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MOOSE (*ALCES ALCES*) BEHAVIOURAL RESPONSE TO WILDFIRES IN INTERIOR BRITISH COLUMBIA

BY

KYLA WALLIN 2023

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THESIS EXAMINING COMMITTEE

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Abstract

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The combination of warmer and drier conditions due to climate change with historic fire suppression, is resulting in an increase in wildfire size, frequency, and season. Because of this, many animal populations are increasingly forced to respond to these natural events. While previous studies have examined ungulate response through changes in habitat use and home range size pre- and post- wildfire, little is known about how species respond during active wildfire events. This study used GPS location data from 20 female moose (*Alces alces*) to understand their movements during the progression of the Tremont Creek and Sparks Lake wildfires in 2021 in Interior British Columbia. Of the 20 individuals studied, 10 were using areas within the fire perimeters and 10 outside, allowing for comparison of individuals unaffected and affected by wildfire. Individual changes in space use and movement rates were studied throughout six time periods during the fire progression. Across both sites, moose exposed to the fire displayed no differences in space use and movement rates compared to those outside of the fire, essentially remaining in the same locations over the duration of the fire. In addition, no fire-related mortality occurred among the study animals, regardless of remaining in the same locations. While no differences in movement metrics were identified between individuals at the same site, differences were present at a larger scale between the two fire sites, indicating a landscape level effect. The findings of this study support that moose appear to demonstrate muted response and movements in relation to wildfire. In addition, this study provides preliminary insight into the response of moose during wildfire events, and improves our understanding of how these events impact individual animals.

Key words: Moose, *Alces alces*, wildfire, space use, movement, response

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Introduction

Wildfire activity is increasing particularly in Western Canada, as a result of a variety of different factors that can be separated into four different components: ignition, drought, fuel, and weather (Parisien et al. 2020, Pausas and Keeley 2021). As these variables shift under the influence of a warming climate, landscapes become more prone to forest fires through the warmer and drier conditions created (Haughian et al. 2012, Pausas and Keely 2021). These changes in climate and the associated rapid shift of fire regimes alter the current conditions to allow for not only more frequent and severe wildfires, but also longer wildfire seasons (Flannigan et al. 2000, Haughian et al. 2012). In addition, fire suppression efforts in Canada have increased over the past decades to protect human values, regardless of the natural benefits that wildfires provide, and has resulted in the shift of fire regimes through the deliberate control of fires (Broton et al. 2013, Parisien et al. 2020). Changes in fire frequency lead to impacts to ecosystem structure and composition, while changes in fire severity influence habitat availability and structure following a wildfire (Nitschke and Innes 2013). Within British Columbia (BC), the increases in the size, frequency, severity, and season length of wildfires are expected to be the greatest in the southern interior of the province, resulting in an overall shift in the fire regime (Haughian et al. 2012, Westerling et al. 2006, Nitschke and Innes 2013). Previously, southern interior BC was characterized by mixed fire regimes, with high-frequency low-severity fires and infrequent high-severity fires, both of which were important for maintaining forest structure (Heyerdahl et al. 2012, Parisien et al. 2020)

Wildfires have large impacts on the forest community structure, with changes occurring within plant and animal composition and diversity within the ecosystem (Whelan 1995). For animal populations, the most direct impact of wildfires is mortality, along with reduced birth rates, changes in food and habitat availability, and higher predation rates (Whelan 1995). There exists however, a large variation among species response to wildfires (Whelan 1995). Following wildfire, as changes occur in successional stages so does use by wildlife species, leading to a multitude of different animal and plant community combinations (Cave et al. 2021). In terms of the survival of individuals, species have varying physical tactics to withstand the extreme heat created by fires such as fur and hair acting as an insulator in addition to body size, and behavioural tactics also being crucial in how an individual is able to survive (Whelan 1995).

