from 2009 - 2013. Using Resource Selection Functions (RSFs) and models to evaluate spatial distribution of horses and bison across the landscapes, we found that free-ranging herbivores generally preferentially selected open areas, recently burned areas and areas burned more frequently when they were available. Bison congregated along both linear (i.e., roads) and non-linear (i.e. petroleum exploration sites) development features. However, selection for these modified landscapes has led to significant death from vehicle collisions. Alternative areas could be developed through activities that promote openings such as the implementation and continuation of prescribed fire or clearing of land. Disturbance processes resulting in openness are important for native and domestic herbivores. Prescribed fire and the ecological processes associated with it, including pyric herbivory, are important considerations when managing rangelands in northeastern British Columbia. Understanding fire patterns can aid in fire management and conservation of biodiversity in this region which is best described by a shifting mosaic fire regime.

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CHAPTER I

MULTI-SCALE HISTORY OF FIRE IN THE BOREAL FOREST OF THE NORTHERN ROCKY MOUNTAINS, BRITISH COLUMBIA

Abstract

The patchwork mosaic of the boreal forest is a result of anthropogenic fire and lightning since the last Ice Age. We studied nearly one century (1922-2012) of fire history across northeastern British Columbia at three scales: northeastern BC (regional), the Muskwa-Kechika Management Area (M-KMA) (sub-regional), and seven watersheds within the M-KMA. Our results suggest fire frequency (both natural and anthropogenic) across northeastern BC is highly variable. While most north-facing slopes experience infrequent fire (0 % to 1.5 %), some south-facing slopes in certain watersheds have a higher frequency (0 % to 8.3 %) of anthropogenic burning. Prescribed fire in the M-KMA, between 1980 and 2008, burned more than 200 000 ha with almost 60 % occurring on south-facing slopes. Individual fires ranged in size from less than one hectare to more than 6000 ha. Understanding fire patterns can aid in fire management and conservation of biodiversity in this region which is best described by a shifting mosaic fire regime.

Introduction

Anthropogenic fire and lightning have shaped the boreal forest and contributed to its current patchwork mosaic since the last Ice Age (Rowe and Scotter 1973, Goldammer and Furyaev 1996, Stocks *et al.* 2003). The presence of fire in the boreal forest is demonstrated by fire statistics (Johnson 1992), charcoal found in soil profiles (Rowe and Scotter 1973, Larsen and MacDonald 1998), morphological, and reproductive characteristics of boreal plant species (Rowe and Scotter 1973), oral accounts by First Nations people (Lewis and Ferguson 1988, Johnson 1992, Suffling and Speller 1998), age structure, and the mosaic character of forest stands (Rowe and Scotter 1973). Lightning-driven fire regimes of large-scale crown fires and high-intensity surface fires occurred in pre-European settlement Canadian boreal forests and Rocky Mountain subalpine forests at fire return intervals from 50 to 700 years (Heinselman 1981, Stocks *et al.* 2003), however, indigenous people burned some isolated areas very frequently (Lewis and Ferguson 1988).

Prehistoric fire return intervals in northeastern British Columbia (BC) appear to fluctuate and may respond to Holocene global climate cycles (Jull and Geertsema 2006). Climatic conditions have also changed in the last millennium, with noteworthy warming in the Medieval Warm Period, and subsequent cooling during the Little Ice Age (Grove 2001). Much of the low lying portion of the boreal forest in northeastern BC has undergone paludification favouring the initiation of muskeg formation some 6,000 years ago (MacDonald and McLeod 1996). Given the variability of climate and complex synergies between various disturbance agents such as forest fire, geomorphological events, windstorms, insect outbreaks and floods (Delong *et al.* 2013), determining a fire return interval for a particular area proves challenging. Indeed it may be difficult to identify a single fire regime for any part of the boreal forest because it is a dynamic system, carrying the memory of past fire return intervals into the present and future (Bergeron and Archambault 1993, Johnson *et al.* 1998). The fire return interval of the boreal forest ranges from small frequent burns (such as in the annual burning of yards and corridors by First Nations as documented by Lewis and Ferguson 1988) to much larger wildfire events (up to thousands of hectares) with century-scale return periods (Heinselman 1981, Lewis and Ferguson 1988, Kasischke *et al.* 1995, Larsen and MacDonald 1998).

The boreal forest provides an example of a landscape where flora and fauna have adapted to the combined pressure of a long season of cold temperatures and snow cover and a short, but intense growing season where natural disturbances, including fire, are active (Bergeron *et al.* 2004, Burton *et al.* 2006). Fire-adaptations of species in the boreal include the ability to resprout after fire such as suckering of Aspen (*Populus tremuloides* Michx) (Schier and Campbell 1978), seed-banking species such as Bicknell's geranium (*Geranium bicknellii*) and Corydalis species (*Corydalis sempervirens* (L.) Pers., *C. aurea* Willd.) (MacKinnon *et al.* 1999, Catling *et al.* 2001), and serotinous cones such as lodgepole pine (*Pinus contorta* var. *latifolia* Douglas ex Louden) (MacKinnon *et al.* 1999). Fire is a critical ecosystem driver across varying spatio-temporal scales in the boreal forest. Specifically, fire influences plant species composition and structure, regulates diseases and insects, maintains and promotes the productivity and diversity of vegetation types, and affects nutrient cycling and energy fluxes (Rowe and Scotter 1973, Volney and Hirsch 1996).

In 1998 the Government of British Columbia created the Muskwa-Kechika Management Area (M-KMA) as a management model for environmental sustainability and economic stability within the boreal Cordillera ecozone of the boreal forest in northeastern British Columbia, Canada (Muskwa-Kechika Management Area 2013). The M-KMA has a long history of wildfire as well as prescribed burning by indigenous people and more recently by guide outfitters who provide guiding services including trophy hunting and back-country adventure tourism opportunities. The M-KMA provides an example in which fire and disturbance related processes are primary ecosystem drivers promoting biological diversity (Parminter 1983). Aspen forests, shrubby meadows, and grassy slopes - all maintained by fire, are dispersed through the conifer-dominated (*Picea glauca* (Moench) Voss, *P. mariana*

(Mill.) BSP, and *Pinus contorta* Douglas ex Louden) valleys and slopes of the northern Rocky Mountains (Raup 1945).

The historical fire return interval for the M-KMA is estimated to be between 50 to 400 years as extrapolated from published research by Stocks and Kauffman (1994) and Johnson *et al.* (1998). This range represents variability within fire return intervals given the limited literature available for the specific region. Although prescribed fire has occurred in the M-KMA over the past century it has become increasingly controversial due to the lack in understanding of the critical ecological role fire plays across the landscape. There is an inclination by Government Agencies to reject fire as a process which determines the ecosystems within the M-KMA. We selected the M-KMA as a case study because a) it lacks a landscape fire management plan which describes the balance of requirements and thresholds for fire and b) it is an area of debate between First Nations, stakeholders, Government and scientists regarding fire management and implementation. There has been no long term evaluation of trends, patterns, and variability in either prescribed and wildfire activity in the region. Although this case study is specific to the M-KMA, a similar analysis could be applied to create an ecologically and socially based fire plan anywhere. Any analyses of fire should recognize scale-dependent patterns, so we consider fire activity at multiple spatial and temporal scales which is the first step in developing a landscape fire management plan.

Our objectives are to provide a framework for assessing fire for a region resulting in recommendations for a long-term fire plan. We used a long-term (90 year) fire history dataset to characterize fire regimes at a regional scale (northeastern British Columbia), a sub-regional scale of the M-KMA and a watershed scale (the seven largest watersheds within the

M-KMA) (Figures 1.1 and 1.2). The regional scale contextualizes the fire regime of the M-KMA within northeastern BC, and the watershed scale provides finer scale spatial variability of fire within the M-KMA. We recognize that data of historical fire patterns over large areas are subject to errors and omissions but in the absence of tree-ring data and sediment deposition analyses (Swetnam 1996) they nonetheless provide a unique opportunity to look at fire from a broad scale perspective in a landscape which is largely undeveloped. We present this as the first critical step in developing a plan for managing wild and prescribed fires across the landscape. Understanding the historical fire patterns that have occurred is important for natural resource management globally. Similar analyses could be applied in other locations where fire occurs across broad spatio-temporal scales. We present information here as a framework for regional fire evaluation and planning.

Methods

The study area was located in northeastern British Columbia, Canada. Fire histories were developed across three scales including northeastern British Columbia (regional), the Muskwa-Kechika Management Area (M-KMA, sub-regional), and the seven largest watersheds within the MKMA following the same methodology as Stocks *et al.* (2003) (Figure 1.1 and 1.2). The regional scale of northeastern BC was analysed using the northeast regional boundary as determined by the Government of British Columbia (Province of British Columbia 2013a). The seven largest watersheds within the M-KMA were mapped by the BC Government in 2003 at a scale of 1:50,000 and accessed through the Data Distribution Service of Data BC (Province of British Columbia 2013b, Province of British Columbia 2013c). The watersheds were clipped to the M-KMA boundary.

We used three unique fire data sets from various branches of the British Columbia government. We acquired two recent history wildfire datasets (1922-2012) from the Wildfire Management Branch of British Columbia: wildfire polygon dataset and wildfire point dataset. Based on preliminary analyses that indicated minimal differences between the two datasets, we selected the wildfire polygon dataset, which defines the actual perimeters of wildfires while the point data set only provides the total area burned associated with each fire point. The point dataset did not provide spatial data indicating what area had burned around the point, which direction the fire moved, and its total spatial orientation across the landscape. We also acquired a prescribed fire dataset from the BC Ministry of Environment which provided data on prescribed fires conducted by the government from 1980 to 2008 so that we could analyze prescribed fire from wildfires for this more recent period. Any wildfire data in the BC Ministry of Environment dataset was removed in order to isolate prescribed fire locations. While all prescribed fires in the region are supposed to be regulated by the BC government it is possible that small local prescribed fires may have gone undetected prior to high quality remotely sensed data. Areas burned by wildfire more than once were counted more than once because they had unique spatial distribution associated with them as developed by the BC Wildfire Management Branch, however, areas that received prescribed fire more than once were only counted once due to limitations in the data. Such limitations included the prescribed fire data set which has one recorded unique area as a burn unit but with multiple years attributed to it and no record of the area burned each year. Therefore, it is not possible to determine the area burned per specific year because it is not known if the fire burned to that specific size each year. This results in an underestimation of fire in the past 30 years due to the lack of spatial patter of fire within the fire polygon for each year. While these data surely include errors they are the best approximation of fire patterns over 90 years representing one of the most extensive fire data sets across a large and contiguous landscape.

We spatially analysed the two data sets. The first analysis performed included the total area burned by wildfire across northeastern BC, the M-KMA, and the seven watersheds within the M-KMA over the time period of 1922 – 2012 using ESRI ArcGIS10.1 (ESRI 2011). The mean per year or the mean annual area burned (AAB) was calculated (Stocks *et al.* 2003). The second analysis performed focused on the area burned by prescribed fire from 1980 – 2008 for the same area. Total area burned was divided by 29 years to obtain the mean per year (Stocks *et al.* 2003). We derived total area burnable (area not occupied by water, ice, snow, and rock), using land cover data from the Geobase developed by the Canadian Council on Geomatics (Government of Canada 2009, Stocks *et al.* 2003, Canadian Council on Geomatics 2013). It is possible that the burnable area has changed between 1922 and 2012. The percent area burned per year, or the percent annual area burned (PAAB), was calculated as per Stocks *et al.* 2003. We used Digital Elevation Models (DEMs) for the three scales using data from the Canadian Council on Geomatics (Government of Canada 2009) and we performed analyses for aspect to develop topoedaphic classifications which would compare the distribution of wildfire and prescribed fire across aspect classes. Aspect was classified into five classes from the DEMs in degrees (1-360°) from north with a value of -1 indicating flat surfaces (Taylor and Skinner 2003, Flatley *et al.* 2011). The scale of the DEM data were 1:250,000 at 20m resolution (Government of Canada 2000).

Results

Of 11.7 million hectares in northeastern BC, approximately 3.8 million ha (32 %) have burned by wildfire and/or prescribed fire since 1922 (Table 1.1). A total of 3204 fires have been recorded across northeastern BC since 1922 (2334 wildfires and 870 prescribed fires). The average size of wildfire is 1517 ha with a maximum of 244 027 ha. The average prescribed fire is 442 ha with a maximum of 6100 ha. These data suggest that it will take a minimum of 281 years for an area equivalent to the size of the entire burnable area of northeastern BC to burn.

The total burnable area across the M-KMA is 4.8 million hectares (Table 1.1). The area burned by fire since 1922 is approximately 1.1 million ha (23 %). A total of 1059 fires have occurred across the M-KMA (399 wildfires and 660 prescribed fires). The largest number of prescribed fires occurred in 1987 with 159 fires. The average size of wildfire is 2322 ha with a maximum size of 244 027 ha. The average size of prescribed fire is 469 ha with a maximum size of 6100 ha. Based on these data, we estimate that it will take 390 years for the entire burnable area to burn.

The burnable area of the seven main watersheds of the M-KMA ranges in size from 1.2 million hectares (Kechika) to 295 000 ha (Halfway) (Table 1.1). The area burned by wildfire ranges across the watersheds from 5.4 % (15 847 ha in the Halfway) to 50.3 % (205 991 ha in the Liard) (Figure 1.4). The area burned by prescribed fire ranges across the watersheds from 2.1 % (26 633 ha in the Kechika) to 11.9 % (92 811 ha in the Fort Nelson) and 14.5 % (49 543 ha in the Toad) of the total burnable area (Figure 1.4). The average size of wildfires ranges from 911 ha (Fort Nelson) with a maximum size of 15 401 ha to 5150 ha (Liard) and

5539 ha (Rabbit) with maximum sizes of 50 784 ha (Liard) and 11 637 (Rabbit) respectively. The maximum size of wildfires across the watersheds includes 232 289 ha (Kechika), 28 952 ha (Toad), 15 401 ha (Fort Nelson), 7223 ha (Halfway) and 17 871 ha (Finlay). The average size of prescribed fires ranges from 288 ha (Halfway) to 2049 ha (Kechika) with a maximum size of 6100 ha (Kechika). Maximum size of prescribed fire across the watersheds includes 4480 ha (Liard), 3549 ha (Toad), 3864 ha (Fort Nelson) and 2018 ha (Halfway). According to our data, we estimate it will take 164 years (Liard) to 949 years (Halfway) for the entire burnable area to burn.

The current distribution of time since fire across the three scales indicates some spatial variation across the watersheds but also some general trends (Table 1.2). The least amount of land area is found within the smallest and most recently burned category (0 to 2 years since fire) across all scales, ranging from 0 to 0.9 % of the total burnable area. The category with the longest time since fire, greater than 90 years, ranges from 44.7 % to 90.4 % of the total burnable area, which is actually the largest range because there is no upper boundary. Minimal recent time since fire in a fire-maintained ecosystem may suggest that there could be potential for fire across the landscape in the near future. The percent of time since fire in each category over the burnable area in the M-KMA also indicates spatial variation where some watersheds have more recent fire than others (Table 1.2). Watersheds with higher anthropogenic presence and targeted burning include the Toad (12 % of the area in 0 to 50 years since fire) and the Fort Nelson (20% of the area in 0 to 50 years since fire). This is indicative of the concentrated efforts resulting from the Northeast Elk Enhancement Project and from anthropogenic burning in the two watersheds (Parminter 1983, Peck and Peek 1991). South facing slopes have the highest percentage of prescribed fire on average throughout the region when compared to other aspects (Table 1.3). A total of 117 195 ha burned on south facing slopes in large watersheds of the M-KMA from 1980 - 2008. The total area of south aspect within the M-KMA is 1 790 282 ha of which 260 416 ha (14.55 %) has burned by wildfire and 116 406 ha has burned by prescribed fire (6.51 %) (Table 1.4). The total area of north aspect within the M-KMA is 2 020 707 ha of which 25 023 ha (1.24 %) has burned by wildfire and 20 733 ha (1.03 %) has burned by prescribed fire (Table 1.4).

Our results suggest the number of prescribed fires declined across the region and the M-KMA over the past 20 years (Figure 1.3a and 1.3b) with the average peak of wildfires being between highest between 1970 to 1989 (Figure 1.5, Figure 1.6 and Figure 1.7). Across northeastern BC, the largest area burned occurred in the decade between 1950 to 1960 where over 1 million hectares burned by wildfire (Figure 1.5). Where anthropogenic fire ignitions are the highest in the Toad and Fort Nelson watersheds (Figure 1.8), the decade of 1980 – 1989 had the largest number of wildfires and largest area burned. Across northeastern BC, person caused wildfires were more than double wildfires from lightning ignitions (Figure 1.8).

Discussion

The M-KMA is a fire dependent landscape where humans have played a critical role in creating heterogeneity through fire across spatial and temporal patterns and scales, however, no one has quantified the extent of its fire patterns in space and time. Fire is a dominant feature across the region as demonstrated by 23 % of the M-KMA (1.1 million ha) which has burned over a 90 year period with 4 % (203 236 ha) attributed to prescribed fire (Figure 1.6). While a significant portion of the M-KMA burned, fire is not uniformly distributed through space and time across the watersheds. Given the vastness of the region, less than 0.60 % is the highest percent annual area burned. There can be differences between where fires initiate and what they burn depending on weather, topography, fuel characteristics and ignitions amongst others (Flannigan *et al.* 2005). A higher percentage of fires may initiate in certain environments, but once started, they may expand outwards to other areas. Area burned varies between south facing and north facing slopes. North-facing slopes are generally cooler and wetter than south-facing slopes which are the first to become snow-free in the spring and which also provide high forage value, quantity and accessibility to wildlife and livestock throughout the year. Within the watersheds, south facing slopes burned 95 000 ha more than north facing slopes largely due to anthropogenic ignitions.

The un-recorded anthropogenic ignitions due to human activity in the area result in a lack of data for analysis and also suggest an under-estimation of fire across the landscape. Certain watersheds have a higher level of human activity and recorded burning (Toad and Fort Nelson) than others (Rabbit and Finlay). Documentation of First Nation and other historical anthropogenic ignitions has begun to be recorded through anecdotal documentation, however, more research needs to occur throughout the region. Recent time since fire and number of fires across these watersheds result in desirable locations for humans to participate in back-country activities such as hunting, commercial recreation and hiking. With the implementation of fire suppression and without the implementation of prescribed fire in these valleys, the M-KMA will not continue to function as a destination location the way it currently does. Additionally, the resources made available through a shifting mosaic of time since fire across the landscape will become limited. Although fire is a critical and dominant process in the region, there is still no long term management plan for it, nor an acceptance or understanding of its critical role across the landscape.

Anthropogenic fire is a historical component of the ecosystem (Seip and Bunnell 1985, Peck and Peek 1991, Sittler 2013). The seven largest watersheds have a total of 202 047 ha of recorded prescribed fire with some watersheds having a higher area burned by prescribed fire such as the Fort Nelson with up to 92 811 ha (11.9 %) burned. Prescribed fire predominantly occurs on south facing slopes where 117 195 ha of the seven watersheds have burned compared to 21 255 ha on north facing slopes of the same watersheds. This is due to past prescribed fires targeting south facing slopes on the north sides of rivers to enhance resources for ungulates (Peck and Peek 1991). Prescribed fire needs to continue to be used in the region to promote, maintain and enhance rangelands for livestock and ungulates (Seip and Bunnell 1985, Peck and Peek 1991, Sittler 2013).

Wildfires are not overly suppressed in the region as demonstrated by the recorded 926 663 ha (19.1 %) of the M-KMA which has burned since 1922. The historical fire return interval considered by Stocks and Kauffman (1994) was 50 – 150 years whereas Johnson *et al*. (1998) found that every 300 – 400 years almost all of the areas will have burned in the western boreal, boreal montane, and near-boreal forest. Our results estimate that it will take 390 years to burn an area equivalent to all the current burnable area across the M-KMA, however, there are limitations in these results based on uncertainties in the data, cloud cover in the spatial data, and the range of the considered fire return interval of 50 – 400 years which is itself a range. Although the years required to burn all the current burnable area is an estimation, it is worthwhile using as a generalized frequency under assumption that the same area will only burn once and that the data are accurate. We have not accounted for fire occurring more than once in a given area although we note anecdotally that wildfires have been reported to overlap prescribed burn areas and vice versa. This would make for a useful analysis in the development of fire management plans.

There is scientific consensus indicating that the carbon-rich boreal zone will have significant impacts from climate change and will have extended fire seasons of increased fire occurrence and severity with resulting influences on terrestrial carbon cycling and storage (Weber and Flannigan 1997, Amiro *et al*. 2001, Stocks *et al.* 2003). Without prescribed fire implementation and strategic fire planning, there could be more wildfire across the landscape. The lack of recent time since fire across the landscape may play a role in larger wildfire events. Leroux and Schmiegelow (2007) suggest that the boreal may be the only region of the world that has the last opportunities for conservation planning and maintaining intact species assemblages and ecological processes while Pyne (2007) suggests that the future of fire in Canada promises more flame, not less.

In conclusion, understanding current patterns of fire through space and time is a crucial step in developing regional fire management strategies, necessary for the conservation of biodiversity. This is the first time such an analysis has been completed for northern British Columbia and similar analyses could be applied elsewhere to inform land managers at broad spatial and temporal scales. A system or tool which tracks the number of fires, their spatial and temporal distribution across the landscape and the degree of heterogeneity required to support the ecosystem services of interest is needed to effectively manage natural resources. To maintain heterogeneity and biological diversity as well as to promote resources for selection by wildlife, fire needs to continue being spatially and temporally distributed across any landscape, including areas of fire refugias and fire absorbency. Incorporating fire patterns across the landscape is an important component of land management in the boreal forest. This research is the first step in developing such a landscape fire management plan. There is further need to develop a matrix which is based on topoedaphic conditions and time since disturbance to meet objectives such as shifting mosaics and heterogeneity across landscapes. Our results provide a first step and an example of how to initiate a regional fire plan that can be applied to any area where adequate fire history data exist.

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Tables

Table 1.1. The fire history across three scales in British Columbia, Canada: regional (NEBC, Table 1.a), sub-regional management area (M-KMA, Table 1.b) and watersheds (Liard, Table 1.c), (Kechika, Table 1.d), (Rabbit, Table 1.e), (Toad, Table 1.f), (Fort Nelson, Table 1.g), (Halfway, Table 1.h), (Finlay, Table 1.i). Mean per year of wildfire (Wild) was calculated from 1922-2012 = 91 years. Mean per year of prescribed fire (Rx) was calculated from 1980-2008 = 29 years. Historical Fire Return Interval (HFRI) is considered from Stocks *et al*. (1994) who suggest a fire return interval for the boreal of 50 - 150 years whereas Johnson *et al*. (1998) found that every 300 - 400 years almost all of the areas will have burned in the western boreal, boreal montane and near-boreal forest. Years required to burn all burnable area are considered to be an estimation due to limitations in the data. Values are in hectares and numbers in parentheses represent percent of the total burnable area.