Large mobile animals are capable of moving to unburnt patches within their home ranges to find refuge or adjust their movement to stay in front of the fire front until a safe area is found (Whelan 1995). Often, the perceived response of individuals to wildfire suffers from 'Bambi dogma', in which images of animals fleeing at the fire front harken back to the 1942 Disney movie, as well as earlier advertising campaigns launched under Smokey the Bear (About the Campaign 2021, Lutts 1992). Because of the variation across communities, populations, individual species responses, and the varying conditions of wildfire, a complex dynamic between wildlife and wildfire exists.

Many different ungulate species have demonstrated changes in space use and resource selectivity following wildfire (Cherry et al. 2018, Irwin 1975). While there are differing results across studies, these changes in space use and resource selection can be in conjunction with the "magnet hypothesis" in which species are attracted to the abundant high-quality forage available following fire. Another theory is that species remain outside of burned areas until resources have replenished (Cherry et al. 2018, Kreling et al. 2021). Despite this, species still maintain strong site fidelity to their pre-fire home ranges by not abandoning these areas and returning soon after wildfire (Cherry et al. 2018). Larger ungulates tend to have larger home ranges and lower energy demands compared to smaller ungulates, and therefore the selection for recent burns and high-quality forage becomes less important (Cherry et al. 2018). Larger ungulates such as caribou, have displayed minimal shifts in space use following wildfire, with recent burns potentially providing lower predation and improved forage nutrition (Silva et al. 2020). In contrast, some studies of white-tailed deer found that they respond by doubling their home range size and increasing their movement rates, while continuing to maintain strong habitat selection (Kreling et al. 2021). The profound effects of wildfires have differing impacts depending on the needs of the specific ungulate species.

Moose habitat selection following wildfire appears to be a function of burn severity, with low severity burn sites with abundant willow being selected for during the winter season and high severity sites with lots of woody browse being selected for in the summer season (Brown et al. 2018). Not only do high severity burn sites produce higher amounts of available summer browse for up to 25 years following wildfire leading to higher forage consumption, they also provide increased deciduous and shrub cover (Brown et al. 2018, Lord and Kielland 2015). As a result, moose tend to select for these early successional stages with high amounts of good quality forage created following wildfire, which also may lead to population increases (DeMars et al. 2018, Gasaway et al. 1988). Moose have been shown to select for 11–30-year-old burns because of their abundant forage, however moose habitat selection still remains complex and is driven by a multitude of different factors such as forage, cover, distance to water, and elevation (Joly et al. 2016). In addition, habitat selection depends on sex and season, winter severity, and female maternal status (Joly et al. 2016). Females without calves have been shown to have higher selection for burned areas, again, likely due to the abundant forage present (Joly et al. 2016). Despite the strong evidence supporting the use of burned areas, moose still rely on unburned areas, and require resources from a variety of habitat types for survival but have been noted to shift their home ranges to include more of a burned site (Brown et al. 2018, Fisher and Wilkinson 2005).

While the previously mentioned studies provide information on ungulate response by comparing pre- and post- wildfire metrics, little is known about species response during active wildfire events. There remains a lack of evidence whether the 'Bambi dogma' in fact occurs, which creates a knowledge gap to be addressed. There is little evidence of large mammals dying directly as a cause of wildfires, but rather through other inherent factors such as smoke inhalation and heat death (Singer et al. 1989, Whelan 1995). Because of this, it can be assumed that species are able to avoid the immediate threat of oncoming fire fronts through developed behavioural and life-history tactics (Singer et al. 1989, Whelan 1995).

Two wildfires located near Kamloops, BC, provided a unique opportunity to examine the response of individual moose to active fire events. In 2021, BC experienced the third worst wildfire season in terms of area burned in recent history, with almost 870, 0000 hectares burnt (Kulkarni 2021, Wildfire Season Summary 2021). The wildfires used in this study burned areas occupied by previously GPS collared moose. Using this data, I examined the space use and movement metrics of individual moose during wildfire progression.

With these analyses, I seek to address the knowledge gap associated with how individual animals, particularly large herbivores, respond to wildfire events unfolding in their seasonal ranges. The specific objectives of this study were to quantify moose movement and changes in space use during wildfire progression and compare these moose within active fire perimeters to those outside. From this, moose behavioural response under the direct threat of wildfire can be determined. The two wildfires occurring in BC in 2021 provided opportune conditions to examine these responses and will contribute greatly in terms of preliminary knowledge on ungulate response during wildfire, in addition to providing a basis for future research.

Methods

Study site

This study took place near Kamloops, BC, Canada (50.6745° N, 120.3273° W), centering on two wildfires that occurred in 2021 (Figure 1). Forests in this area fall primarily under Interior Douglas-fir (IDF), Montane Spruce (MS), and Sub-boreal Pine Spruce (SBPS) ecosystems, and are classified as generally having a dry forest type (Biogeoclimatic Ecosystem Classification – Center for Forest … 2023). Regions within the IDF are generally drier, and consist of mainly Douglas-fir (*Pseudotsuga menziesii*), Lodgepole pine (*Pinus contorta*), Ponderosa pine (*Pinus ponderosa*) and Trembling aspen (*Populus tremuloides*) (Center for Forests … 2023). These areas are characterized by a grassy understory with Soopolallie (*Sheperdia canadensis*), Saskatoon (*Amelanchier alnifolia*), and Common juniper (*Juniperis communis*) present (Thompson Region … 2023). Both the SBPS and MS are similar to the IDF in terms of their vegetation composition with Lodgepole pine being the dominant tree species found (Thompson Region … 2023). Historically, cool and small forests fires occurred in these areas every three to thirty years, creating a frequent low-severity fire regime to maintain the structure of these dry forested areas (Wildfire Protection 2023, Arsenault and Klenner 2005). In recent decades however, increased fuel suppression efforts has led to increased fuel load and therefore increased frequency and size of wildfires, in addition to the wildfire season extending into the fall due to warmer and drier conditions (Wildfire Protection 2023, Wildfire Season Summary 2021).

During BC's 2021 wildfire season, a total of 1,642 wildfires burned throughout the province, two of which were located near Kamloops, BC, and were used in this study (Wildfire Season Summary 2021). The Tremont Creek wildfire (50° 38' 8.412" N, 120° 57' 5.22" W) was located approximately 60 minutes southwest of Kamloops. The fire was discovered on July 12th 2021 and burned a total of 63,548 ha (Wildfire Season Summary 2021). The Sparks Lake wildfire (51° 3' 36.324" N, 120° 47' 30.624" W) was located north of Kamloops; it was