Location	Northeast BC
Hectares total	19 091 797
Hectares burnable	11 736 663
Unburnable Land Cover: cloud cover (ha)	2 205 926
Unburnable Land Cover: shadow cover (ha)	412 403
Area burned 1922-2012 (Wild) (ha)	3 539 814 (30.2)
Area burned 1980-2008 (Rx) (ha)	261 766 (2.2)
Mean per year Wild 1922-2012 (ha)	38 899 (0.3)
Mean per year Rx 1980-2008 (ha)	9026 (0.1)
Average size Wild 1922-2012 (ha)	1517
Average size Rx 1980-2008 (ha)	442
Maximum size Wild 1922-2012 (ha)	244 027
Maximum size Rx 1980-2008 (ha)	6100
Years required to burn all (Wild + Rx)	281
Historical Fire Return Interval (years)	50 - 400

(a)

Location	M-KMA
Hectares total	6 386 093
Hectares burnable	4 843 838
Unburnable Land Cover: cloud cover (ha)	268 458
Unburnable Land Cover: shadow cover (ha)	127 233
Area burned 1922-2012 (Wild) (ha)	926 663 (19.1)
Area burned 1980-2008 (Rx) (ha)	203 236 (4.2)
Mean per year Wild 1922-2012 (ha)	10 183 (0.2)
Mean per year Rx 1980-2008 (ha)	7008 (0.1)
Average size Wild 1922-2012 (ha)	2322
Average size Rx 1980-2008 (ha)	469
Maximum size Wild 1922-2012 (ha)	244 027
Maximum size Rx 1980-2008 (ha)	6100
Years required to burn all (Wild + Rx)	390
Historical Fire Return Interval (years)	50 - 400

(b)

Location	Liard
Hectares total	671 988
Hectares burnable	409 626
Unburnable Land Cover: cloud cover (ha)	198 861
Unburnable Land Cover: shadow cover (ha)	3646
Area burned 1922-2012 (Wild) (ha)	205 991 (50.3)
Area burned 1980-2008 (Rx) (ha)	20 655 (5.0)
Mean per year Wild 1922-2012 (ha)	2264 (0.6)
Mean per year Rx 1980-2008 (ha)	712 (0.2)
Average size Wild 1922-2012 (ha)	5150
Average size Rx 1980-2008 (ha)	383
Maximum size Wild 1922-2012 (ha)	50 784
Maximum size Rx 1980-2008 (ha)	4480
Years required to burn all (Wild + Rx)	164
Historical Fire Return Interval (yrs)	50 - 400

(c)

Location	Kechika
Hectares total	1 965 538
Hectares burnable	1 282 879
Unburnable Land Cover: cloud cover (ha)	198 885
Unburnable Land Cover: shadow cover (ha)	25 901
Area burned 1922-2012 (Wild) (ha)	413 050 (32.2)
Area burned 1980-2008 (Rx) (ha)	26 633 (2.1)
Mean per year Wild 1922-2012 (ha)	4539 (0.4)
Mean per year Rx 1980-2008 (ha)	918 (0.1)
Average size Wild 1922-2012 (ha)	4258
Average size Rx 1980-2008 (ha)	2049
Maximum size Wild 1922-2012 (ha)	232 389
Maximum size Rx 1980-2008 (ha)	6100
Years required to burn all (Wild + Rx)	266
Historical Fire Return Interval (yrs)	50 - 400

(d)

Location	Rabbit
Hectares total	370 533
Hectares burnable	156 649
Unburnable Land Cover: cloud cover (ha)	185 088
Unburnable Land Cover: shadow cover (ha)	1084
Area burned 1922-2012 (Wild) (ha)	16 616 (10.6)
Area burned 1980-2008 (Rx) (ha)	0 (0)
Mean per year Wild 1922-2012 (ha)	183 (0.1)
Mean per year Rx 1980-2008 (ha)	0 (0)
Average size Wild 1922-2012 (ha)	5539
Average size Rx 1980-2008 (ha)	0
Maximum size Wild 1922-2012 (ha)	11 637
Maximum size Rx 1980-2008 (ha)	0
Years required to burn all (Wild + Rx)	858
Historical Fire Return Interval (yrs)	50 - 400

(e)

Location	Toad
Hectares total	712 011
Hectares burnable	341 804
Unburnable Land Cover: cloud cover (ha)	108 337
Unburnable Land Cover: shadow cover (ha)	28 293
Area burned 1922-2012 (Wild) (ha)	86 460 (25.3)
Area burned 1980-2008 (Rx) (ha)	49 543 (14.5)
Mean per year Wild 1922-2012 (ha)	950 (0.3)
Mean per year Rx 1980-2008 (ha)	1708 (0.5)
Average size Wild 1922-2012 (ha)	1054
Average size Rx 1980-2008 (ha)	522
Maximum size Wild 1922-2012 (ha)	28 952
Maximum size Rx 1980-2008 (ha)	3549
Years required to burn all (Wild + Rx)	229
Historical Fire Return Interval (yrs)	50 - 400

(f)

Location	Ft Nelson
Hectares total	1 295 040
Hectares burnable	781 882
Unburnable Land Cover: cloud cover (ha)	163 049
Unburnable Land Cover: shadow cover (ha)	36 419
Area burned 1922-2012 (Wild) (ha)	113 910 (14.6)
Area burned 1980-2008 (Rx) (ha)	92 811 (11.9)
Mean per year Wild 1922-2012 (ha)	1252 (0.2)
Mean per year Rx 1980-2008 (ha)	3200 (0.4)
Average size Wild 1922-2012 (ha)	911
Average size Rx 1980-2008 (ha)	393
Maximum size Wild 1922-2012 (ha)	15 401
Maximum size Rx 1980-2008 (ha)	3864
Years required to burn all (Wild + Rx)	344
Historical Fire Return Interval (yrs)	50 - 400

(g)

Location	Halfway
Hectares total	336 903
Hectares burnable	294 728
Unburnable Land Cover: cloud cover (ha)	979
Unburnable Land Cover: shadow cover (ha)	1965
Area burned 1922-2012 (Wild) (ha)	15 847 (5.4)
Area burned 1980-2008 (Rx) (ha)	12 405 (4.2)
Mean per year Wild 1922-2012 (ha)	174 (0.1)
Mean per year Rx 1980-2008 (ha)	428 (0.1)
Average size Wild 1922-2012 (ha)	1132
Average size Rx 1980-2008 (ha)	288
Maximum size Wild 1922-2012 (ha)	7223
Maximum size Rx 1980-2008 (ha)	2018
Years required to burn all (Wild + Rx)	949
Historical Fire Return Interval (yrs)	50 - 400

(h)

Location	Finlay
Hectares total	875 794
Hectares burnable	610 461
Unburnable Land Cover: cloud cover (ha)	47 877
Unburnable Land Cover: shadow cover (ha)	25 693
Area burned 1922-2012 (Wild) (ha)	64 862 (10.6)
Area burned 1980-2008 (Rx) (ha)	0 (0)
Mean per year Wild 1922-2012 (ha)	713 (0.1)
Mean per year Rx 1980-2008 (ha)	0 (0)
Average size Wild 1922-2012 (ha)	1474
Average size Rx 1980-2008 (ha)	0
Maximum size Wild 1922-2012 (ha)	17 871
Maximum size Rx 1980-2008 (ha)	0
Years required to burn all (Wild + Rx)	856
Historical Fire Return Interval (yrs)	50 - 400

(i)

Table 1.2. Current distribution of fire across regional (NEBC, Table 1.2.a), sub-regional management area (M-KMA, Table 1.2.b) and watershed (Table 1.2.c – Table 1.2.i) scales with values in hectares and numbers in parentheses representing percent of the total burnable area in the selected areas of British Columbia, Canada.

Current ha (burnable) area in	Northeast BC
0 - 2 years since fire	87 218 (0.7)
2 - 10 years since fire	259 405 (2.2)
10 - 25 years since fire	260 401 (2.2)
25 - 50 years since fire	1 154 755 (9.8)
50 - 90 years since fire	1 996 034 (17.0)
>90 years since fire	7 935 083 (67.6)
unknown	43 767 (0.4)

(a)

Current ha (burnable) area in	M-KMA
0 - 2 years since fire	17 229 (0.4)
2 - 10 years since fire	98 192 (2.0)
10 - 25 years since fire	144 162 (3.0)
25 - 50 years since fire	428 375 (8.9)
50 - 90 years since fire	414 006 (8.6)
>90 years since fire	3 713 939 (76.7)
unknown	27 935 (0.6)

(b)

Current ha (burnable) area in	Liard
0 - 2 years since fire	62 (0.0)
2 - 10 years since fire	5871 (1.4)
10 - 25 years since fire	16 580 (4.1)
25 - 50 years since fire	147 312 (36.0)
50 - 90 years since fire	54 620 (13.3)
>90 years since fire	182 980 (44.7)
unknown	2201 (0.5)

(c)

Current ha (burnable) area in	Kechika
0 - 2 years since fire	12 011 (0.9)
2 - 10 years since fire	57 264 (4.5)
10 - 25 years since fire	18 150 (1.4)
25 - 50 years since fire	82 327 (6.4)
50 - 90 years since fire	262 085 (20.4)
>90 years since fire	843 196 (65.7)
unknown	7846 (0.6)

(d)

Current ha (burnable) area in	Rabbit
0 - 2 years since fire	0 (0)
2 - 10 years since fire	0 (0)
10 - 25 years since fire	103 (0.1)
25 - 50 years since fire	4876 (3.1)
50 - 90 years since fire	11 637 (7.4)
>90 years since fire	140 033 (89.4)
unknown	0 (0)

(e)

Current ha (burnable) area in	Toad
0 - 2 years since fire	205 (0.1)
2 - 10 years since fire	15 258 (4.5)
10 - 25 years since fire	25 922 (7.6)
25 - 50 years since fire	57 469 (16.9)
50 - 90 years since fire	27 354 (8.0)
>90 years since fire	205 801 (60.2)
unknown	9795 (2.9)

(f)

Current ha (burnable) area in	Ft Nelson
0 - 2 years since fire	4949 (0.6)
2 - 10 years since fire	14 688 (1.9)
10 - 25 years since fire	60 572 (7.8)
25 - 50 years since fire	76 450 (9.8)
50 - 90 years since fire	43 160 (5.6)
>90 years since fire	575 161 (73.6)
unknown	6902 (0.9)

(g)

Current ha (burnable) area in	Halfway
0 - 2 years since fire	0 (0)
2 - 10 years since fire	2822 (1.0)
10 - 25 years since fire	15 446 (5.2)
25 - 50 years since fire	7793 (2.6)
50 - 90 years since fire	2191 (0.7)
>90 years since fire	266 476 (90.4)
unknown	0 (0)

(h)

Current ha (burnable) area in	Finlay
0 - 2 years since fire	2 (0)
2 - 10 years since fire	2289 (0.4)
10 - 25 years since fire	7086 (1.2)
25 - 50 years since fire	42 534 (7.0)
50 - 90 years since fire	12 951 (2.1)
>90 years since fire	545 599 (89.3)
unknown	0 (0)

(i)

Table 1.3. Wildfire (Wild) and prescribed fire (Rx) distribution across aspect classes[a] in British Columbia, Canada over two scales: management area (M-KMA)(a) and watersheds Liard (b), Kechika (c), Rabbit (d), Toad (e), Fort Nelson (f), Halfway (g) and Finlay (h) with values in hectares and numbers in parentheses representing percent of total burnable area.

	M-KMA	
Aspect[a]	Wild ha (%)	Rx ha (%)
North	250 231 (5.2)	20 733 (0.4)
East	153 393 (3.2)	27 859 (0.6)
South	260 416 (5.4)	116 406 (2.4)
West	138 445 (2.9)	37 912 (0.8)
Flat	6959 (0.1)	53 (0.0)

[a] North (class 1) = 315° - 45°. East (class 2) = 45° - 135°. South (class 3) = 135° - 225°. West (class 4) = 225° - 315°. Flat (class 5) = -1°. Data ranged from -1° to 359°.

(a)

	Liard	
Aspect[a]	Wild ha (%)	Rx ha (%)
North	64 248 (15.7)	2200 (0.5)
East	35 692 (8.7)	2758 (0.7)
South	50 127 (12.2)	12 132 (3.0)
West	21 902 (5.3)	3528 (0.9)
Flat	1284 (0.3)	4 (0.0)

[a] North (class 1) = 315° - 45°. East (class 2) = 45° - 135°. South (class 3) = 135° - 225°. West (class 4) = 225° - 315°. Flat (class 5) = -1°. Data ranged from -1° to 359°.

(b)

	Kechika	
Aspect[a]	Wild ha (%)	Rx ha (%)
North	110 077 (8.6)	4409 (0.3)
East	58 827 (4.6)	3549 (0.3)
South	107 421 (8.4)	14 594 (1.1)
West	73 129 (5.7)	6071 (0.5)
Flat	4696 (0.4)	40 (0.0)

[a] North (class 1) = 315° - 45°. East (class 2) = 45° - 135°. South (class 3) = 135° - 225°. West (class 4) = 225° - 315°. Flat (class 5) = -1°. Data ranged from -1° to 359°.

(c)

	Rabbit	
Aspect[a]	Wild ha (%)	Rx ha (%)
North	7535 (4.8)	0 (0.0)
East	4077 (2.6)	0 (0.0)
South	3491 (2.2)	0 (0.0)
West	1364 (0.9)	0 (0.0)
Flat	102 (0.1)	0 (0.0)

[a] North (class 1) = 315° - 45°. East (class 2) = 45° - 135°. South (class 3) = 135° - 225°. West (class 4) = 225° - 315°.

(d)

	Toad	
Aspect[a]	Wild ha (%)	Rx ha (%)
North	25 458 (7.4)	5141 (1.5)
East	16 936 (5.0)	5966 (1.7)
South	28 330 (8.3)	28 288 (8.3)
West	10 980 (3.2)	10 087 (3.0)
Flat	51 (0.0)	0 (0.0)

[a] North (class 1) = 315° - 45°. East (class 2) = 45° - 135°. South (class 3) = 135° - 225°. West (class 4) = 225° - 315°. Flat (class 5) = -1°. Data ranged from -1° to 359°.

(e)

	Ft Nelson	
Aspect[a]	Wild ha (%)	Rx ha (%)
North	28 777 (3.7)	9067 (1.2)
East	23 777 (3.0)	14 690 (1.9)
South	38 190 (4.9)	52 347 (6.7)
West	16 970 (2.2)	16 602 (2.1)
Flat	77 (0.0)	9 (0.0)

[a] North (class 1) = 315° - 45°. East (class 2) = 45° - 135°. South (class 3) = 135° - 225°. West (class 4) = 225° - 315°. Flat (class 5) = -1°. Data ranged from -1° to 359°.

(f)

	Halfway	
Aspect[a]	Wild ha (%)	Rx ha (%)
North	4455 (1.5)	438 (0.1)
East	3303 (1.1)	1648 (0.6)
South	5896 (2.0)	9834 (3.3)
West	1796 (0.6)	1650 (0.6)
Flat	1 (0.0)	0 (0.0)

[a] North (class 1) = 315° - 45°. East (class 2) = 45° - 135°. South (class 3) = 135° - 225°. West (class 4) = 225° - 315°. Flat (class 5) = -1°. Data ranged from -1° to 359°.

(g)

	Finlay	
Aspect[a]	Wild ha (%)	Rx ha (%)
North	20 142 (3.3)	0 (0.0)
East	9 243 (1.5)	0 (0.0)
South	23 298 (3.8)	0 (0.0)
West	9282 (1.5)	0 (0.0)
Flat	732 (0.1)	0 (0.0)

[a] North (class 1) = 315° - 45°. East (class 2) = 45° - 135°. South (class 3) = 135° - 225°. West (class 4) = 225° - 315°. Flat (class 5) = -1°. Data ranged from -1° to 359°.

(h)

Table 1.4. Hectares available within north and south aspect classes are compared to area burned or used by wildfire and prescribed fire across the M-KMA and its seven largest watersheds shown in hectares and percent of total area of aspect class available.

	North[a]		South[b]	
MKMA	Ha	%	Ha	%
Available	2 020 707		1 790 282	
Used by wildfire	25 023	1.24	260 416	14.55
Used by prescribed fire	20 733	1.03	116 406	6.50
Liard				
Available	340 795		325 445	
Used by wildfire	64 248	18.85	50 127	15.40
Used by prescribed fire	2 200	0.65	12 132	3.73
Kechika				
Available	807 633		645 883	
Used by wildfire	110 077	13.63	107 421	16.63
Used by prescribed fire	4 409	0.55	14 594	2.26
Rabbit				
Available	199 471		151 775	
Used by wildfire	7 535	3.78	3 491	2.30
Used by prescribed fire		0.00		0.00
Toad				
Available	295 608		296 977	
Used by wildfire	25 458	8.61	28 330	9.54
Used by prescribed fire	5 141	1.74	28 288	9.53
Ft Nelson				
Available	429 249		371 749	
Used by wildfire	28 777	6.70	38 190	10.27
Used by prescribed fire	9 067	2.11	52 347	14.08
Halfway				
Available	150 392		133 301	
Used by wildfire	4 455	2.96	5 896	4.42
Used by prescribed fire	438	0.29	9 834	7.38
Finlay				
Available	333 682		305 341	
Used by wildfire	20 142	6.04	23 298	7.63
Used by prescribed fire		0.00		0.00

[a] North (class 1) = 315° - 45°. [b] South (class 3) = 135° - 225°. Data ranged from -1° to 359°.

Figure legend

Figure 1.1. Study area in northeastern British Columbia, Canada (dotted) and the Muskwa-Kechika Management Area (bold).

Figure 1.2. The Muskwa-Kechika Management Area, British Columbia, Canada with wildfire (1922 – 2012) and prescribed fire (1980 – 2009) (a) across the seven selected watersheds (b).

Figure 1.3. The number of prescribed fires in northeastern British Columbia, Canada (a) and in the Muskwa-Kechika Management Area, British Columbia, Canada (b) per year from 1980 – 2008.

Figure 1.4.a. The total area burned by wildfire since 1922 (black) and prescribed fire since 1980 (grey) across the seven largest watersheds of the Muskwa-Kechika Management Area.

Figure 1.4.b. The percent annual area burned by wildfire since 1922 across the seven largest watersheds of the Muskwa-Kechika Management Area.

Figure 1.5. The number of wildfires in northeastern British Columbia since 1922 (a) and the area burned in hectares (b) per decade.

Figure 1.6. The number of wildfires in the Muskwa-Kechika Management Area (M-KMA), British Columbia since 1922 (a) and the area burned in hectares (b) per decade. No recorded wildfires occurred prior to 1940 in the M-KMA.

Figure 1.7. The number of wildfires across the seven largest watersheds in the Muskwa-Kechika Management Area (M-KMA), British Columbia since 1922 (a1 – g1) and the area

burned in hectares (a2 – g2) per decade. No recorded wildfires occurred prior to 1940 in the M-KMA.

Figure 1.8. Ignition sources of wildfires between 1922 – 2012 across northeastern British Columbia and the Muskwa-Kechika Management Area (M-KMA) (a) and the seven largest watersheds within the M-KMA (b).

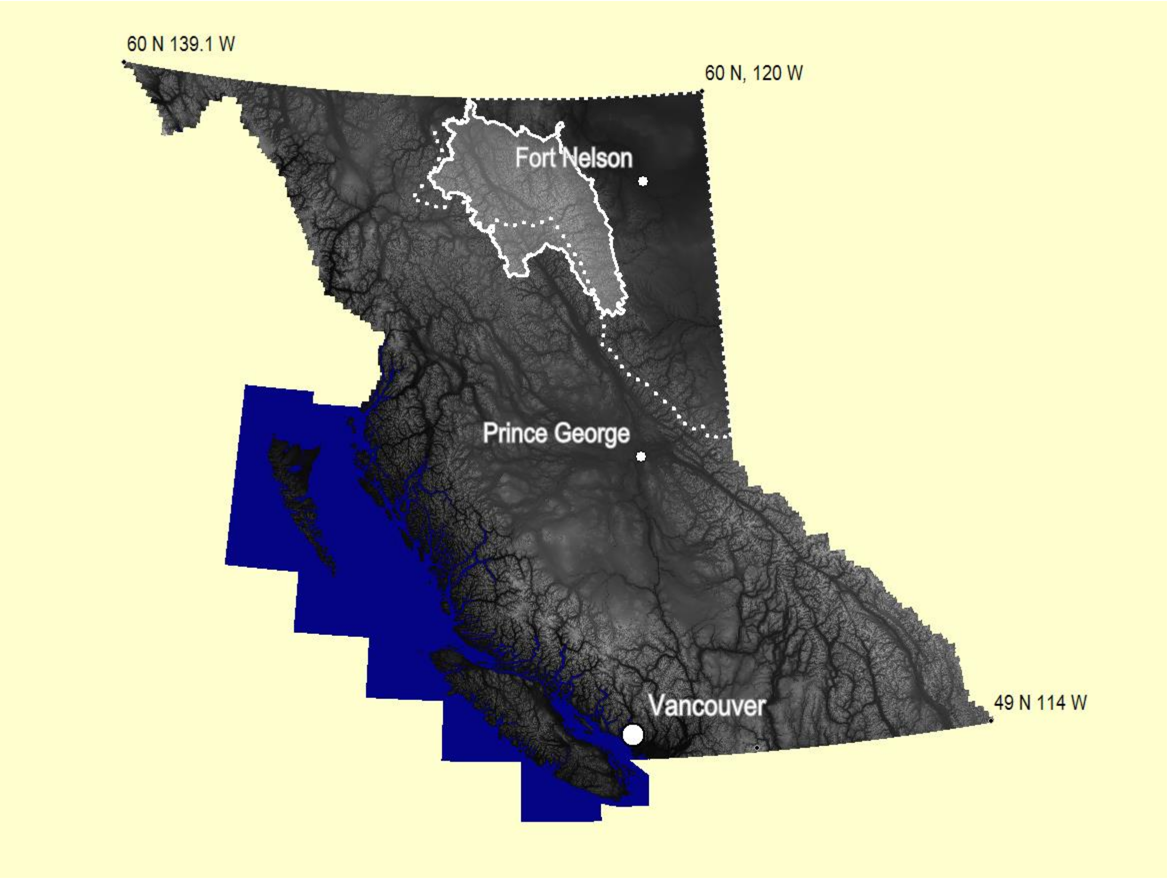

60 N 139.1 W
60 N, 120 W
Fort Nelson
Prince George
Vancouver
49 N 114 W

Figure 1.1.