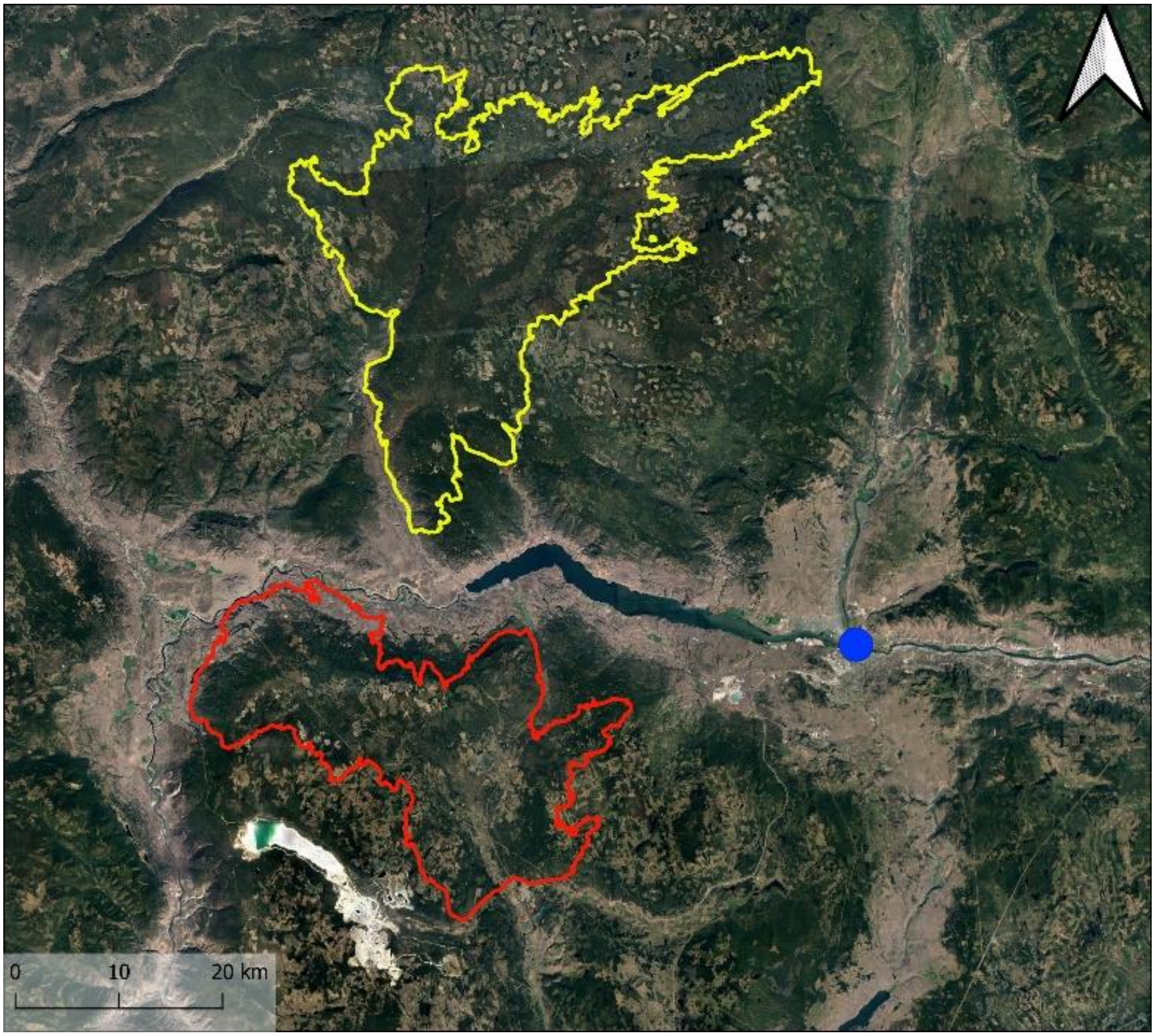

Figure 1. Map outlining the 2021 Sparks Lake wildfire perimeter (yellow) and the 2021 Tremont Creek wildfire perimeter (red) and their relation to Kamloops British Columbia (50.6745° N, 120.3273° W), as indicated by the blue point.

discovered on June 28th 2021 and eventually burnt an area of 95,980 ha (Wildfire Season Summary 2021). The ignition of this wildfire corresponded with a record-breaking heat dome event that took place from June 25 to July 1 2021, and caused extreme highs in temperature (Surviving the heat … 2023).

Both the Tremont Creek and Sparks Lake wildfires coincided with research projects focusing on understanding factors effecting overall moose populations and female moose reproductive success (Roberge et al. *in progress,* Procter et al. 2020, Boucher et al. 2022). At both sites, adult female moose had been previously captured via chemical immobilization and were fitted with Vectronic Iridium Survey or Telonics TWG-4667-4 GPS collars following standardized protocols (Procter et al. 2020). Fix rate varied by the study area; collars on moose in the Sparks Lake region collected a location every four hours, while collars in the Tremont Creek area collected a location every two hours. All collars were equipped with mortality beacons; if no movement was detected for eight hours, the collars were programmed to send a mortality signal, and sites were investigated rapidly to determine cause of death. All failed GPS location signals were removed from the dataset.

Data collection

GPS collar data for female collared moose within the proximity of the two wildfires were obtained from the BC Ministry of Forests and Thompson Rivers University. From this data base, I randomly selected five moose within the fire perimeter and five outside for each area. Individual moose were categorized as being Outside (unaffected by) the wildfire if no GPS data locations from the animal fell within any of the wildfire perimeter progressions. Conversely, moose were considered to be Inside (affected by) the wildfire if any GPS data locations fell within the wildfire perimeter progressions. An exception was made for one moose at Tremont Creek, where a very small amount of space use overlap occurred during one of the measured fire perimeters (see below); however, that moose never further interacted with the fire perimeter and therefore I considered this moose to be unaffected by the wildfire.

The time frame for this study was restricted largely to the summer season (June 28 – September 20) for moose in the Kamloops region (Francis et al. 2020). The individual locations of moose were compartmentalized into six Time Periods (Table 1) during each wildfire, ranging in length from 4-26 days, with the majority being 4-6 days (86%). The selection of the length of

Table 1. Summary of sampling periods for the movements and locations of collared moose in the path of two wildfires in BC, Canada during the summer of 2021. “Time Period” refers to windows of time during which the location and recent movement of each individual moose was quantified in relation to the initiation and progress of the respective wildfires. “Associated Fire Perimeter” refers to the data of which the most concurrent perimeter of the two fires was available within each “Time Period”.

Site	Time Period	Dates	Length (days)	Associated Fire Perimeter
Sparks Lake (start June 28th 2021)	Before	June 26 – June 29	4	N/A
	1	June 30 – July 5	6	July 5
	2	July 6 – July 9	4	July 9
	3	July 10 – July 14	5	July 14
	4	July 15 – August 9	26	August 9
	5	August 10 – August 15	6	August 15
	6	August 16 – August 20	5	August 20
Tremont Creek (start July 12th 2021)	Before	July 10 – July 13	4	N/A
	1	July 14 – July 17	4	July 17
	2	July 18 – July 21	4	July 21
	3	July 22 – August 5	15	August 5
	4	August 6 – August 12	7	August 12
	5	August 13 – August 16	4	August 16
	6	August 17 – August 20	4	August 20

these Time Periods were strongly dependent on the availability of representative fire perimeter shapefiles, and provided insight on changes in moose movement and space use throughout the summer.

I used 95% Minimum Convex Polygons (MCPs) to estimate short-term space use for each moose using the *ade4* (Dray and Dufour 2007), *adehabitatHR* (Calenge 2006), and *adehabitatMA* (Calenge 2006) packages in R (R Core Team 2023). This was done for each individual moose during each of the six time periods during the lifespan of the wildfires (Table 1). In addition, a MCP was created for each individual consisting of the four days prior to the wildfire ignition.

I calculated five metrics for all individual moose within the different time periods, including:

(i) **space use size**
(ii) **distance to the fire perimeter**
(iii) **percent overlap between consecutive space use areas,**
(iv) **percent overlap of space use areas and the associated fire perimeter**, **and,**
(v) **step length**

For all five metrics, I predicted significant differences would be seen between the two categories of moose (Inside and Outside) at both locations, as well as through time for moose with initial space use areas in line with the progression of the wildfires. These changes presumably would reflect behaviour of the fire-impacted moose to increasingly shift their space use away from the advancing fire and alter their movement rates as a result of the wildfire.

Space use size

Space use size (ha) was calculated for each of the space use polygons for each moose. This served as an indicator if moose were having to increase or decrease the areas they were inhabiting as result of the wildfire.

Distance to the fire perimeter

Distance (km) from the centroid of each of the space use polygons for each moose to the associated fire perimeter to that particular Time Period was calculated. Negative values reflected space use areas located within the fire perimeter.

Consecutive space use overlap

Consecutive space use overlap was calculated by comparing the space use areas of two adjacent Time Periods to indicate if moose were adjusting the areas in which they were inhabiting as a result of the wildfire. Comparisons for Time Period 1 were made to the "Before" MCP that was created for each moose during the four days prior to the start of the wildfires (Table 1). The initial fire perimeter available for the Sparks Lake wildfire was June 30th, and therefore the data used from the 1st and 2nd day of the "Before" MCP overlapped marginally with what is considered calving season for moose (Francis et al. 2020). I considered this not a significant issue because of the minimal overlap.