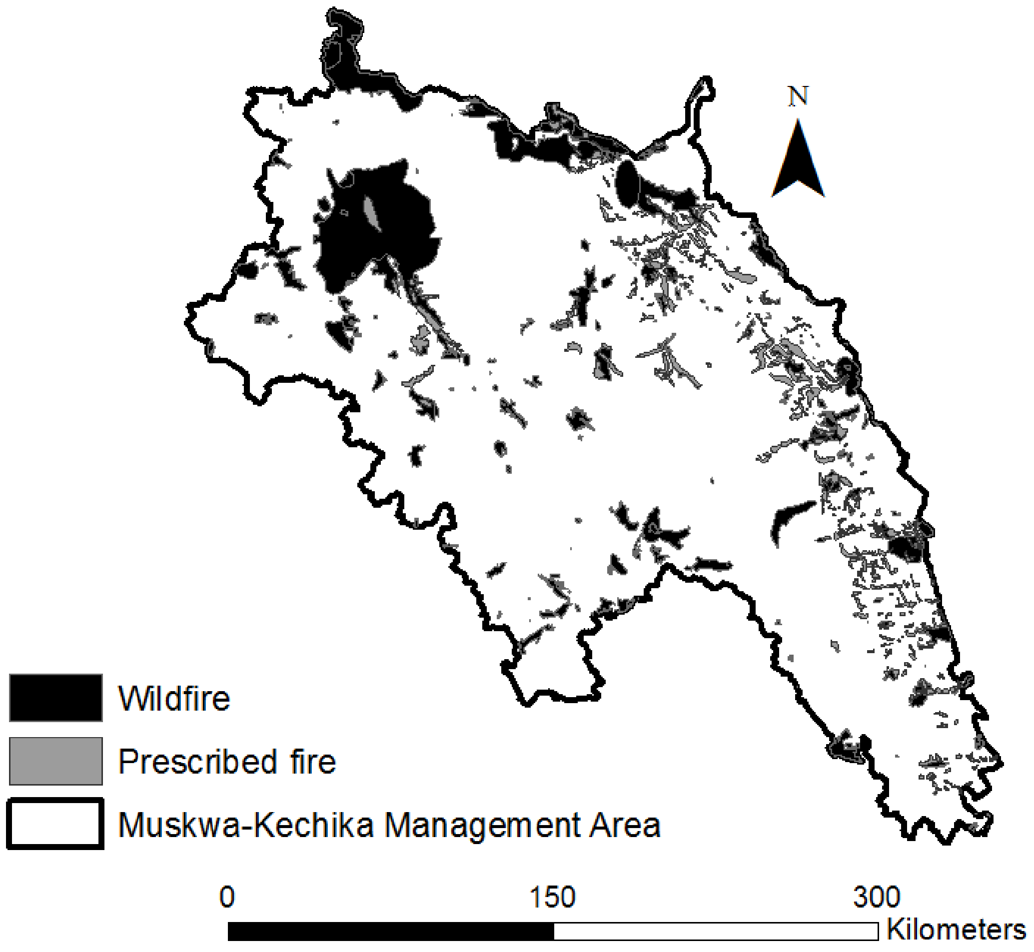

N
Wildfire
Prescribed fire
Muskwa-Kechika Management Area
0
150
300
Kilometers

Figure 1.2.a.

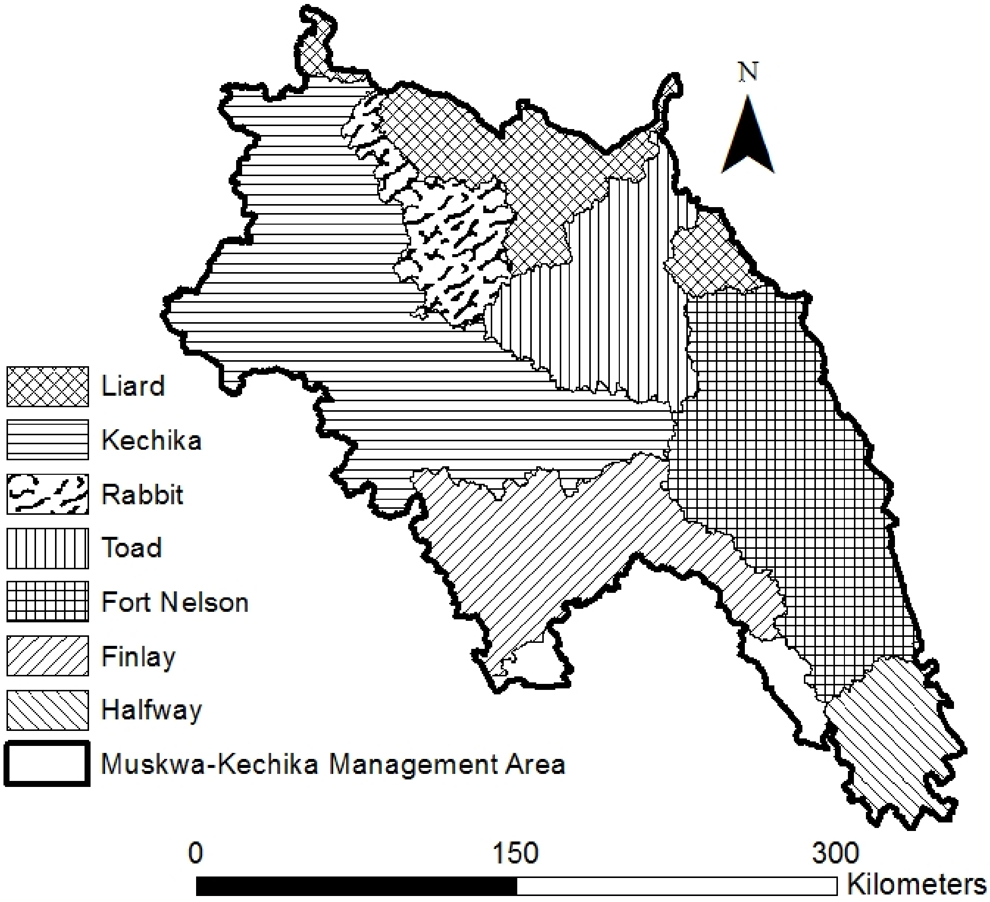

N
Liard
Kechika
Rabbit
Toad
Fort Nelson
Finlay
Halfway
Muskwa-Kechika Management Area
0
150
300
Kilometers

Figure 1.2.b.

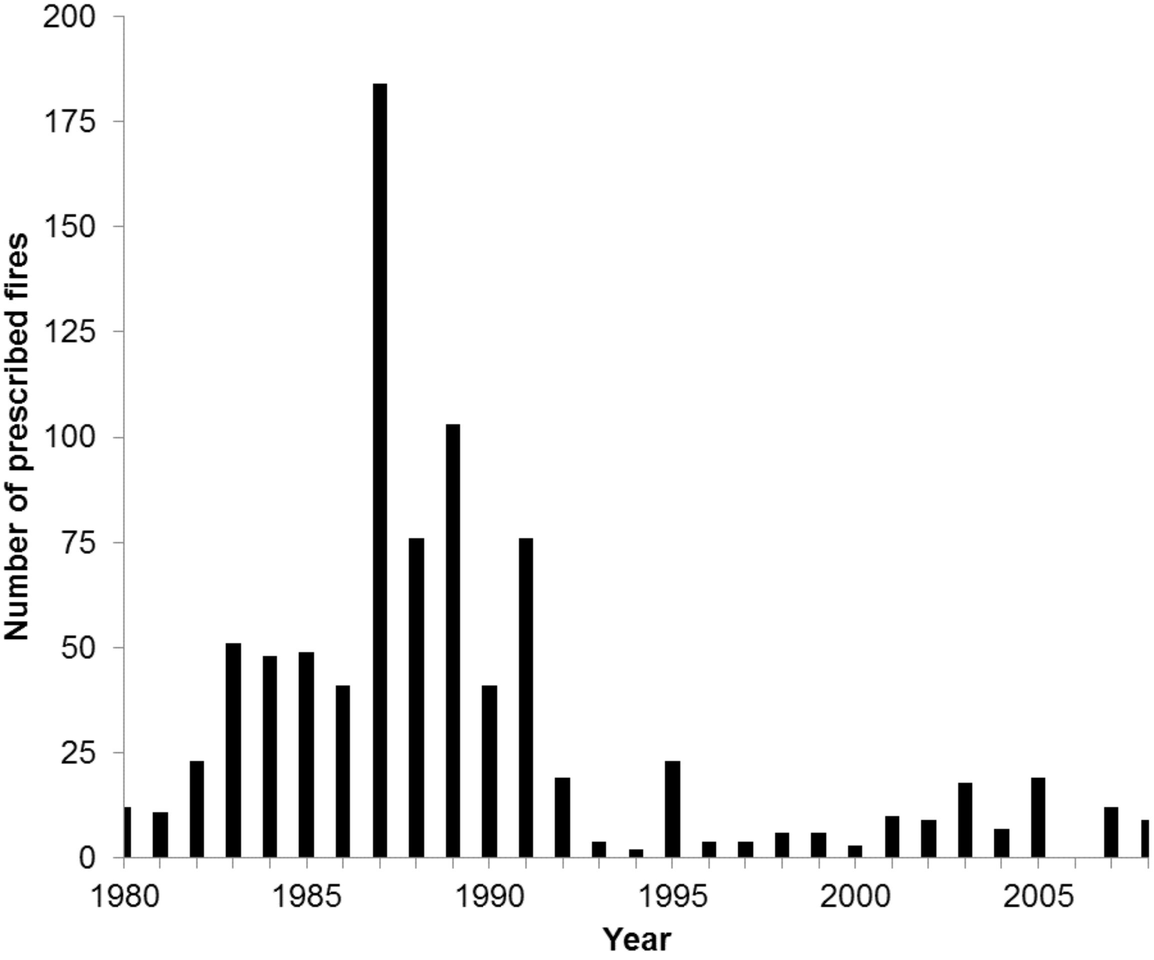

200
175
150
125
100
75
50
25
0
Number of prescribed fires
1980
1985
1990
1995
2000
2005
Year

Figure 1.3.a

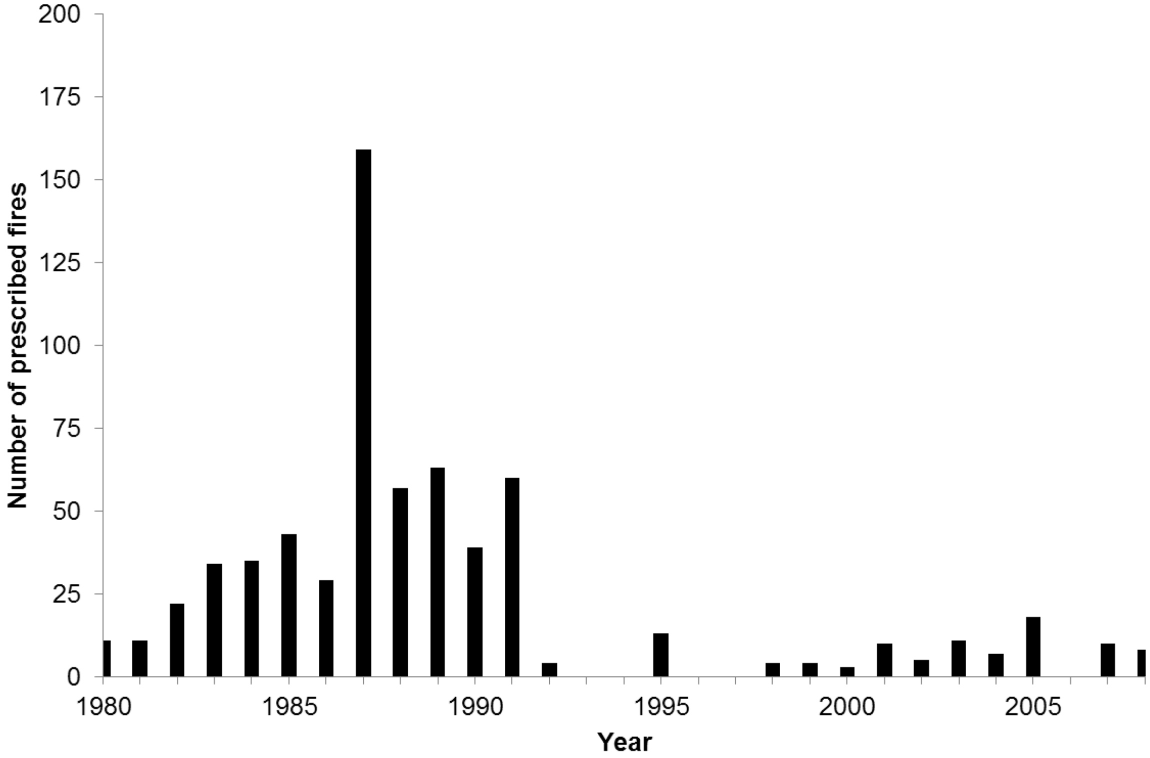

200
175
150
125
100
75
50
25
0
Number of prescribed fires
1980
1985
1990
1995
2000
2005
Year

Figure 1.3.b.

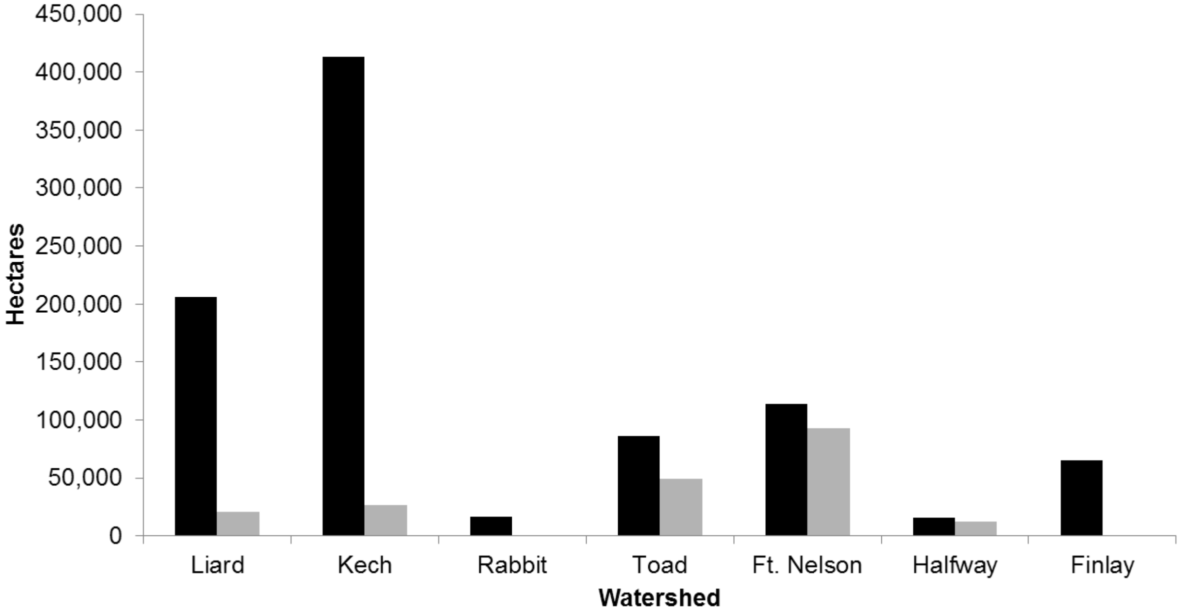

450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Hectares
Liard
Kech
Rabbit
Toad
Ft. Nelson
Halfway
Finlay
Watershed

Figure 1.4.a.

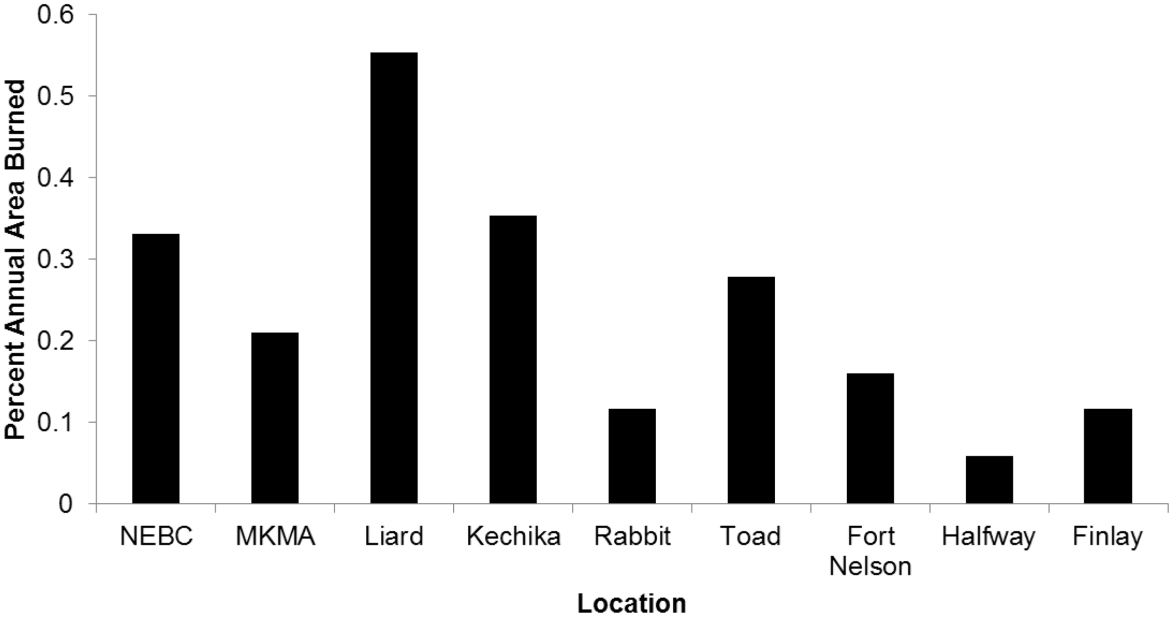

0.6
0.5
0.4
0.3
0.2
0.1
0
Percent Annual Area Burned
NEBC
MKMA
Liard
Kechika
Rabbit
Toad
Fort Nelson
Halfway
Finlay
Location

Figure 1.4.b

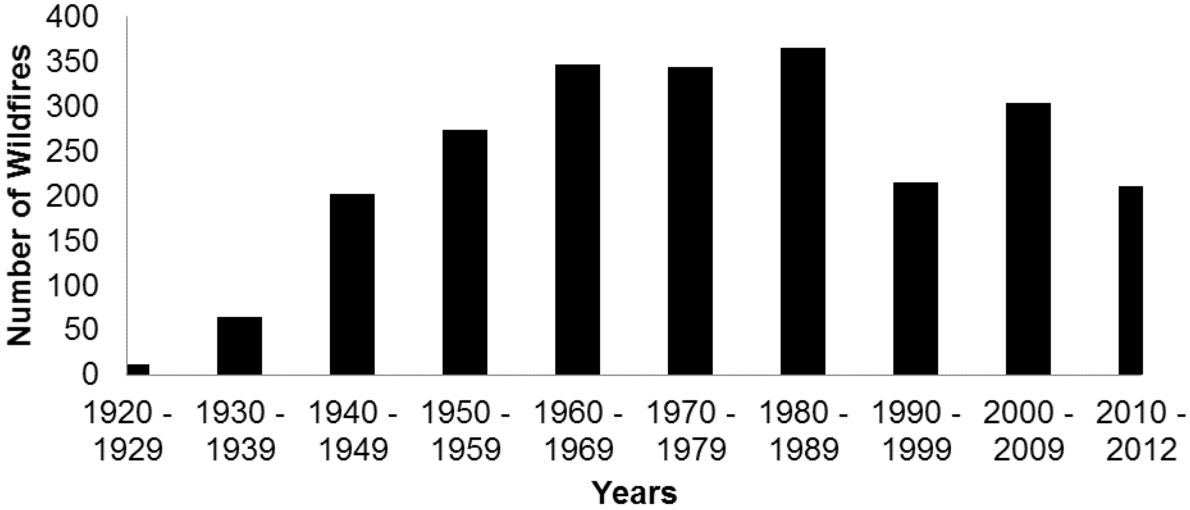
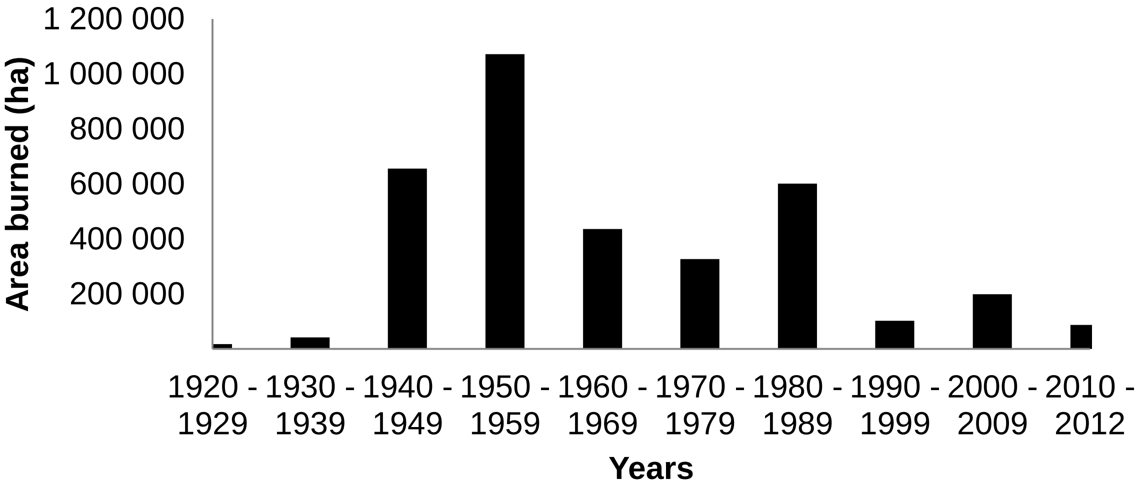
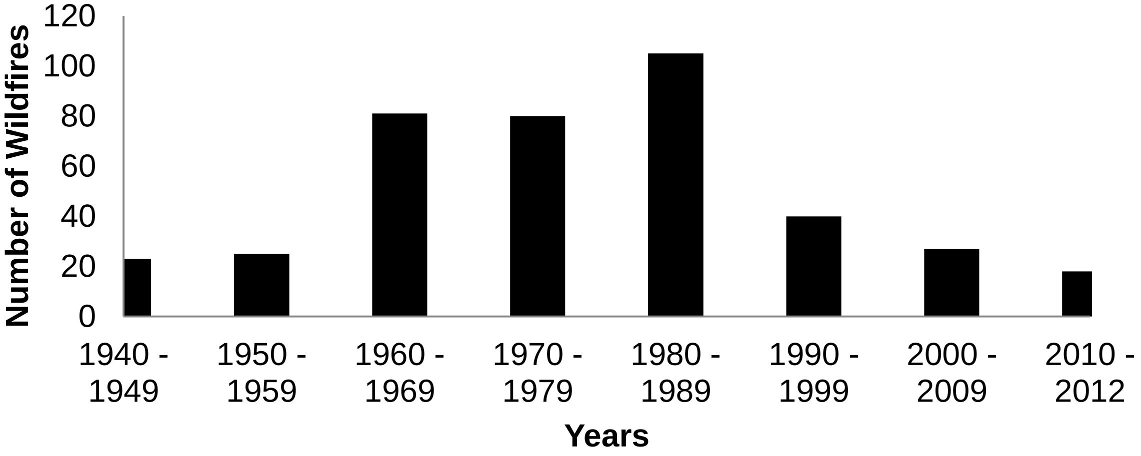

Number of Wildfires
400
350
300
250
200
150
100
50
0
1920 - 1929
1930 - 1939
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.5.a.