Space use and fire perimeter overlap

Percent overlap between each space use area and the associated fire perimeter was only calculated for moose classified as being Inside the wildfires. This calculation was restricted to include only Time Periods 3 to 6, as moose did not enter the wildfires until Time Period 3. This metric provided insight on whether moose increasing or decreasing the amount of their space use areas that were affected by the wildfire.

Step length

Step length was calculated as the distance between two consecutive GPS data points, and provides a movement metric on whether individuals are moving more or less within their space use areas (Thurfjell et al. 2014). Step length was calculated for moose location data within each time period using the *ade4* (Dray and Dufour 2007), and *adehabitatLT* (Calenge 2006) packages in R (R Core Team 2023). For the purpose of the step length calculation, I subsampled Tremont Creek GPS data to align with those from the Sparks Lake fire (i.e. four hour fix rate); all other movement metrics for the Tremont Creek moose were based on a two hour fix frequency.

Statistical analysis

All statistical analyses were completed using R version 4.2.2 (R Core Team 2023). A three-way mixed model ANOVA with 1-within subject factor (Time Period) and 2-between subject factors (Position Category and Site) was used to examine the effects of Position Category (Inside or Outside), Time Period, and Site (Sparks Lake or Tremont Creek) on the five different calculated metrics, namely space use size (ha), distance (m) to fire perimeter, consecutive space use overlap (%), space use overlap with the associated fire perimeter (%), and step length (m).

Significant one-way interactions were analyzed using the Games-Howell test (Hilton and Armstrong 2006) to compare all possible combinations of group differences to determine significance between groups. Following this, a simple linear regression was used on the mean values of significant variables identified by the Games-Howell test to identify any changes of the metrics through time. Significant two-way interactions were further explored using a simple main effect post-hoc test with a Bonferroni, followed by a simple pairwise comparison to examine which groups within these interactions were significantly different.

Results

No mortality events throughout the duration of the study (June 26 – August 20) occurred for the 20 study animals. None of the moose (either Inside or Outside of the fire perimeter) made any extremely long, unidirectional movements that led to their permanent or temporary displacement from their original inhabited area (Figure 2, Figure 3).

Space use size

Space use size did not differ for moose in both Inside and Outside of the fire (Figure 5, $F_{1, 16} = 2.77$, $P = 0.12$) at either site, but they did demonstrate differences based on Site and Time Period ($F_{2.43, 38.95} = 2.77$, $P = 0.04$). Moose had significantly larger space use sizes at the Sparks Lake site compared to the Tremont Creek site during Time Periods 1, 2, and 4 (Simple main effects, all Ps ≤ 0.02; Pairwise comparison, all Ps ≤ 0.02), however overall, moose at Sparks Lake had larger space use sizes compared to moose at Tremont Creek across all moose (ANOVA, $F_{1, 16} = 22.29$, $P < 0.001$; Games Howell, $P < 0.001$) In addition, moose Outside the fire exhibited larger space use sizes at the Sparks Lake site (M = 535ha; ANOVA, $F_{2.43, 38.95} = 3.35$, $P = 0.04$; Simple main effects, $P < 0.001$; Pairwise comparison, $P < 0.001$) compared to moose Outside the fire at the Tremont Creek site (M = 137ha)

There were significant differences in space use size of moose across both sites between some Time Periods (ie. Time periods 2 and 4, and 3 and 5; ANOVA, $F_{2.43, 38.95} = 3.79$, $P = 0.02$; Games Howell, all Ps < 0.04), however no discernable pattern of changes in space use throughout the progression of Time Periods was notable (Regression, $F_{1,4} = 0.18$, $P = 0.70$, $R^2 = -0.20$, Figure 4, Figure 5).