1 200 000
1 000 000
800 000
600 000
400 000
200 000
Area burned (ha)
1920 - 1929
1930 - 1939
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.5.b.



Number of Wildfires
120
100
80
60
40
20
0
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.6.a.

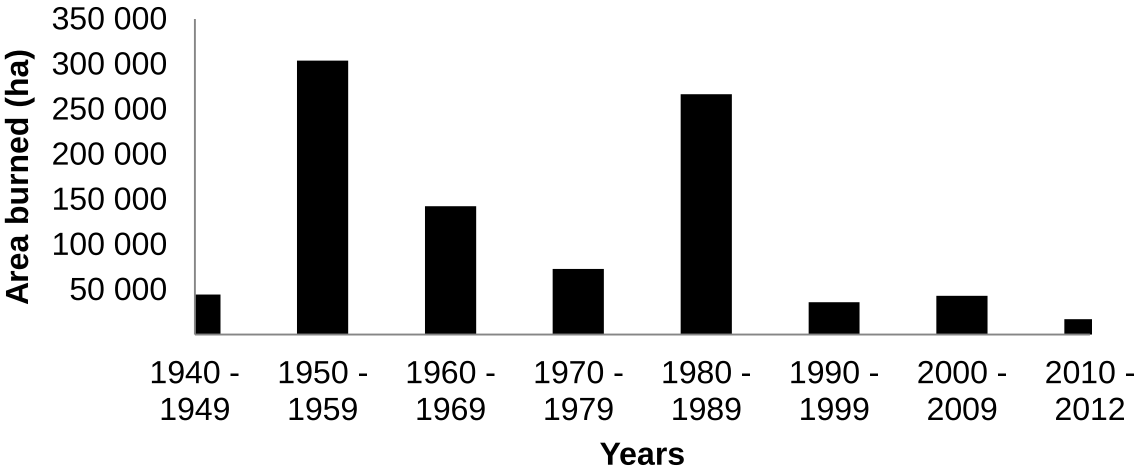

350 000
300 000
250 000
200 000
150 000
100 000
50 000
Area burned (ha)
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.6.b.

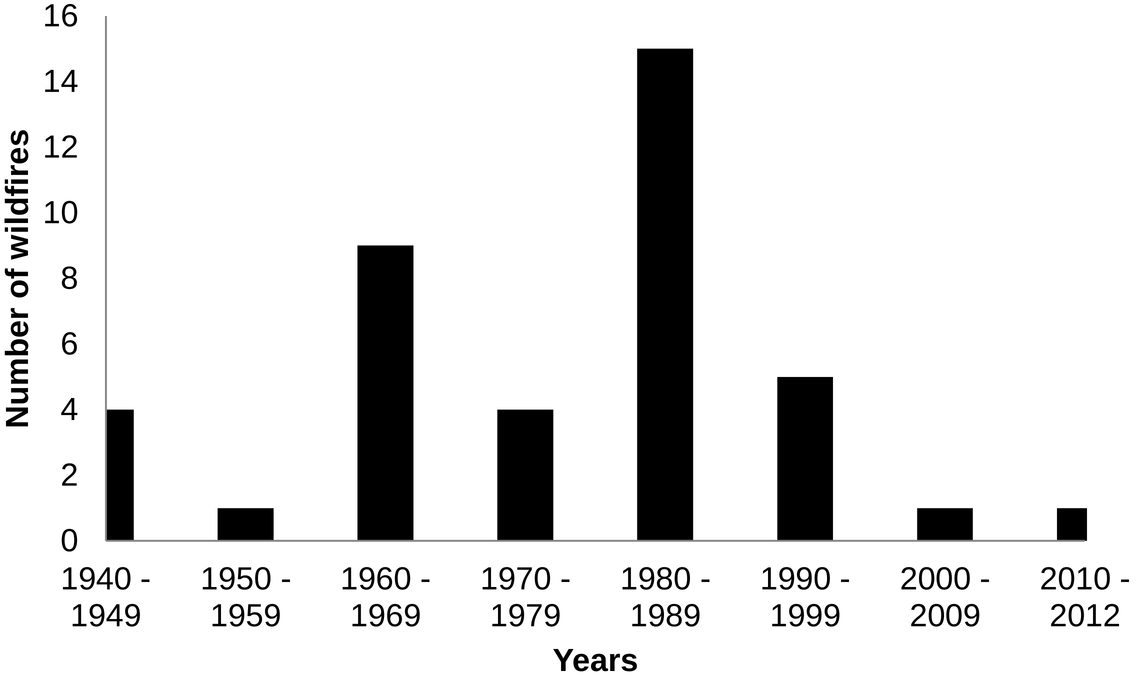

16
14
12
10
8
6
4
2
0
Number of wildfires
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.a.

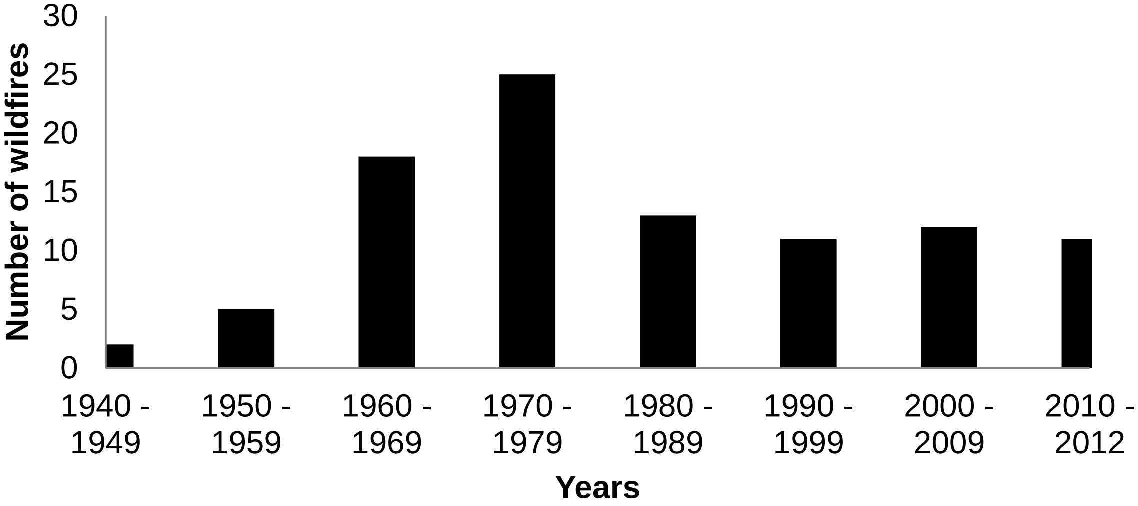

30
25
20
15
10
5
0
Number of wildfires
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.b

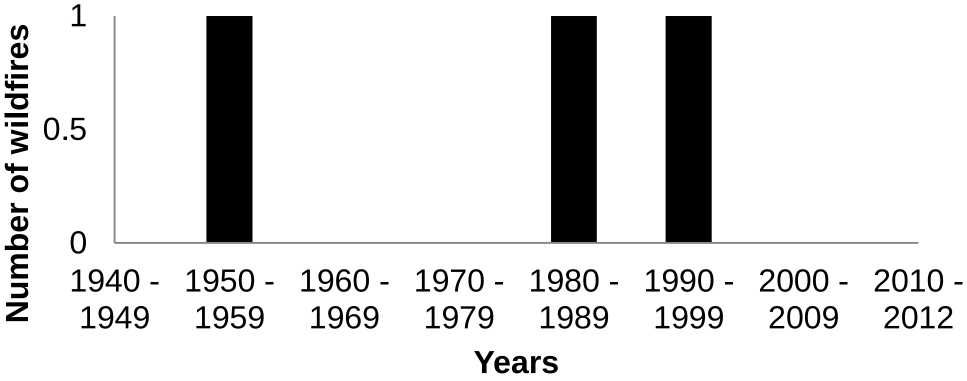

Number of wildfires
1
0.5
0
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.c.

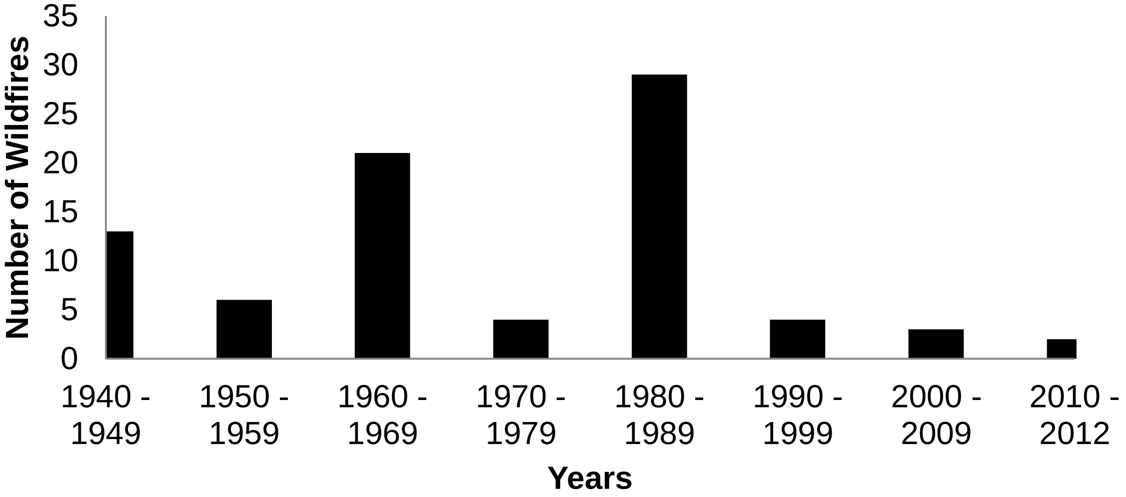
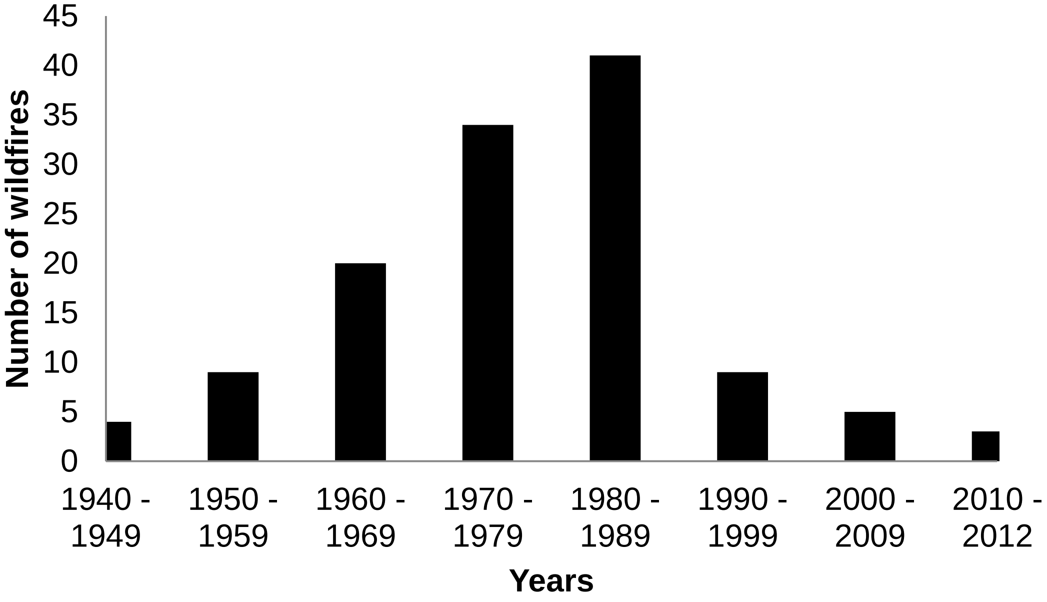

35
30
25
20
15
10
5
0
Number of Wildfires
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.d.



Number of wildfires
45
40
35
30
25
20
15
10
5
0
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.e.

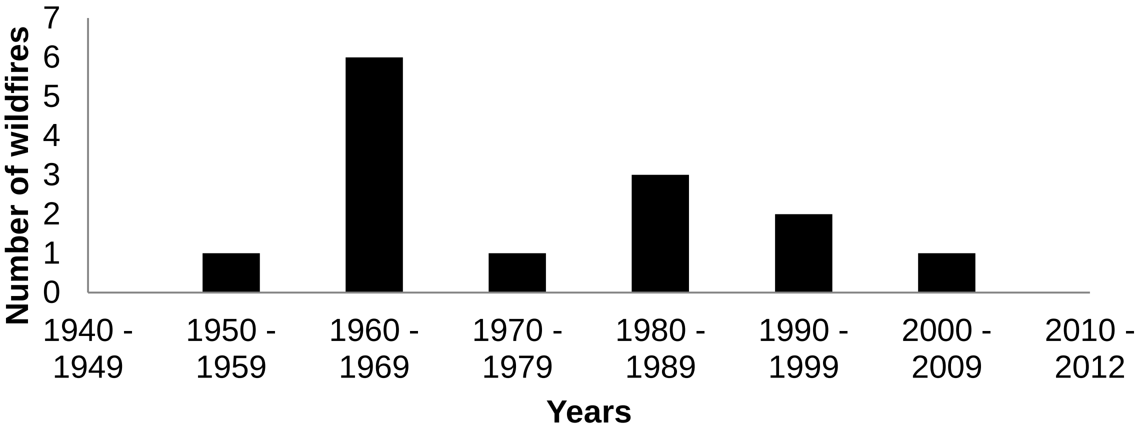

Number of wildfires
7
6
5
4
3
2
1
0
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.f.

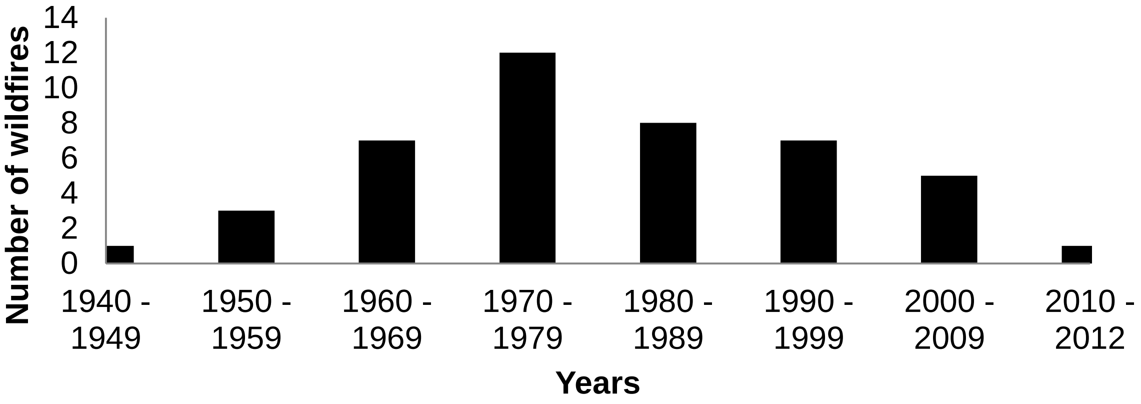

Number of wildfires
14
12
10
8
6
4
2
0
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.g.

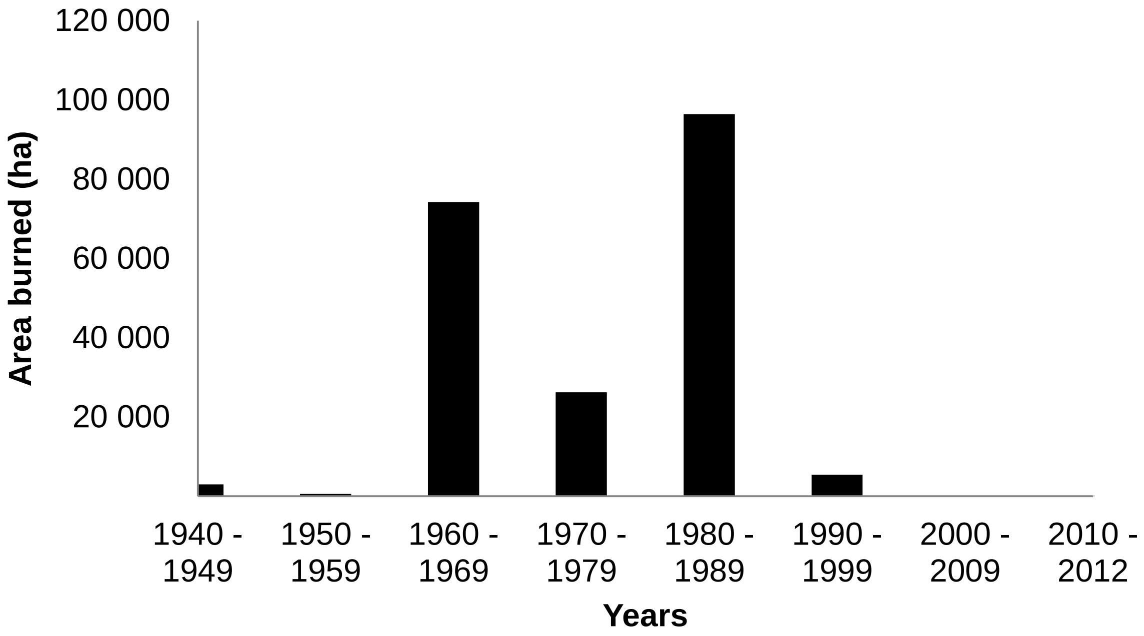

120 000
100 000
80 000
60 000
40 000
20 000
Area burned (ha)
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.b.a

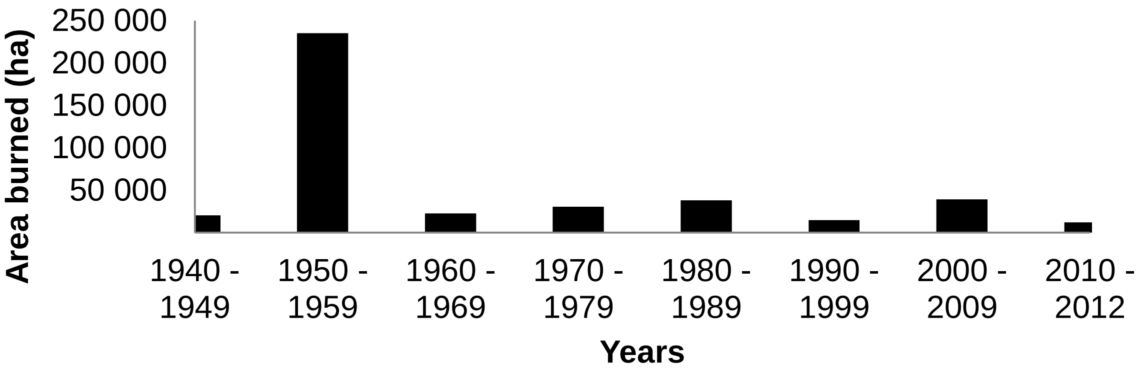

250 000
200 000
150 000
100 000
50 000
Area burned (ha)
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.b.b.

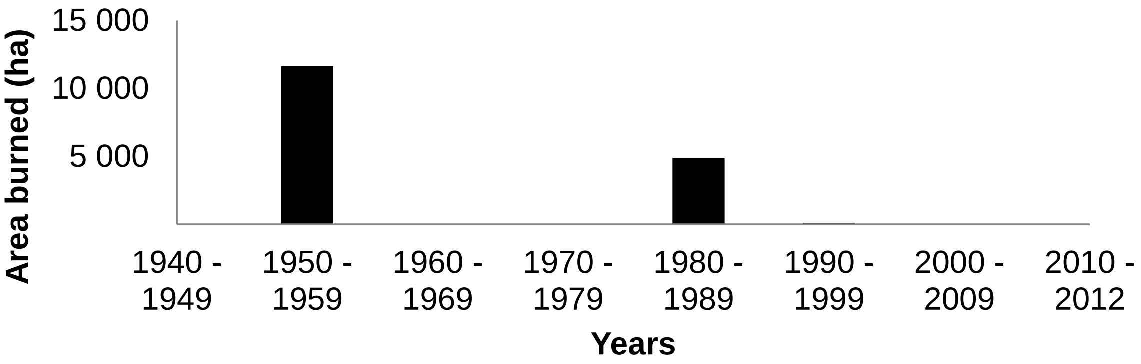

15 000
10 000
5 000
Area burned (ha)
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.b.c.