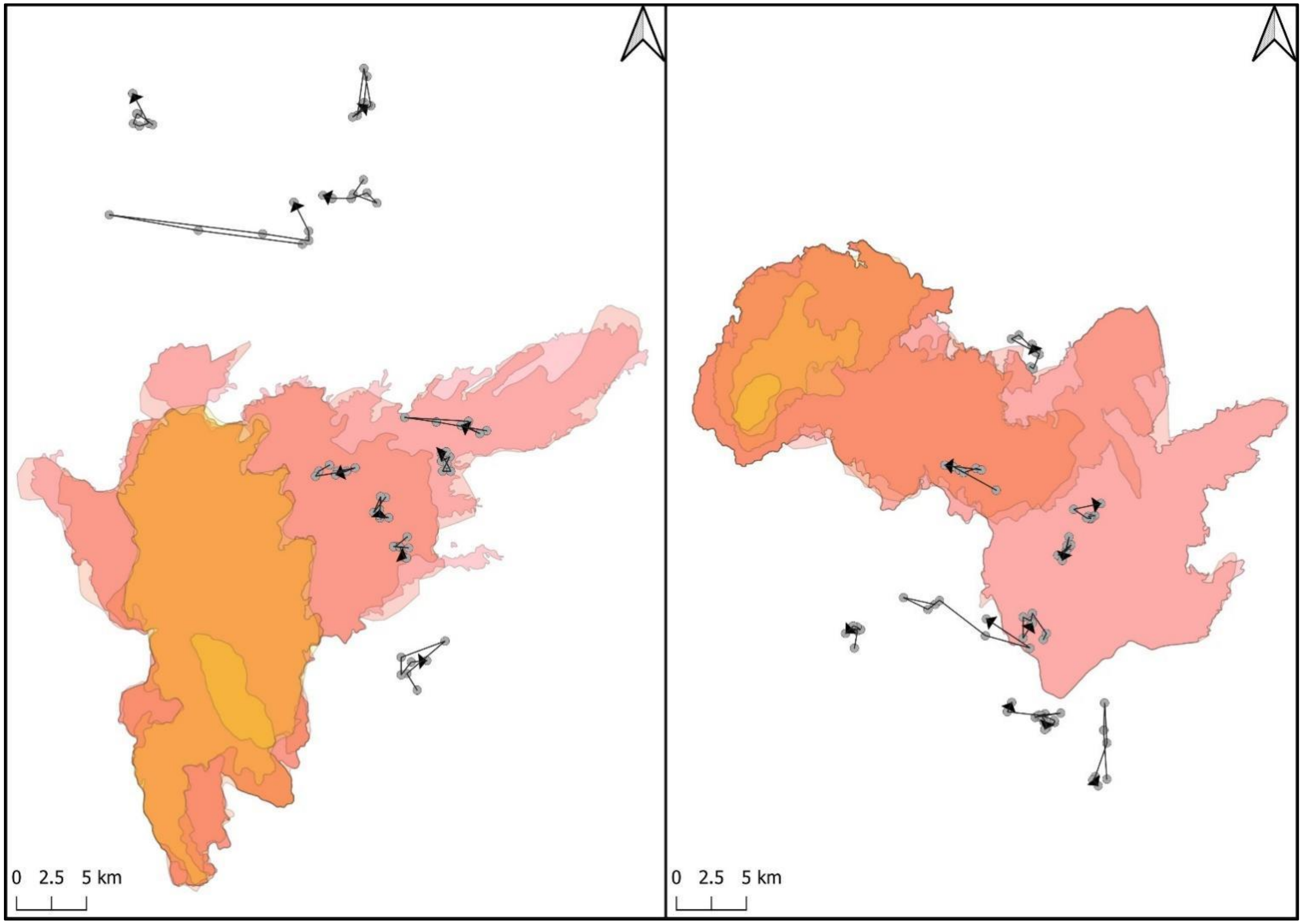

Figure 2. Sparks Lake (left) and Tremont Creek wildfire (right) progressions, occurring in Interior British Columbia in 2021, along with moose movement of all individuals in the study. Grey points represent the centroid of space use areas, and arrows indicate the progression of space use areas for each individual for six different time periods created throughout the wildfire progression. Yellow wildfire polygons represent the beginning of the wildfire, and transition red as the wildfire progresses.