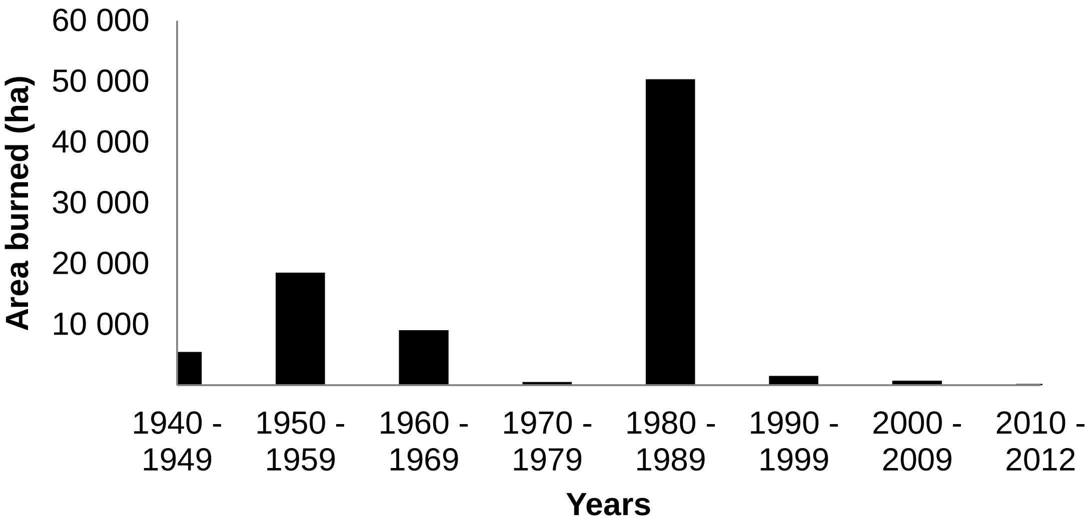

60 000
50 000
40 000
30 000
20 000
10 000
Area burned (ha)
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.b.d.

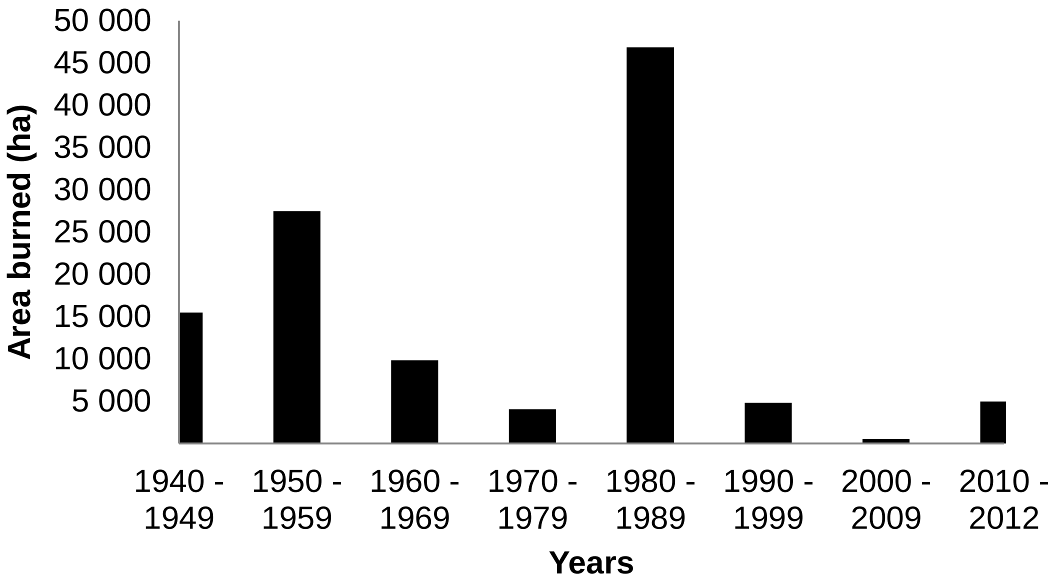

50 000
45 000
40 000
35 000
30 000
25 000
20 000
15 000
10 000
5 000
Area burned (ha)
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.b.e

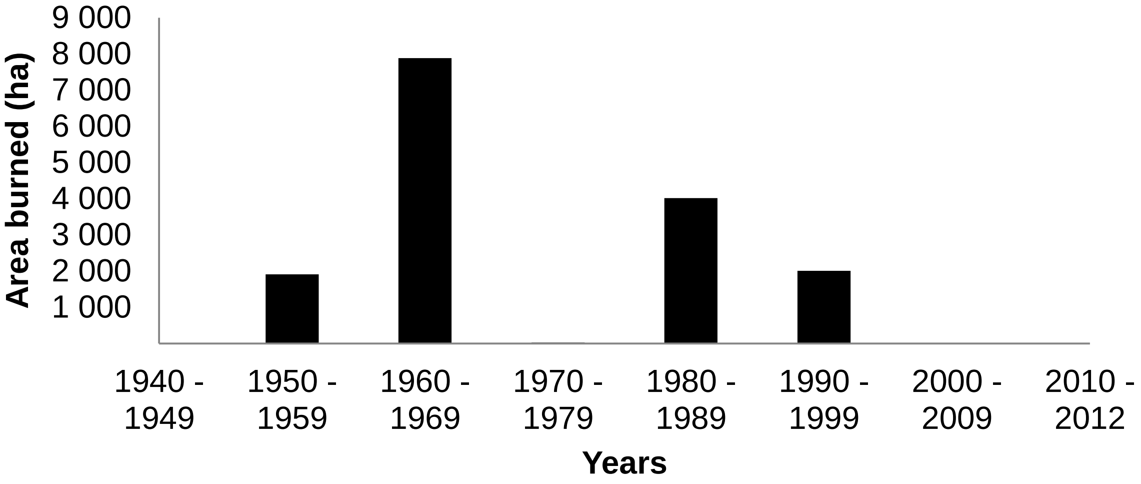

9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
Area burned (ha)
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.b.f.

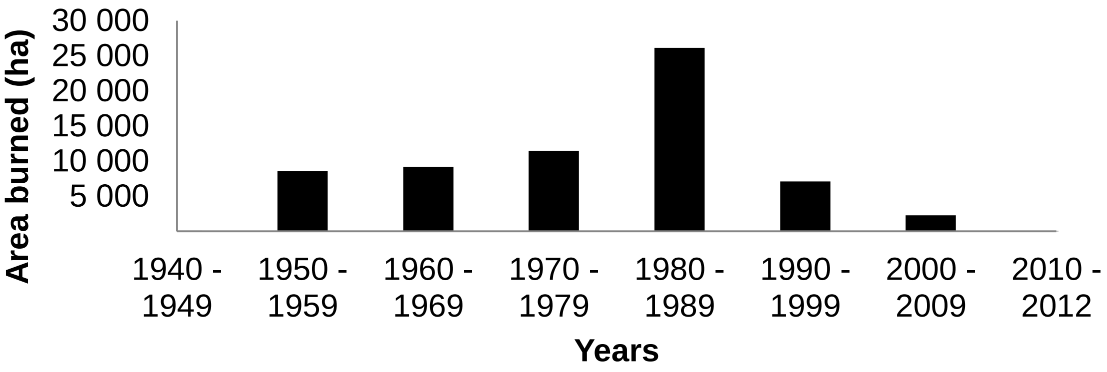
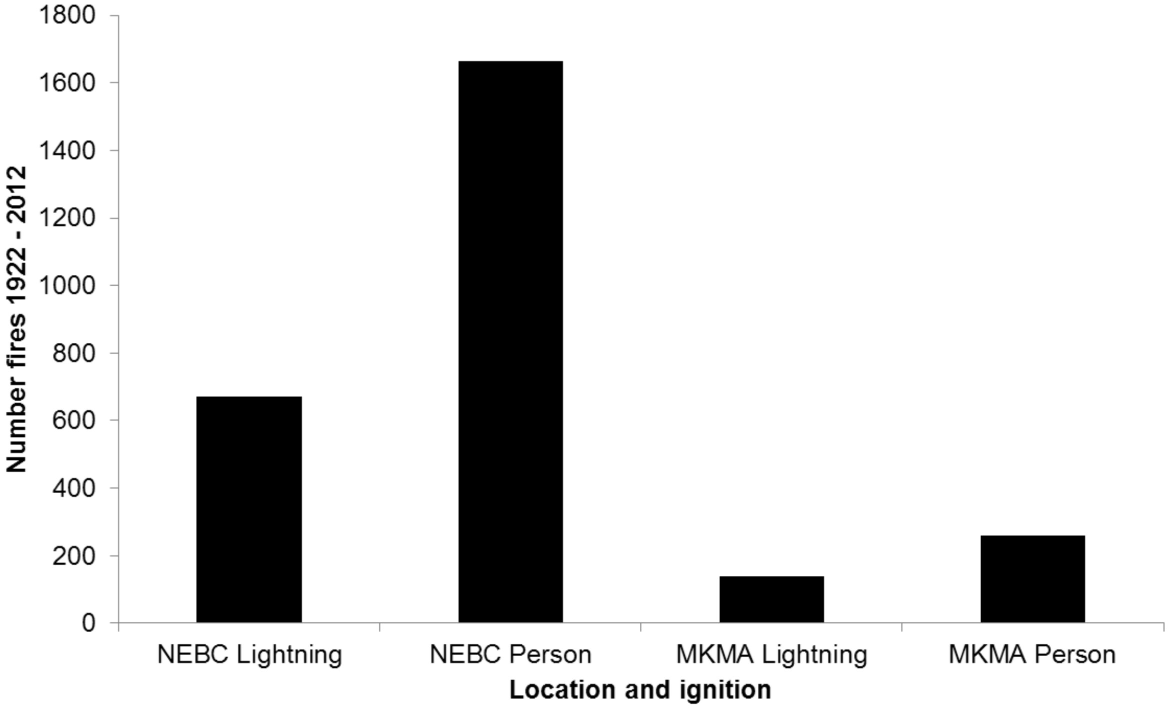

Area burned (ha)
30 000
25 000
20 000
15 000
10 000
5 000
1940 - 1949
1950 - 1959
1960 - 1969
1970 - 1979
1980 - 1989
1990 - 1999
2000 - 2009
2010 - 2012
Years

Figure 1.7.b.g.



1800
1600
1400
1200
1000
800
600
400
200
0
Number fires 1922 - 2012
NEBC Lightning
NEBC Person
MKMA Lightning
MKMA Person
Location and ignition

Figure 1.8.a.

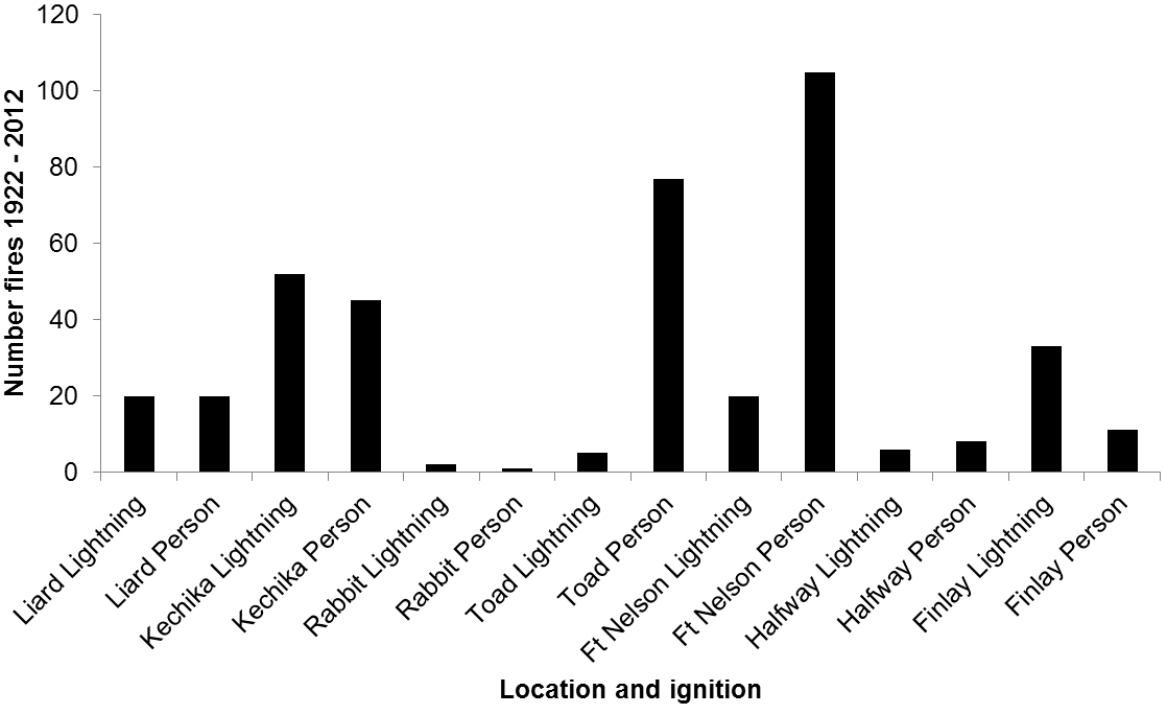

Number fires 1922 - 2012
120
100
80
60
40
20
0
Liard Lightning
Liard Person
Kechika Lightning
Kechika Person
Rabbit Lightning
Rabbit Person
Toad Lightning
Toad Person
Ft Nelson Lightning
Ft Nelson Person
Halfway Lightning
Halfway Person
Finlay Lightning
Finlay Person
Location and ignition

Figure 1.8.b.

CHAPTER II

REWILDING EXTIRPATED SPECIES SHOULD INLCUDE HABITAT MANAGEMENT: REINTRODUCTION OF WOOD BISON IN NORTHERN BRITISH COLUMBIA

Abstract

Landscapes are often rewilded with extirpated species with insufficient consideration for habitat required to sustain viable populations. Rewilding involves ecosystem manipulations using closely related species as proxies for extinct large vertebrates. Wood bison (*Bison bison athabascae*), extirpated from British Columbia, Canada in the early 1900's, were designated as endangered in 1978 under the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and were reintroduced in 1995 and 1999 to two locations in northeast British Columbia. We used these reintroduced populations of wood bison to evaluate the role of oil and gas development, and fire in altering patterns of herbivory. There were recent fires on the landscape of the Nordquist herd, but not on the landscape of the Etthithun herd. We found that bison congregated along both linear (i.e., roads) and non-linear (i.e., petroleum exploration sites) development features across the landscape. When bison in the Nordquist herd were not along the Alaska Highway, they used a road to access a recently burned area where they had been initially released. Wood bison selected open areas in general and since minimal habitat maintenance and management has occurred since the reintroductions within the Boreal forest, bison appear to select artificial openings along highways and petroleum development roads. However, selection for these modified landscapes has led to significant deaths from vehicle collisions, threatening the success of the reintroduction. Alternative areas could be developed through activities that promote openings such as the implementation of prescribed fire or clearing of land.

Introduction

While re-wilding and restoring extirpated species may have noble aspirations and conservation grounded objectives (Donlan *et al*. 2005), there is often little consideration for habitat restoration and management or resource availability (Kleiman 1989, Doremus and Pagel 2001, Scott *et al.* 2005, Seddon *et al.* 2007, Descare *et al.* 2010, Scott *et al.* 2010). Rewilding involves ecosystem manipulations using closely related species as proxies for extinct large vertebrates and includes actively restoring natural processes (Donlan *et al.* 2005). However, there is often a lack of attention given to the importance of species habitat requirements (Parminter 1989, Sarrazin and Barbault 1996, Scott 1999, Armstrong and Seddon 2007, IUCN/SSC 2013) during reintroduction planning and implementation to ensure that resources are distributed in appropriate spatio-temporal scales (Griffith *et al*. 1989, Kleiman 1989, Scott *et al.* 2005, Scott *et al.* 2010). Lack of consideration and maintenance of important resources in conserving reintroduced species (Griffith *et al*. 1989, Wolf *et al*. 1996, Jule *et al*. 2008, Moorhouse *et al*. 2009) and failures of reintroduction are documented with European bison (*Bison bonasus*) (Kuemmerle *et al*. 2011), giant tortoise (*Geochelone gigantean*) (Hambler 1994), greater prairie-chicken (*Tympanuchus cupido pinnatus*) (Vogel *et al*. 2015), Canada lynx (*Lynx canadensis*) (Steury and Murray 2004, Murray *et al.* 2008), caribou (*Rangifer tarandus caribou*) (Bergerud and Mercer 1989, *Warren et al.* 1996), macropods (*Macropodoidea*) (Short *et al.* 1992), rock hyrax (*Procavia capensis*) (Wimberger *et al.* 2009), bighorn sheep (*Ovis canadensis*) (Ostermann *et al.* 2001), grey squirrels (*Sciurus carolinensis*) (Adams *et al*. 2004), voles (*Microtus rossiaemeridionalis*) (Banks *et al.* 2000), and African wild dogs (*Lycaon pictus*) (Gusset *et al*. 2006). A summary of bird reintroductions found that more than 1,000 cases failed (Kleiman 1989). Griffith *et al.* (1989) reports a 44 % success over 80 translocations of threatened, endangered or sensitive species whereas Fischer and Lindenmayer (2000) report only 26 % success over 116 reintroductions.

Wood bison (*Bison bison athabascae*, Rhoads 1897) were extirpated from the province of British Columbia (BC), Canada due to over-hunting with the last wood bison shot outside of Fort St. John in 1906 (Soper 1941, MacGregor 1952, Harper *et al*. 2000). Wood bison were once abundant in the Boreal forest of northwest Canada to Alaska, with oral history documenting their presence in northern British Columbia (Harper 2002). Prior to 1800, Alberta, BC, the Northwest Territories and the Yukon had as many as several hundred thousand wood bison (Soper 1941, MacGregor 1952, Harper *et al*. 2000). Wood bison are an important species in the Boreal forest of North America and are considered the largest species of megafauna in these landscapes (Gates and Larter 1990, Larter and Gates 1990, Campbell *et al*. 1994, Harper 2002, Jensen 2005). They have been designated as "wildlife" and "big game" under the British Columbia Wildlife Act (Harper *et al*. 2000) and as such, could be considered a harvestable species. They were first listed in 1978 and are currently listed federally as a Schedule 1, threatened species under the Species at Risk Act (SARA) and were designated as a species of special concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2013 (Government of Canada, Harper and Gates 2000). Wood bison are also listed as near threatened on the International Union for the Conservation of Nature (IUCN) and on the Convention on the International Trade of Endangered Species of Fauna and Flora (CITES) (Gates and Aune 2008).

As of 2008, there was a total of approximately 11,000 wood bison globally (Gates and Aune 2008). The Government of Canada reports that as of 2006, there were 4,188 wood bison in seven free-ranging, disease free herds with the majority of these herds reintroduced by various agencies (Species at Risk Public Registry). Within BC, there are two reintroduced wood bison herds: the Nordquist herd and the Etthithun (Fontas) herd. The first reintroduction of wood bison occurred in 1995 when 49 wood bison from Elk Island National Park, Alberta, were reintroduced to the Nordquist Lake area in the Boreal forest of northeastern BC, Canada (Figure 2.1) (Harper and Gates 2000). These bison came from the genetic stock of 18 – 37 animals from the pure Nyarling River wood bison found in 1965 in the Northwest Territories (Harper and Gates 2000, Gates *et al*. 2001). In 1999, a second reintroduction occurred with 40 individuals released in the Etthithun Lake area by the Fontas River in the woodlands and muskeg of the Boreal forest of northeastern BC, Canada (Harper and Gates 2000) (Figure 2.1).

The Canadian Wood Bison Recovery Strategy is associated with the federal listing of wood bison and includes a management plan outlining conservation efforts. The strategy calls for disease free, free-roaming herds of 400 individuals distributed across northern Canada. While herd sizes have more than doubled since reintroduction (108 – 150 animals in the Nordquist herd and 120 – 160 animals in the Etthithun herd) (Figure 2.2a and 2.2b) there is considerable mortality amongst the herds aside from natural predation (Harper and Teucher 2010), disease (bovine brucellosis [*Brucella abortus*], bovine tuberculosis [*Mycobacterium bovis*] and anthrax [*Bacillus anthracis*]), and drowning (Larter *et al*. 2003, Rowe 2007, Thiessen 2009, Thiessen 2010). Collisions with vehicles are a threat to both herds (Harper and Teucher 2010). In other wood bison populations, wolf (*Canis lupus*) and bear (*Ursus sp*.) predation is a limiting factor particularly on juvenile survival (Van Camp 1987, Carbyn 1993, Varley and Gunther 2002). While data are not available for predation rates on the Nordquist or Etthithun herds, anecdotal information suggests that from 4 to 32 animals in the Nordquist herd have been killed per year from vehicle accidents on the Alaska Highway since 2003. These accidents often also result in serious injuries (i.e. paralysis, concussion, crushed vehicles) to the humans who collide with them. There has also been at least one instance where an Etthithun herd bison cow had to be euthanized because it was stuck under piping on a lease site. However, there is limited effort in resolving the number of bison killed each year by vehicles. A comprehensive evaluation of habitat conditions available to bison that may be causing them to concentrate near highways and roads is lacking.

The diet of bison primarily consists of sedges and grasses with a minor component of terrestrial lichen available in grassy meadows and shrubby savannas (Harper 2002). Bison require open rangelands and sedge meadows for foraging and wallowing (Soper 1941, Larter and Gates 1990, Harper and Gates 2000, Harper *et al*. 2000, Fortin *et al*. 2002, Goddard 2011, Leverkus *et al*. 2015**), open forest for rutting, rubbing and foraging (Soper 1941, Larter and Gates 1990, Harper *et al*. 2000, Fortin *et al.* 2002, Leverkus *et al.* 2015**), dense forest for cover, rubbing and foraging (Soper 1941, Larter and Gates 1990), and riparian areas for foraging and wallowing (Soper 1941, DeLong *et al*. 1991, Larter and Gates 1990, Harper *et al*. 2000, Fortin *et al*. 2002). Fire plays such an important role in the Boreal forest that the type (surface or crown), intensity (amount of energy released), severity (overall effect of fire on the ecosystem), frequency (number of fires), and time since last fire have significant influence on the distribution and composition of vegetation present on most sites (Parminter 1983).

Northeast British Columbia represents a large, fairly intact, landscape that provides novel and unique opportunities to evaluate the role of the ongoing human impacts and natural disturbances that are relevant to conservation of wood bison. However, there is increasing human activity in this region in the form of energy development. Additionally, there has been an alteration of land management practices over the past 30 years, such as the reduction of prescribed fires (Leverkus *et al*. 2015*). For example, prescribed fires have decreased from 175 per year in the mid-1980's to less than 25 per year in the late 2000's across northeastern BC (Leverkus *et al*. 2015*). This decrease in fire frequency creates a stronger dependency on wildfires or other disturbances to maintain open areas across the landscape. Bison are thought to preferentially select for small openings within a forested landscape (Goddard 2011), so it is difficult to predict habitat use in an industrializing landscape. Understanding herbivore grazing patterns and distribution in this biophysically diverse region is critical to extending the understanding of resource selection and disturbance driven herbivory. This knowledge is also critical in developing efficient natural resource management plans for this species in regions where development is increasing. Our objective was to evaluate habitat use relative to the biophysical environment and anthropogenic disturbance across multiple spatial scales on sites where wood bison herds have been reintroduced. We also briefly discuss management alternatives based on our findings.

Methods

Telemetry data were acquired from Lotek 3300L global positioning systems (GPS) deployed on 10 bison cows from 2009-2011 by the BC Ministry of Environment in two study locations: five cows in the Nordquist herd in the Boreal cordillera and five cows in the Etthithun herd in the taiga plains (Natural Resources Canada). Additional data came from three GPS Telemetry Solutions transmitters on Nordquist herd cows from 2010-2013. GPS transmitters were programmed to record GPS locations once every hour over 24 hours per day. A total of 33,664 locations (Nordquist) and 13,526 locations (Etthithun) were recorded in BC from February 2009 to March 2013. Due to malfunction and broken GPS collars, some of the data was not fixed properly and may represent an uneven collection of data over the course of this study. Technical issues with collar integrity include: collars flipping upside down, wires snapping, collars breaking and lack of ability to connect with the satellites. Female bison were collared because they have seasonally high nutritional requirements and their herding behaviour allows for extrapolations to be made for larger numbers rather than bulls that have a tendency to split off into small bachelor groups or roam by themselves (Shaw and Carter 1990, Fortin and Fortin 2009). By collaring cows, a greater understanding of herd dynamics and patterns of movement and resource use can be obtained (Coppedge and Shaw 1998, Stoye *et al*. 2012, Rands *et al*. 2014, Liu *et al*. 2015).

We compared animal distribution to available land cover conditions to determine use/avoidance of linear development features (highways, cutlines, forest service roads [FSRs], petroleum development roads [PDRs], paved roads, unpaved roads, overgrown roads, recreational roads, trails, pipelines, seismic lines, firebreaks, and right-of-ways), non-linear development features (polygons such as airstrips, aboveground waste disposal, agricultural fields, borrow pits, buildings, campgrounds, clearcuts, salt licks, communication/transmission towers, petroleum exploration development features, guide outfitter camps, Indian Reserve, settlements), other anthropogenic features in addition to non-linear development features (including camps, cutlines, log decks, facilities, helipads, firebreaks, gravel reserves, lodges, mines, permanent structures, pits, powerlines, pump-off disposal sites, overgrown and paved roads, right-of-ways, roadways, and trails), fire (presence of fire, number of times burned, and time since fire of wildfire and prescribed fire), slope, aspect, and nine broad cover types (bare/rock, forest, open broadleaf forest/aspen parkland, water, snow/ice, clouds, grass [including sedge meadows], wetland, and shrubland). The original Alaska Highway data acquired were buffered by 50 m per side for a total footprint of 100m. All other linear development features in the Nordquist area were buffered by 2.5 m per side for a total of 5 m width because of their actual disturbance width coverage on the ground. PDRs, FSRs and roads in the Etthithun area were buffered by 25 m per side for a total of 50 m width to represent their actual disturbance coverage on the ground. All other Etthithun linear development features (pipelines, seismic lines, etc) were buffered by 5 m per side for a total of 10 m width to represent their actual disturbance coverage on the ground. Non-linear development feature point data (wells, valve sites, towers, etc) were buffered and then combined with non-linear development feature polygon data. Anthropogenic features were established through combinations of buffered non-linear development feature data from point sources and combined with polygons from data sources including right-of-ways, firebreaks, and other data resulting from human disturbance not already captured by linear and non-linear development disturbance. We established three random points for each observed location to provide estimates of available conditions (Allred *et al*. 2011) such as cover type and development disturbance feature. We compared the actual GPS location data derived from the bison to distance from primary roads and road right-of-ways and use of linear development features, non-linear development features, anthropogenic features and cover types. For linear development features, non-linear development features, anthropogenic features, we analysed the Nordquist and Etthithun herds for presence in each feature and compared it to presence in the feature with a 100 m buffer added to it. Since bison do not always occupy the cleared area associated with each feature (i.e. well pad or right-of-way which have often been re-seeded with agronomic species) and have been observed grazing along the edge of the adjacent forest, we wanted to ensure that we captured the localized concentrated areas of use. Therefore we selected to buffer the features by 100 m.

For analyses of habitat selection we focused on two spatial extents: broad scale and fine scale. The broad scale extent was intended to address the selection of a home range within broad landscapes while the fine scale extent was intended to address habitat selection within the home range. The broad scale extent was determined through a combination of natural barriers and buffers on a Minimum Convex Polygon (MCP) to ensure a conservative estimate of where bison could easily select space use. The fine scale extent was determined using the 95 percent kernel isopleth from the Kernel Density Estimate (KDE) as derived through Hawthorne's tools using ArcGIS9.3 and ArcGIS10.1 because it has greater resolution on the boundaries (Anderson *et al*. 2005, Leggett 2006, Compton *et al*. 2007, Laver and Kelley 2008, Girard *et al*. 2013). KDEs were generated 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. The 95 percent kernel isopleth was used to analyze selection and use on a fine scale (Bingham and Noon 1997, Anderson *et al*. 2005, Kie *et al.* 2010, Worton 1989).

Selection of cover type was analysed using a combination of archived Landsat imagery from the US Geological Survey (USGS) at 30 x 30-m resolution (2009 imagery for Nordquist) and cover type data at 20 x 20-m resolution from the Canadian Council on Geomatics' Geobase/Geogratis (2000 imagery for Etthithun). The data layers were processed using ArcGIS10.1. Multivariate analysis using isocluster unsupervised classification yielded 20 classes which were re-classified into nine broad cover types including: bare/rock, forest, open broadleaf forest/aspen parkland, water, snow/ice, clouds, grass, wetland, and shrubland. Digital Elevation Models (DEMs) were developed and analysed for aspect and slope using data from the Canadian Council on Geomatics and Geogratis (Government of Canada 2009) (Leverkus *et al.* 2015*). Aspect data were transformed into two variables of northness and eastness as per Allred *et al*. 2011. Additional data sources included: the BC Oil and Gas Commission (industrial roads and seismic lines, and well pads, lease sites, borrow pits, etc), DataBC (Land and Resources Data Warehouse provided agricultural land and tenured areas), BC Wildfire Management Branch (wildfire), BC Fish and Wildlife Branch (prescribed fire), and the Northern BC Guides Association (prescribed fire). Linear development features considered in this analysis include Petroleum Development Roads (PDRs), Forest Service Roads (FSRs), seismic lines, pipelines, miscellaneous lines and other roads developed to 2011.

Resource selection function (RSF) (Boyce *et al*. 2002) and models on the two populations were developed to include presence or absence of bison in features buffered by 5 m including linear development features, non-linear development features, anthropogenic features, fire footprint, and cover type across the broad scale. All features were buffered by an additional 5 m to account for potential inaccuracy in the GPS collar fix locations and edges of landscape features. The 100 m buffered features were only used to compare availability to use of linear, non-linear and anthropogenic development features. The 5 m buffered features were compared to slope, aspect, time since fire, and number of times burned (Boyce *et al.* 2002, Duchesne *et al*. 2010, Latham *et al*. 2011, Allred *et al*. 2011, Buchanan *et al*. 2014, Ehlers *et al.* 2014). The most current data on wildfires and prescribed fires in British Columbia from 1922 to 2012 were spatially analysed as per Leverkus et al. 2015* using the methods outlined up Stocks et al. 2003. Resource selection variables were standardized as per Allred *et al*. (2011) and Gelman and Hill (2007). 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 resulting from the GLMs indicate preference of selection as either a positive or negative relationship of relative influence. We ran initial RSF models through an additive process starting with cover type comparing bison presence within each cover type and feature. We progressively added fire, linear development features and non-linear development features.

Results

Our broad scale RSF model found that there were more than 686,000 ha available to the Nordquist bison herd and 577,000 ha available to the Etthithun bison herd., The fine scale RSF model showed concentrated selection across almost 40,000 ha (Nordquist) and more than 90,000 ha (Etthithun). The differences between the distributions of the two herds could be associated with the amount of linear development within their home ranges, primarily the Alaska Highway at Nordquist compared to a higher density of Petroleum Development Roads (PDRs) at Etthithun (Figure 2.3a and 2.3b).

We found that bison did not use all features equally in proportion to their availability. The resource selection coefficients indicate that roads and other anthropogenic structures were the features that were most strongly selected for by both bison herds (Table 2.1). Based on resource selection coefficients, the primary driver of bison site selection was a positive selection for presence of linear development features (roads) ($p<0.05$; nordquist = 2.22, etthithun = 0.63). Preference for linear development features was stronger for the Nordquist than the Etthithun herd where the resource selection coefficient was two times that of all other coefficients.

Our results show that bison minimize their distance from linear and non-linear development features. The total length of linear development features at Nordquist including roads, firebreaks, the old Alaska Highway, and old trails was 1,515 km. Nordquist bison spent 77 % of their time near the Alaska Highway that represents only 8 % of the landscape (Table 2.2). The total length of linear development features in the Etthithun area was 3,743 km. Etthithun bison spent 64 % of their time near linear development features which represent 47 % of the landscape (Table 2.3). They spent 40 % of their time near non-linear development features which represent 10 % of the landscape and 41% of their time within anthropogenic features which represent less than 7 % the landscape (Table 2.3).

Secondary selection in the Nordquist herd was influenced by slope, time since fire, number of times burned and open cover type (bare, grass and open broadleaf) (Table 2.1). Bison in the Nordquist herd avoided steeper slopes and increased time spent in recently burned areas while bison in the Etthithun herd selected for non-linear development features and bare cover type as secondary selection (Table 2.1). Recent fire was absent on the landscape of the Etthithun herd. Compared to use of roads and other linear development and non-linear development features, resource selection coefficients indicate that water, forest, wetland, and aspect did not have a strong influence on bison space use across the landscape. However, bison in both herds preferred open areas (grass, bare and rock cover type) (Table 2.1). Nordquist bison spent half of their time in open areas (grass, open broadleaf and bare cover type) representing 30 % of the landscape (Table 2.2) and Etthithun bison spent one-third of their time in open areas (bare and grass cover type) representing 15 % of the landscape (Table 2.3). When the Nordquist herd was not along the Alaska Highway right-of-way and associated linear development features, they occupied the area of their original reintroduction in locations where efforts have been made to conduct prescribed fires (Figure 2.3a). Bison in the Nordquist herd selected for recently burned areas ($p<0.01$; nordquist = 0.10), with more fires ($p<0.01$; nordquist = 0.43) (Table 2.1) in an area that had recent fire activity of 1,430 ha between 2009 - 2012.

Discussion

Our data show that bison are strongly attracted to linear development features and are almost exclusively found on the Alaska Highway (Nordquist) and Petroleum Development Roads (Etthithun). The probability of bison being present along linear development features increased as linear development features increased across the landscape. Others have documented bison use of roads and corridors in Yellowstone (Meagher 1989, Bjornlie and Garrott 2001, Bruggeman *et al*. 2007). Bison selected open areas and avoided forests. The Nordquist herd is located within the northern extent of the Northern Rocky Mountains, where steep slopes and exposed rock prevent access and distribution across the landscape. Bison on these landscapes significantly avoided steeper slopes and some of the most level ground was along the road indicating that these two features are difficult to separate.

In British Columbia bison distribution has been constricted due to industrial development and lack of alternative resources to select from. Historically, bison were distributed across northern British Columbia, Alberta, Northwest Territories, Yukon and Alaska (Stephenson *et al*. 2001). They have an effective digestive system with ability to forage in areas of recent disturbance and ability to move and use a variety of cover types (Stephenson *et al*. 2001), while also being adapted to low temperatures and snow conditions (Stephenson *et al*. 2001). Others have also suggested that wood bison historically foraged for grasses amid forests of black and white spruce (*Picea mariana* and *P. glauca*), aspen (*Populus tremuloides*), jack and lodgepole pine (*Pinus banksiana* and *P. contorta var. latifolia*), and poplar (*Populus balsamifera*), and that they exploited large areas of open land (Yerbury 1980). Current habitat has been constricted because the only openings across the landscape within the Etthithun herd arise from linear development (roads, seismic lines, pipelines) and non-linear development features (lease sites and infrastructure) resulting from oil and gas activities. Earlier industrial exploration left significant disturbance areas across the forested landscape which, in some areas, have been slow to re-establish native vegetation and are still evident today (Lee and Boutin 2006). From the 1950's to 2000, vegetation was cleared using bulldozers. Linear development features associated with exploration and increased anthropogenic presence on the landscape including right-of-ways, pipelines, lease sites and other anthropogenic features have primarily been re-seeded using agronomic species such as smooth brome (*Bromus inermis inermis*), timothy (*Phleum pratense*), alfalfa (*Medicago sativa*) and sweet clover (*Melilotus sp*.). These species and the level and open nature of these developments are likely attractants for bison. Similarly, the Alaska Highway right-of-way offers easy access to agronomic species which were seeded at the time of the reintroduction of the herd.

Roads and other linear development features are an issue for many species. Some predators such as wolves (James and Stuart-Smith 2000, Sorenson *et al*. 2008, Latham *et al.* 2011a, and Latham *et al.* 2011b) may be attracted to roads while other species such as lynx, fisher, marten and weasel may avoid roads (Nielsen *et al*. 2007). Increases of linear development features across the landscape influences animal distribution and results in higher edge effects which include avoidance by potential dispersers, adverse abiotic conditions, increased risk of predation, species-specific corridor efficacy, inappropriate habitat, corridor gaps and bottlenecks, sex and age filtering of target species, inadequate assessment of dispersal distances, loss of mutualists or food specialists increased risk of parasitism or disease, invasion and competition from exotic species, community drift, corridors used as dispersal sinks and increased exposure to human depredations (Hilty *et al*. 2006, Benítez-López *et al*. 2010). Linear and non-linear development features cause fragmentation, blocking of migratory movement, removal of habitat from certain locations and the cumulative effects of noise, dust, increased human presence and occupancy on the landscape (Beckmann *et al.* 2012). Increased roads and rail density across a landscape can increase the number of vehicle collisions and mortality arising from collisions (Singh and Sharma 2001, Beckmann *et al.* 2012). The attraction and selection for linear development features, such as roads, may result in increased bison mortality.

Bison restoration can be successful when habitat requirements are met. Prior to the reintroduction of the Nordquist herd, the vegetation at the site of the original reintroduction showed grass production up to 900kg/ha (Elliott 1989). At that time, more than 185,000 ha had been burned by wildfire within the previous decade while a minimum total of 109 wildfires and prescribed fires had burned more than 403,000 ha since 1922. Our results suggest that bison select for openness created through disturbance and that when they are not concentrated along roads and other anthropogenically maintained openings, they use an area historically maintained by fires when fires are available. It is unclear as to how ecological considerations of bison conservation and restoration were implemented in BC and how they will be implemented in the future. Government agencies currently think bison prefer small sedge meadows and forested ecosystems (Haper and Gates 2000, Goddard 2011, Redford *et al.* 2011). In addition, the Canadian Wood Bison Recovery Team no longer exists, but, it is understood that there are plans to continue re-introducing bison herds in Canada with the potential targets of 1,000 individuals per herd. Without management teams implementing habitat maintenance and team-based approaches to recovery efforts involving science (Kleiman and Mallinson 1998), it will be challenging for bison herds to achieve successful restoration. Additionally, the initial reintroduction of bison to the Etthithun Lake area in March 1996 provides an example of a failed reintroduction. Out of the 18 bison released, 15 remained as of January 1997 with 3 killed by industrial vehicle collisions by March 1997 (Harper and Gates 2000). The remaining individuals joined a herd of feral commercial bison and the entire group was later collected, removed from the landscape and sold privately (Harper and Gates 2000).

In the case of wood bison, there is a need for more open areas available for bison selection away from roads and potentially harmful industrial sites. This can be achieved through the application of prescribed fire to increase openness and to promote pyric herbivory which could assist in drawing bison away from hazardous areas (Fuhlendorf *et al.* 2009). Since the diet of bison primarily consists of sedges and grasses with a minor component of terrestrial lichen available in grassy meadows and shrubby savannas (Harper 2002), processes which produce such vegetation are important for bison. Time since disturbance and number of disturbances drive the availability, access to and quality of grazing areas for bison in the Boreal. For example, the

Smith River Fire 084 of 2009 burned 24,000 ha in the Nordquist bison home range, but, windthrown trees have created barricades (Ripple and Larsen 2001, de Chantal and Granstrom 2007) preventing the bison from accessing recently burned areas and resources. Additionally, there is a very minimal recent prescribed fire in the Nordquist distribution area. The average prescribed burn area for wood bison habitat by the BC Ministry of Environment is only 99.5 ha within the Nordquist herd distribution (Goddard 2011). The minimal number of fires and long time since fire in the Etthithun bison distribution results in a lack of openness from natural disturbance. Long-term fire removal and length of fire-return interval can determine the proportion of area occupied by grassland, shrub, and conifer communities resulting in differences in the degree of openness across a landscape (Rowe and Scotter 1973, Lewis and Ferguson 1988, Bork *et al.* 1997, Fuhlendorf *et al.* 2011). Disturbances such as fire in the Boreal forest result in open spaces resulting in patchiness across the otherwise closed canopy forest of the Boreal (Turner *et al*. 2001). The number of times an area burns within the Boreal forest can increase accessibility due to larger openings created by fire with less vertical structure from stands of trees. Larger degrees of openness across the landscape occur from frequent number of fires and recent time since fire resulting in changes in the amount of cover type in grass and open broadleaf forest. Timber harvesting may be an alternative option in the area although there are economical limitations.

Bison in the Etthithun herd are currently dependent on oil and gas development to create openings. Our results show that as the distance to the historical fire edge increases, the probability of bison being present in the Etthithun herd decreases. This further increases the dependency on oil and gas activity. Currently the Etthithun bison have higher distribution across the landscape, not by direct ecological planning but rather through the cumulative effect and impact of oil and gas development across their home range resulting in the creation of open areas from linear, non-linear and anthropogenic development features. While energy development assists in providing open areas for bison to forage and access resources otherwise unavailable, the quality of these static mosaics created from the industrialization of this landscape is unknown. For example, impacts from surface and air leaks and spills on bison or other wildlife in the area have not yet been researched neither has effects of poaching.

There are many ironies in the restoration of wood bison to northeastern BC. Following the reintroduction of bison to northeastern BC, there was minimal planned habitat management for both herds. The Etthithun herd is spatially distributed across the industrialized landscape of its reintroduction. Conversely, the Nordquist herd selects for minimal distance from the Alaska Highway. Even though there is a strong history of fire in the region compared to the Etthithun herd, the Nordquist herd could benefit from increased disturbance to create openness. Energy developed areas may provide the most viable current availability of openness for bison, however, if the goal is to have free-roaming, disease-free populations, land managers will need to reintroduce disturbances such as fire to create openings away from hazardous features (Alaska Highway and petroleum development sites) because our results show that bison preferentially select for areas of openness when they are available. In the absence of appropriate resource availability for selection by species, industrialized anthropogenic landscapes may provide adequate habitat with tradeoffs including negative interactions with vehicles, toxic situations related to oil and gas activities, and harm to humans and their livestock. Due to the presence of linear development features and non-linear development features within bison distribution and the lack of ecologically appropriate open areas, wood bison in British Columbia are not randomly spatiotemporally distributed across the landscape. Ecologically and culturally appropriate habitat management planning and implementation is required to successfully restore and conserve wood bison across the landscape for current and future generations.

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Tables

Table 2.1. Estimated resource selection function coefficients for Nordquist and Etthithun wood bison herds in northeastern BC, Canada from 2009 - 2013. Model parameters include presence within a fire, number of times burned, time since fire (year), presence within cover type (bare or rock, forest, grass, open broadleaf, shrubland, wetland, water), presence within linear development features (eg., roads, seismic lines) and non-linear development features (eg., rectangular wellpads). Additional parameters include northness and eastness (^{O}; both derivatives of aspect) and slope (%). Standardized variables are shown for coefficient comparison. Standard error (SE) and significance (p) are included.

Resource variable	Nordquist	SE	p	Etthithun	SE	p
Fire	0.1015	0.0204	<0.01	-0.2115	0.0136	<0.01
Times burned	0.4260	0.0133	<0.01	--	--	--
Time since fire	-0.6687	0.0189	<0.01	--	--	--
Bare	0.3031	0.0126	<0.01	0.4870	0.0160	<0.01
Forest	0.0485	0.0167	<0.01	0.0951	0.0231	<0.01
Grass	0.4790	0.0114	<0.01	0.1439	0.0136	<0.01
Open broadleaf	0.6095	0.0137	<0.01	0.0080	0.0171	0.64
Shrubland	-0.1498	0.0154	<0.01	0.0962	0.0127	<0.01
Water	-0.0786	0.0107	<0.01	-0.0480	0.0153	<0.01
Wetland	0.1001	0.0077	<0.01	-0.0542	0.0248	0.03
Linear	2.2217	0.0177	<0.01	0.6250	0.0118	<0.01
Non-linear	0.2044	0.0074	<0.01	0.5116	0.0101	<0.01
Eastness	-0.0794	0.0109	<0.01	0.0336	0.0115	<0.01
Northness	0.0208	0.0109	0.06	0.0043	0.0115	0.71
Slope	-1.1891	0.0179	<0.01	0.0401	0.0117	<0.01

Table 2.2. Nordquist wood bison GPS locations from 2009 – 2013 were analysed for percent of locations spent within each resource variable (cover type and other features) across the fine scale derived from the 95 percent isopleth. Bison locations were also analysed for presence in 100 m buffers on linear development features (roads, seismic lines, etc), the Alaska Highway, non-linear development features (wells, pits, etc) and anthropogenic features (campgrounds, airstrips, etc).

Resource variable	Area (ha)	% of area	# locations	% locations
Total landcover	39,613	100.0	33,068	100.0
Bare	3,604	9.1	5,533	16.7
Forest	22,223	56.1	14,617	44.2
Open broadleaf	7,645	19.3	8,157	24.7
Water	3,353	8.5	224	0.7
Grass	673	1.7	3,062	9.3
Wetland	361	0.9	409	1.2
Shrubland	996	2.5	812	2.5
Other features				
Linear	1,128	2.8	20,685	62.6
Linear (100m)	6,616	16.7	26,859	81.2
Alaska Highway	1,016	2.6	20,529	62.1
Alaska Highway (100m)	3,068	7.7	25,470	77.0
Non-Linear	480	1.2	2,030	6.1
Non-Linear (100m)	1,068	2.7	4,574	13.8
Anthropogenic	5,974	15.1	26,505	80.2
Anthropogenic (100m)	11,225	28.3	28,361	85.8

Table 2.3. Etthithun wood bison GPS locations from 2009 – 2011 were analysed for percent of locations spent within each resource variable across the fine scale derived from the 95 percent isopleth. Bison locations were also analysed for presence in 100 m buffers on linear development features (roads, seismic lines, etc), non-linear development features (wells, pits, etc), and anthropogenic features (campgrounds, airstrips, etc).

Resource variable	Area (ha)	% of area	# locations	% locations
Total landcover	90,266	100.0	13,373	100.0
Bare	1,047	1.2	1,902	14.2
Forest	36,202	40.1	3,879	29.0
Open broadleaf	10,161	11.3	1,308	9.8
Water	630	0.7	28	0.2
Grass	2,541	2.8	1,073	8.0
Wetland	36,294	40.2	4,503	33.7
Shrubland	3,391	3.8	680	5.1
Other feature				
Linear	5,097	5.6	3,222	24.1
Linear (100m)	42,328	46.9	8,498	63.5
Non-Linear	1,409	1.6	2,542	19.0
Non-Linear (100m)	8,832	9.8	5,296	39.6
Anthropogenic	6,170	6.8	5,455	40.8
Anthropogenic (100m)	44,700	49.5	9,511	71.1

Figure legend

Figure 2.1. GPS locations of the Nordquist (red) (2009 – 2013) and Etthithun (black) (2009 – 0211) wood bison herds in northeast British Columbia, Canada with the Alaska highway (gold).

Figure 2.2. Mean, maximum and minimum number of animals sighted and counted from the Alaska Highway in the Nordquist herd per year from 2005 – 2013 established by transects conducted by the BC Ministry of Environment (Rowe 2007, Thiessen 2009, Harper and Teucher 2010, Thiessen 2010) and others (Leverkus and Dickie 2010, Leverkus 2011, and personal communications). Vertical lines represent ± 1 SE.

Figure 2.3. Kernel Density Estimates (KDE) of the Nordquist (a) and Etthithun wood bison herd (b) (high to low colour scale indicating high to low areas of selection) with roads (black: Alaska Highway and Petroleum Development Roads) within the Minimum Convex Polygons (blue) highlighting the selection for linear development features across the landscape from 2009 - 2013. The area off the road is a burned area in the Nordquist distribution.

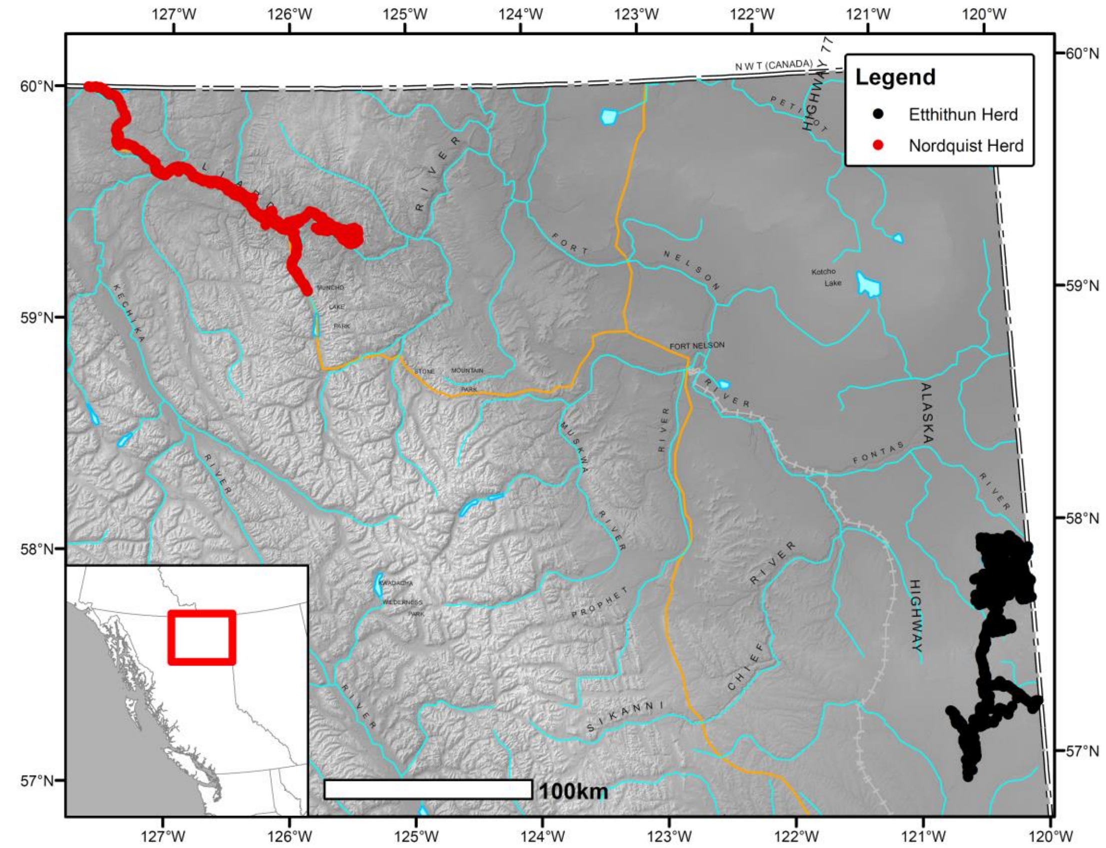
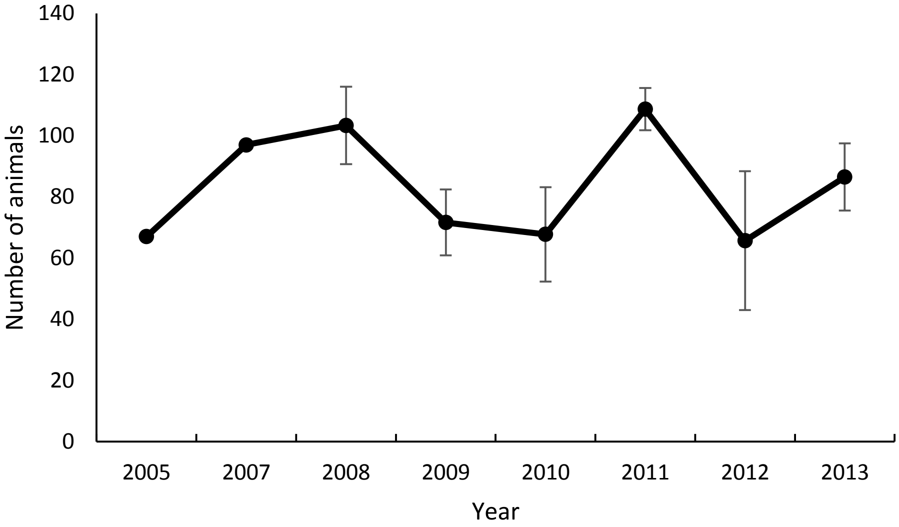

127°W
126°W
125°W
124°W
123°W
122°W
121°W
120°W
60°N
59°N
58°N
57°N
Legend
● Etthithun Herd
● Nordquist Herd
N W T (CANADA)
HIGHWAY 77
PETITOT
LIARD
RIVER
FORT NELSON
Kotcho Lake
KECHIKA
MUNCHO LAKE PARK
STONE MOUNTAIN PARK
FORT NELSON
RIVER
MUSKWA
RIVER
ALASKA
FONTAS
RIVER
RIVER
KWADACHA WILDERNESS PARK
PROPHET
RIVER
HIGHWAY
CHIEF
SIKANNI
RIVER
100km

Figure 2.1.


Number of animals
0
20
40
60
80
100
120
140
2005
2007
2008
2009
2010
2011
2012
2013
Year

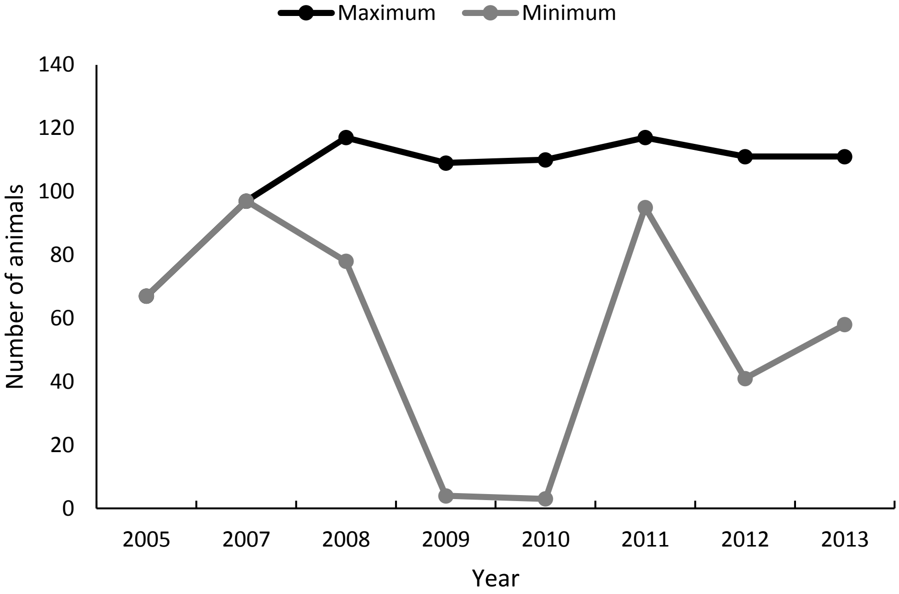

Maximum
Minimum
Number of animals
0
20
40
60
80
100
120
140
2005
2007
2008
2009
2010
2011
2012
2013
Year

Figure 2.2

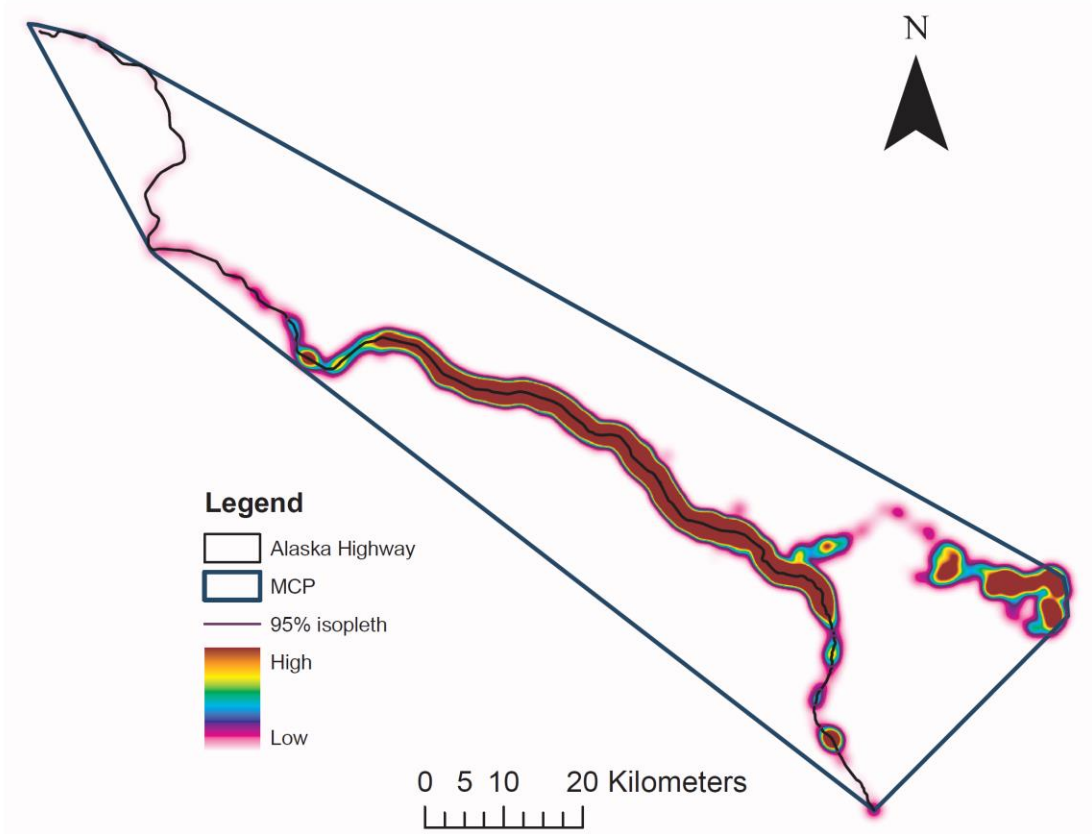

N
Legend
Alaska Highway
MCP
95% isopleth
High
Low
0 5 10 20 Kilometers

Figure 2.3.

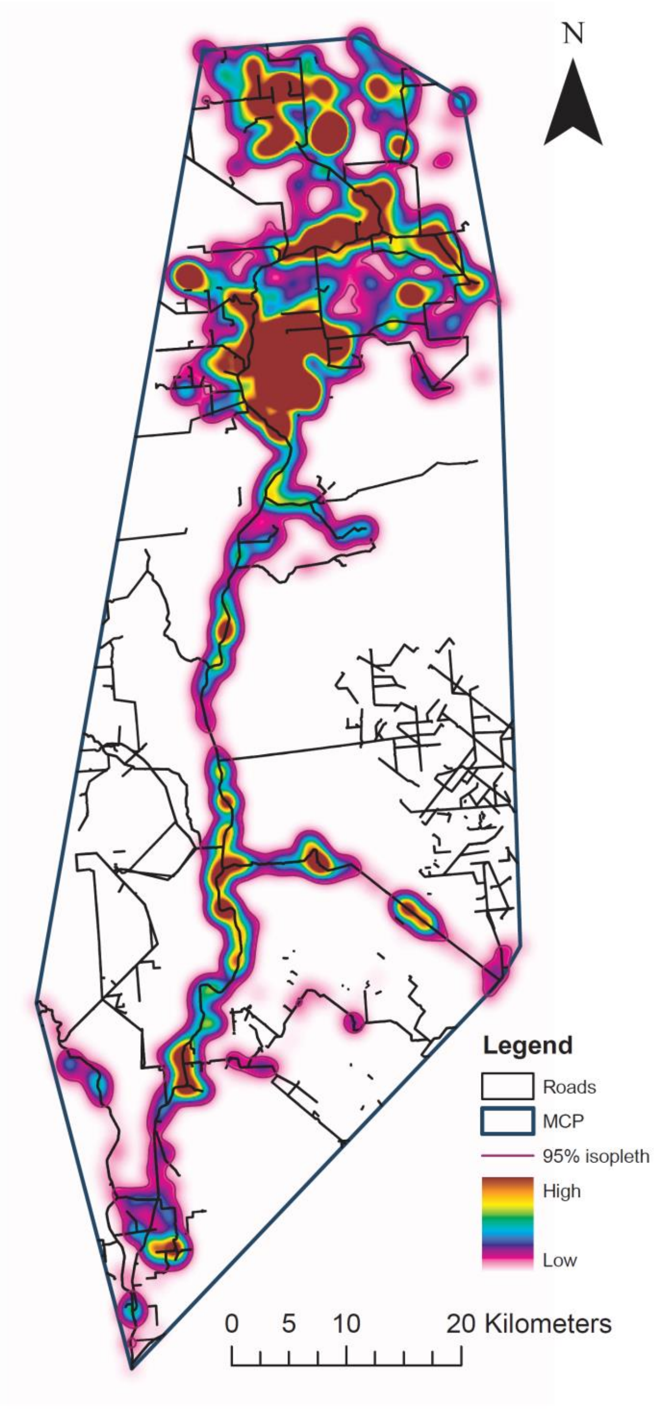


Figure 2.3.

CHAPTER III

RESOURCE SELECTION OF FREE-RANGING HORSES IN NORTHERN CANADA

Abstract

Fire is the primary driver of ecological structure and function in the boreal forest with resulting cover type strongly associated with time since fire. The number of fires and number of times that a particular area has been burned influences access, availability and quality of forage for grazing and browsing animals. Prescribed fire was historically used by First Nations in the region. Similar to historical use, current prescribed fire is implemented by guide outfitters in mountainous portions of the boreal forest of northeastern British Columbia to promote mosaics of vegetation height and species composition across the landscape to meet nutritional requirements of free-ranging horses. We used herds of horses occupying four distinct landscapes to evaluate the role of fire on boreal vegetation use by free-ranging horses. Using Resource Selection Functions (RSFs) and models to evaluate spatial distribution of horses across the four landscapes, we found that horses preferentially selected recently burned areas and areas burned more frequently when they were available. We also found that horses avoided steep slopes and forest cover types. Prescribed fires are ignited in the springtime while snow is still present and offers a firebreak. Prescribed fire and the ecological processes associated with it, including pyric herbivory, are important considerations when managing rangelands in northeastern British Columbia.

Introduction

Broad landscapes occupied by multiple species need to provide variability in vegetation structure, composition and spatial distribution to meet the varying resource requirements of each individual species. Heterogeneous landscapes, which differ in vertical structure, distribution and composition offer different cover type features for individual species selection (Rowe and Scotter 1973, Fuhlendorf *et al*. 2012). Some species may require large areas of openness whereas others may require closed canopy forests (Lamprey 1963, Heady 1966, Rowe and Scotter 1973, Fisher and Wilkinson 2005).

We define openness in the boreal forest as areas relatively free of obstructions to sight or movement that are dominated by grass, bare ground, rock, soil or low shrubs and that lack vertical structure and dense tree canopy cover. In the boreal forest of northwest Canada, openness results after disturbances such as fire, geomorphological events (landslides), and flooding. 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 species selection (Rowe and Scotter 1973, Goldammer and Furyaev 1996, Stocks *et al.* 2003, Leverkus *et al.* 2015**).

Anthropogenic fire is a historical component of the ecosystem across the boreal region (Seip and Bunnell 1985, Peck and Peek 1991, Gottesfeld 1994, Sittler 2013). First Nations and subsequently guide outfitters have incorporated fire in their management of the land for many decades, primarily targeting south facing slopes resulting in a cultural landscape of varying time since fire (Lewis 1978, Parminter 1983, Lewis and Ferguson 1988, Peck and Peek 1991, Leverkus *et al.* 2015**). South facing slopes in the area are warmer with higher radiant heat, often snow free in the winter providing critical winter grazing and browsing for animals, quicker to loose snow in the spring, and support productive grassland communities, which yield high quality forage (Luckhurst 1973). Across this landscape, the repeated application of fire combined with lightning ignited wildfires, 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).

Guide outfitters manage rangelands in northern BC through prescribed fire. BC is the western most Province in Canada and it is the third largest province (Integrated Land Management Bureau) occupying approximately 10% of Canada's land surface (Government of British Columbia). In BC, Crown land or public land, is managed by a number of government agencies. Under authorization by the Government of BC, guide outfitters are licenced to range their horses on Crown rangeland. Guide outfitters in northeastern BC offer back-country commercial services to assist in big-game hunting and other recreation using horses. At the end of the hunting season, most horses are released to free-roam on rangelands through the winter, allowing them to select resources alongside other native grazing and browsing ungulates. The availability of grasses and forbs for horses in the Northern hemisphere is limited in the winter (Cornelissen and Vulink 2015) making forage site selection and availability important survival mechanisms. Range management practices across these northern rangelands rely on the implementation of prescribed fire to promote access to and availability of forage particularly during the winter. Horses require areas for foraging (Haber 1988, Burns 2001, Beever *et al.* 2008, Edwards 2008, Vince 2011, Girard *et al.* 2013a) where grasses are preferred (Duncan 1983) along with other areas for cover (Edwards 2008, Beever *et al.* 2008, Vince 2011, Girard *et al.* 2013a). Winter hay feeding occurs when snow pack levels are high and access to forage is limiting. Our study provides novel information about the distribution of horses in a wilderness setting free of fences, allowing them to select areas across broad landscapes to meet their resource requirements.

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. Many herbivores preferentially select 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). Focused grazing occurs on recently burned patches, which keeps fuel loads low in these areas compared to other areas. Northeastern British Columbia (BC) represents a large intact landscape that provides a novel opportunity to evaluate the role of pyric herbivory from a broad perspective due to its extensive fire history (lightning and human-caused) with many large herbivores and megafauna (Leverkus *et al*. 2015***). While fire and grazing have been studied in the region (Rowe and Scotter 1973, Lewis and Ferguson 1988, Sittler 2013), there is minimal effort to evaluate the fire-grazing interaction. Understanding domestic herbivore grazing patterns in these complex landscapes as they relate to time since fire is important because of the current lack in incorporating pyric herbivory in natural resource management plans for the region (Leverkus *et al.* 2015*, Leverkus *et al.* 2015***).

Across the region, the home ranges of four horse herds were identified in two watersheds with varying fire histories resulting from both wildfire and prescribed fire. The Kechika horse herd is located in the Kechika watershed with an area of 1,965,538 ha of which 439, 683 ha has burned by wildfire and prescribed fire over the past century (Leverkus *et al*. 2015**). The Tuchodi, Gathto and Sikanni 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 wildfire and prescribed fire in the past century (Leverkus *et al*. 2015**). Less than 7 % of the burnable landscape in the Kechika watershed and less than 11 % of the burnable landscape in the Fort Nelson watershed has burned within the past 25 years (Leverkus *et al.* 2015**). Fire across these rangelands promotes differences in vertical structure and species composition resulting in a shifting mosaic pattern across the landscape, which supports biological diversity (Rowe and Scotter 1973). Understanding if the practice of prescribed burning is important to horses in northeastern BC is an integral first step in the strategic management of fire across this broad landscape because current management regimes and policies disregard the important role of pyric herbivory in BC. Therefore, our objective was to evaluate rangeland vegetation use of four free-ranging horse herds in BC relative to the biophysical environment.

Methods

Telemetry data from four horse herds were acquired through Lotek 3300L global positioning systems (GPS) deployed on thirteen male horses between the age of 5 and 12 as four replications in four 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. Males were collared because they were present across each watershed. 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.

We compared animal 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, seven cover types (bare/rock, forest, aspen parkland, water, snow/ice, clouds, and grass), anthropogenic features, slope and aspect. We established three random points for each observed location to provide estimates of available conditions (Allred *et al.* 2011) such as cover type.

For analyses of vegetation selection we focused on two 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. The fine scale extent was determined using the 95 percent 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 Kelley 2008, Girard *et al.* 2013a). KDEs were generated 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. The 95 percent kernel isopleth was used to analyze selection and use on a fine scale (Bingham and Noon 1997, Worton 1989, Anderson *et al.* 2005, Kie *et al.* 2010).

Selection of cover type at the four locations was analysed using a combination of archived Landsat imagery from the US Geological Survey (USGS) at 30 x 30-m resolution (Tuchodi, Gathto and Kechika from 2010 and Sikanni from 2011) and cover type data at 20 x 20-m resolution from 2000 from the Canadian Council on Geomatics' Geobase/Geogratis (Government of Canada 2009). The data layers were processed using ArcGIS10.1. Multivariate analysis using isocluster unsupervised classification yielded 20 classes, which were re-classified into seven 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. 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 four study sites are classified as bare/rock in our analysis because of the transparency of the water. Digital Elevation Models (DEMs) were developed and analysed for aspect and slope using data from the Government of BC geographic database (Government of Canada 2009) (Leverkus *et al.* 2015**). The most current data on wildfires and prescribed fires in BC from 1922 to 2012 was spatially analysed as per Leverkus *et al.* 2015**. Time since fire (years), times burned and presence in burned areas were included in the analysis.

Resource selection functions (RSFs) (Boyce *et al.* 2002) and models on the four herds were developed to include 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), number of times burned (wildfire and prescribed fire) (Boyce *et al.* 2002, Duchesne *et al.* 2010, Allred *et al.* 2011, Girard *et al.* 2013a, 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 as per 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 resulting from the GLMs indicate preference of selection as either a positive or negative relationship of relative influence. We ran two 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 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 (number of times burned, time since fire and burned areas) and slope are the primary drivers influencing horse site selection across all four herds (Table 3.1). Resource selection coefficients indicate 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 had a positive selection for time since fire, therefore, as time since fire increased the probability of horses being present also increased. Horses from the Kechika and Gathto herds had a positive selection for number of fires with the Kechika herd having five times the preference over all the other herds.

There are 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 showing a decreased probability of presence as the number of times burned increased (Table 3.1). Based on resource selection coefficients horses selected for lower slopes ($p<0.05$; Kechika = -2.52, Tuchodi = -0.93, Gathto = -1.04, Sikanni = -2.48) (Table 3.1). Horses across all four herds avoided steeper slopes with the strongest avoidance by the Sikanni and Kechika herds (Table 3.1).

Locations of horses ranged across the four herds from 25,829 (Kechika), 27,260 (Tuchodi), 21,767 (Gathto) to 4,387 (Sikanni) in BC from October 2010 – July 2012. While all four horse herds were free to roam across broad landscapes in northeastern BC (Figure 3.1) they focused their selection on concentrated areas represented by the 95 percent isopleth (Table 3.2). Forest and aspen parkland were the primary cover types across the region. The surrounding areas of the fine scale sites were often comprised of a landscape that may have experienced multiple fires since 1922 and earlier (Figure 3.2). 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 (Figure 3.3 and 3.4).

Based on resource selection coefficients horses selected for specific cover type (Table 3.1). Aspect and water had minimal influences on horse distribution across the landscape (Table 3.1). This may be due to the abundance and availability of water prior to and after the winter months as well as the availability of snow distributed across the rangelands to meet their nutritional requirements. Horses had highest use of aspen parkland and grass of all cover types (Table 3.3). Horses spent 68 % to 98 % of their time in open cover types (aspen parkland and grass), which represent 43 % to 71 % of the area respectively (Table 3.3). Horses avoided forest cover type ($p<0.05$, Kechika = -0.49, Tuchodi = -0.56, Gathto = -1.16, Sikanni = -0.50). Specifically, horses spent 2 % to 13 % of their time in closed canopy forest cover type that represents 17 % to 52 % of the landscape.

Discussion

Our data show that horses are strongly attracted to fire (times burned, time since fire and burned areas) and open cover type. The number of times an area burns within the boreal forest can increase the accessibility to an area through larger openings with less vertical structure. Fire in these landscapes influences the percent area of cover type in grass and aspen parkland, which horses showed an attraction to. Conversely, our results show that horses avoided forest cover type, which is consistent with the findings of Girard *et al.* (2013b) who found that horse use was positively related to distance to forest edge.

The fire-grazing interaction is important for horses on northern rangelands where steep slopes and exposed rock prevent access and distribution across the landscape. This is consistent with the findings of Girard *et al.* (2013b) for free-ranging horses in Alberta that selected against terrain ruggedness as well as Hull *et al.* (2014) who documented that both giant pandas and horses selected for low slopes with high solar radiation in China. In BC, vegetation structure, composition and distribution are known to be driven by time since disturbance in the region (Rowe and Scotter 1973). Across the Kechika and Fort Nelson watersheds, vegetation and cover type are driven by areas burned by fires coupled with herbivory. Pyric herbivory shapes the structure and coverage of vegetation (Fuhlendorf *et al.* 2009). These areas are primarily dominated by aspen parklands and open grasslands that are both fire dependant plant communities of the boreal landscape.

Although it may be true that there is a difference in the forage palatability between a closed canopy aspen parkland and a closed canopy conifer forest, there is limited imagery available to analyze these specific differences. Both forest types have longer time since fire components in comparison to the aspen parkland class that has been influenced by pyric herbivory more recently. Additionally, access to forage is also a consideration when comparing forested areas to the parkland areas, suggesting that resource selection could be influenced by the presence or absence of a forest canopy. In a similar study, it was 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 is limited (Kaczensky *et al.* 2008). In an adjacent valley to the Sikanni, Lord and Luckhurst (1974) demonstrated that 60% of thinhorn stone's sheep (*Ovis dalli stonei*) winter forage was dependent on the hairy wild rye (*Elymus innovates*) plant community, anecdotally noted to be dominant following fire on northern rangelands and selected for by horses and other ungulates. Resource selection for minimal time since fire in other species occurs during the winter months particularly when forage is limited (Seip and Bunnell 1984, Seip and Bunnell 1985). Open rangeland is additionally important for snow removal, which is essential for winter utilization of northern rangelands (Elliott 1983).

Rangelands in the boreal forest are similar to other rangeland systems in that herbivores are attracted to fire. Focused grazing occurs on recently burned patches and lowers fuel loads in these areas compared to other areas, however, one fire in an area may not be sufficient to meet the desired effects. Pyric herbivory is not clearly recognized in rangeland 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).

The majority of prescribed fires across this landscape are not randomly distributed yet they provide grazing yards and corridors, which support nutritional requirements for multiple species (Rowe and Scotter 1973, Lewis and Ferguson 1988). It is hard to separate slope from fire because guide outfitters 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 primarily for survival of horses throughout the year, particularly in the winter, with secondary benefits for other species occupying the same area. The historical practice of prescribed fire by guide outfitters is appropriate because horses are attracted to fire derived proportions of the landscape. However, limited time since fire across 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 is needed in order for herbivores to remain on the landscape (van Wilgen *et al*. 2007). Rangelands in northeastern BC are reliant on fire. Fire is therefore an integral part of the management scenario with recent time since fire resulting in openness and accessibility of forage on rangelands.

Implications

In the boreal forest, rangeland vegetation composition, structure and richness are driven by time since fire. If the desire is to continue permitting grazing animals in remote locations, appropriate resources must be made available for them. Long term rangeland maintenance based on historical disturbance regimes and current landscape objectives is required. This can be achieved through the continued application of prescribed fire to increase open rangeland conditions and to promote pyric herbivory. Since the diet of horses primarily consists of sedges and grasses available in grassland meadows and aspen parklands, processes such as fire that produce such vegetation are critical for horses. Time since fire and number of fires drive the availability, access to and quality of grazing areas for horses on rangelands in the boreal forest. In addition, other herbivores occupying the same distribution area benefit from fire. In a remote region with ecosystems driven and maintained by fire, it is important to continue having fire distributed through space and time to meet the needs of domestic and native herbivores.

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Tables

Table 3.1. Estimated resource selection function coefficients for Kechika, Tuchodi, Gathto and Sikanni horse herds in northeastern BC, Canada from 2010 - 2012. Model parameters include presence within a fire, number of times burned, time since fire (years), cover type (bare, forest, grass, aspen 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 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 3.2. The research sites (named by the valley systems they occur in) were located in northeastern British Columbia, Canada from 2010 - 2012. The broad area (ha) was the home range. The fine scale area (ha) was 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 GPS collars were deployed on the animals and data was 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	268059	2223	5	10/2010 - 07/2012	24	45	25829	58	223357
Tuchodi	383209	5038	4	10/2010 - 07/2012	24	36	27260	171	94002
Gathto	383209	9462	3	10/2010 - 07/2012	24	27	21767	171	94002
Sikanni	27636	3230	1	11/2011 - 07/2012	24	8	4387	49	9939

Table 3.3. Horse GPS locations per herd were analysed for percent of locations spent within each resource variable of cover type (bare, forest, aspen parkland, water, snow/ice, and grass) and anthropogenic features (base camps and supplemental feeding locations) across the finer scale extent derived from the 95 percent isopleth from 2010 - 2012. The cover type classes of cloud, shadow, and edge of image were removed as they represented less than 1% of the area.

Study Area	RSF variable	Area (ha)	% of area	# locations	% locations
Kechika	Total landcover	2223	100	25353	100
	Bare	2	0.1	18	0.1
	Forest	376	16.9	535	2.1
	Aspen	938	42.2	11537	45.5
	Water	656	29.5	92	0.4
	Snow/Ice	2	0.1	0	0.0
	Grass	248	11.1	13171	52.0
	Anthropogenic	64	2.9	1151	4.5
Tuchodi	Total landcover	5039	100	26924	100
	Bare	404	8.0	1396	5.2
	Forest	1294	25.7	3011	11.2
	Aspen	2568	51.0	19484	72.4
	Water	33	0.6	35	0.1
	Snow/Ice	70	1.4	13	0.0
	Grass	667	13.2	2986	11.1
	Anthropogenic	17	0.3	1494	5.5
Gathto	Total landcover	9462	100	20861	100
	Bare	418	4.4	323	1.5
	Forest	2246	23.7	620	3.0
	Aspen	4699	49.7	14098	67.6
	Water	34	0.4	77	0.4
	Snow/Ice	0	0.0	0	0.0
	Grass	2057	21.7	5743	27.5
	Anthropogenic	0	0.0	0	0.0
Sikanni	Total landcover	3230	100	4377	100
	Bare	49	1.5	868	19.8
	Forest	1678	51.9	546	12.5
	Water	71	2.2	2	0.0
	Grass	1393	43.1	2961	67.6
	Anthropogenic	17	0.5	1903	43.5

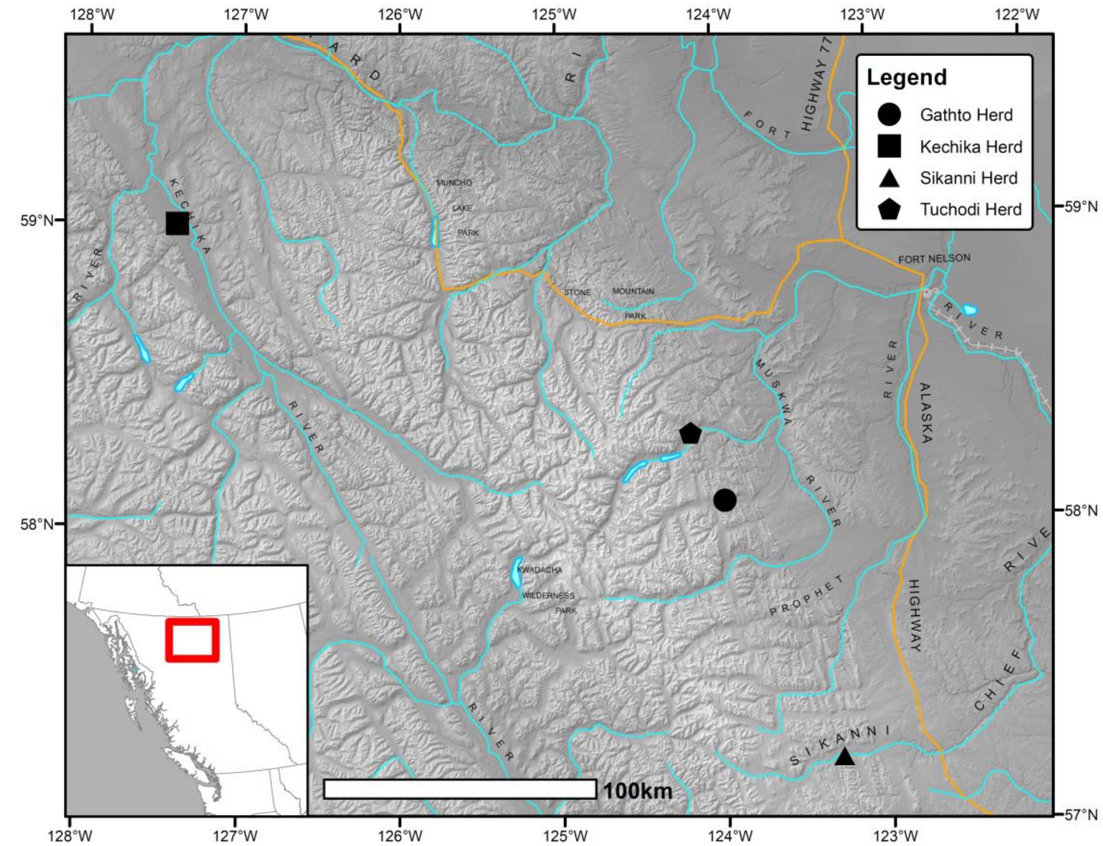
Figure legend

Figure 3.1. Locations of four horse herds named by the valley systems they occur in (Kechika, Tuchodi, Gathto and Sikanni) that are distributed across the Northern Rocky Mountains from 2010 – 2012 in northeastern British Columbia, Canada.

Figure 3.2. Spatial distribution of the fire history from 1922 – 2012 of the area selected by each of the four horse herds (Kechika, Tuchodi, Gathto and Sikanni) within the 95 percent isopleth (black exterior line).

Figure 3.3. Number of fires from 1922-2012 across the selected areas derived from the 95 percent isopleth of each horse herd (Kechika, Tuchodi, Gathto and Sikanni) in northeastern British Columbia, Canada.

Figure 3.4. The total recorded area burned from 1922 -2012 across the selected areas derived from the 95 percent isopleth of each horse herd (Kechika, Tuchodi, Gathto and Sikanni) in northeastern British Columbia, Canada.



128°W
127°W
126°W
125°W
124°W
123°W
122°W
59°N
58°N
57°N
Legend
● Gathto Herd
■ Kechika Herd
▲ Sikanni Herd
⬟ Tuchodi Herd
HIGHWAY 77
FORT
FORT NELSON
RIVER
KECHIKA
RIVER
RIVER
MUNCHO LAKE PARK
STONE MOUNTAIN PARK
MUSKWA
RIVER
RIVER
ALASKA HIGHWAY
KWADACHA WILDERNESS PARK
PROPHET
RIVER
CHIEF
RIVE
SIKANNI
100km

Figure 3.1

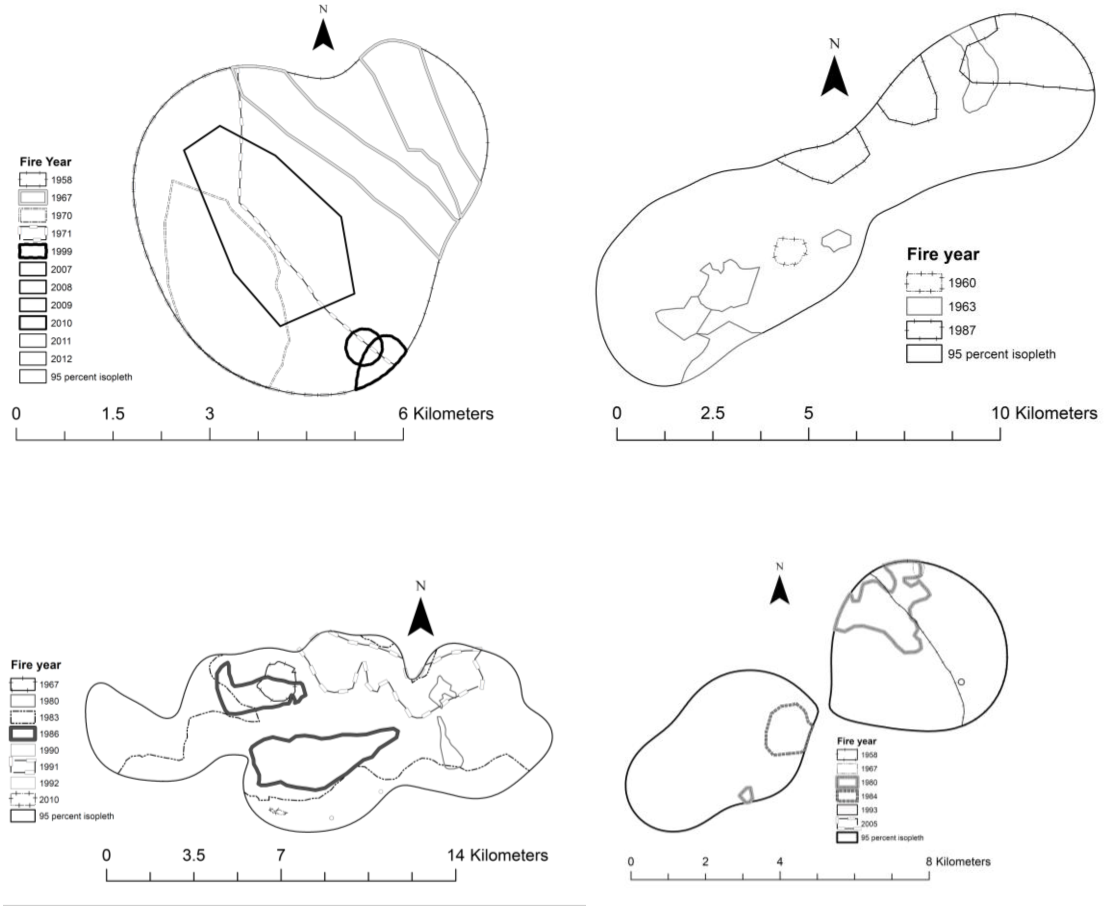

N
Fire Year
1958
1967
1970
1971
1999
2007
2008
2009
2010
2011
2012
95 percent isopleth
0
1.5
3
6 Kilometers
N
Fire year
1960
1963
1987
95 percent isopleth
0
2.5
5
10 Kilometers
N
Fire year
1967
1980
1983
1986
1990
1991
1992
2010
95 percent isopleth
0
3.5
7
14 Kilometers
N
Fire year
1958
1967
1980
1984
1993
2005
95 percent isopleth
0
2
4
8 Kilometers

Figure 3.2

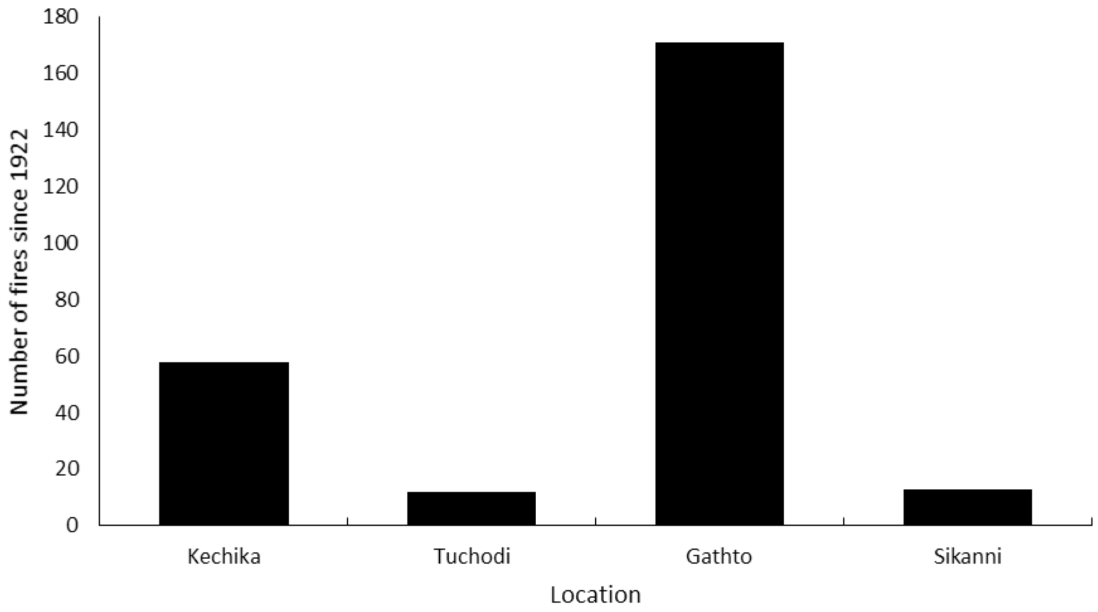

180
160
140
120
100
80
60
40
20
0
Number of fires since 1922
Kechika
Tuchodi
Gathto
Sikanni
Location

Figure 3.3

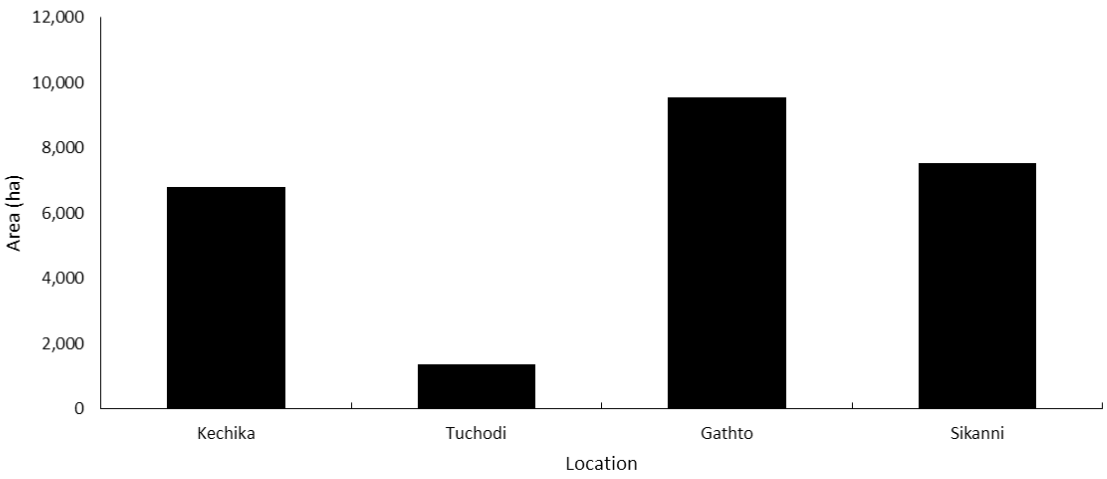

12,000
10,000
8,000
6,000
4,000
2,000
0
Area (ha)
Kechika
Tuchodi
Gathto
Sikanni
Location

Figure 3.4

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