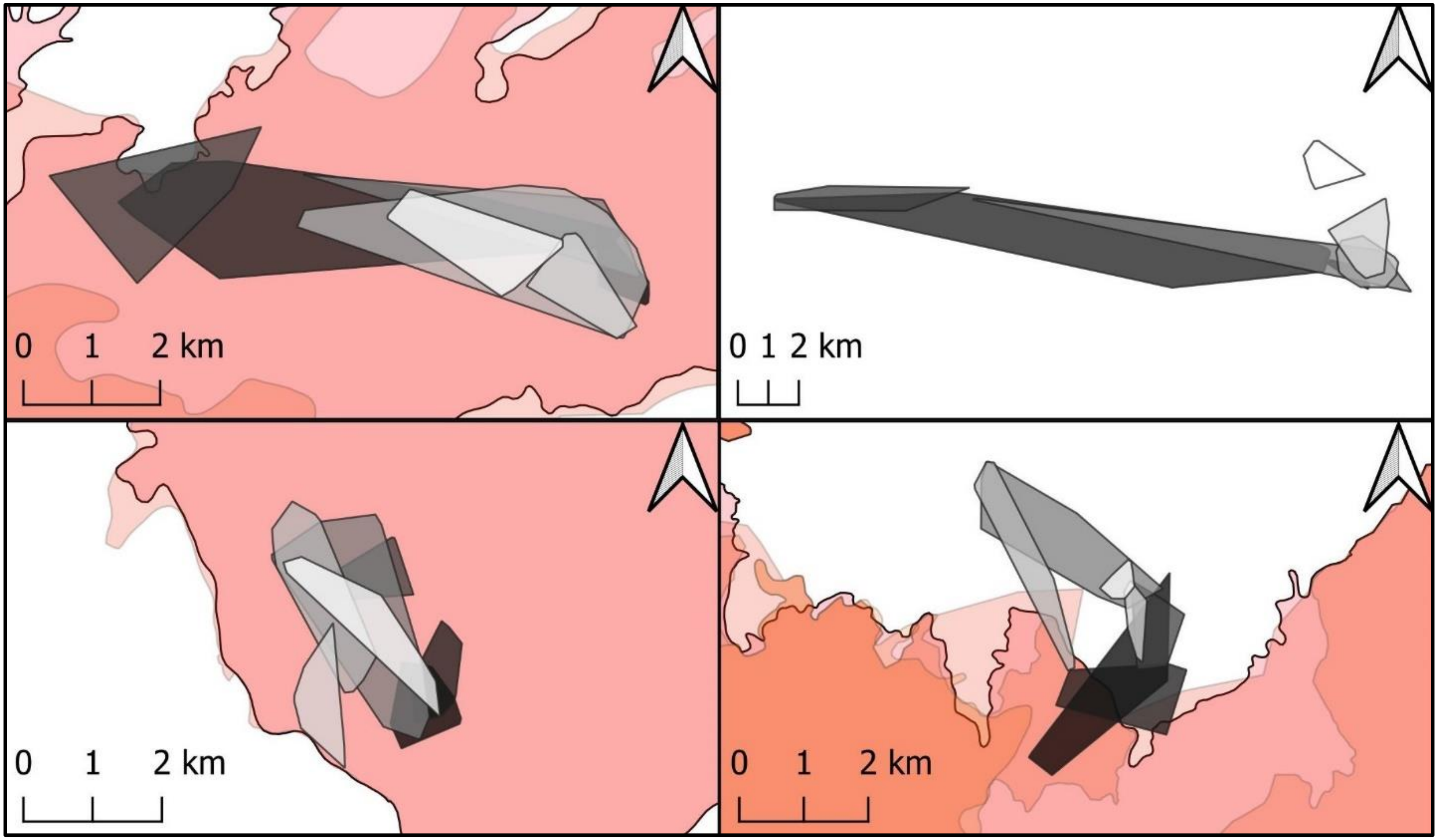

Figure 3. Examples of space use areas of moose at the Sparks Lake (top) and Tremont Creek (bottom) wildfire sites occurring in Interior British Columbia in 2021. The darkest polygons represent space use areas at the beginning of the wildfires, transitioning to lighter shading for each of the subsequent six time periods created throughout the wildfire progressions.

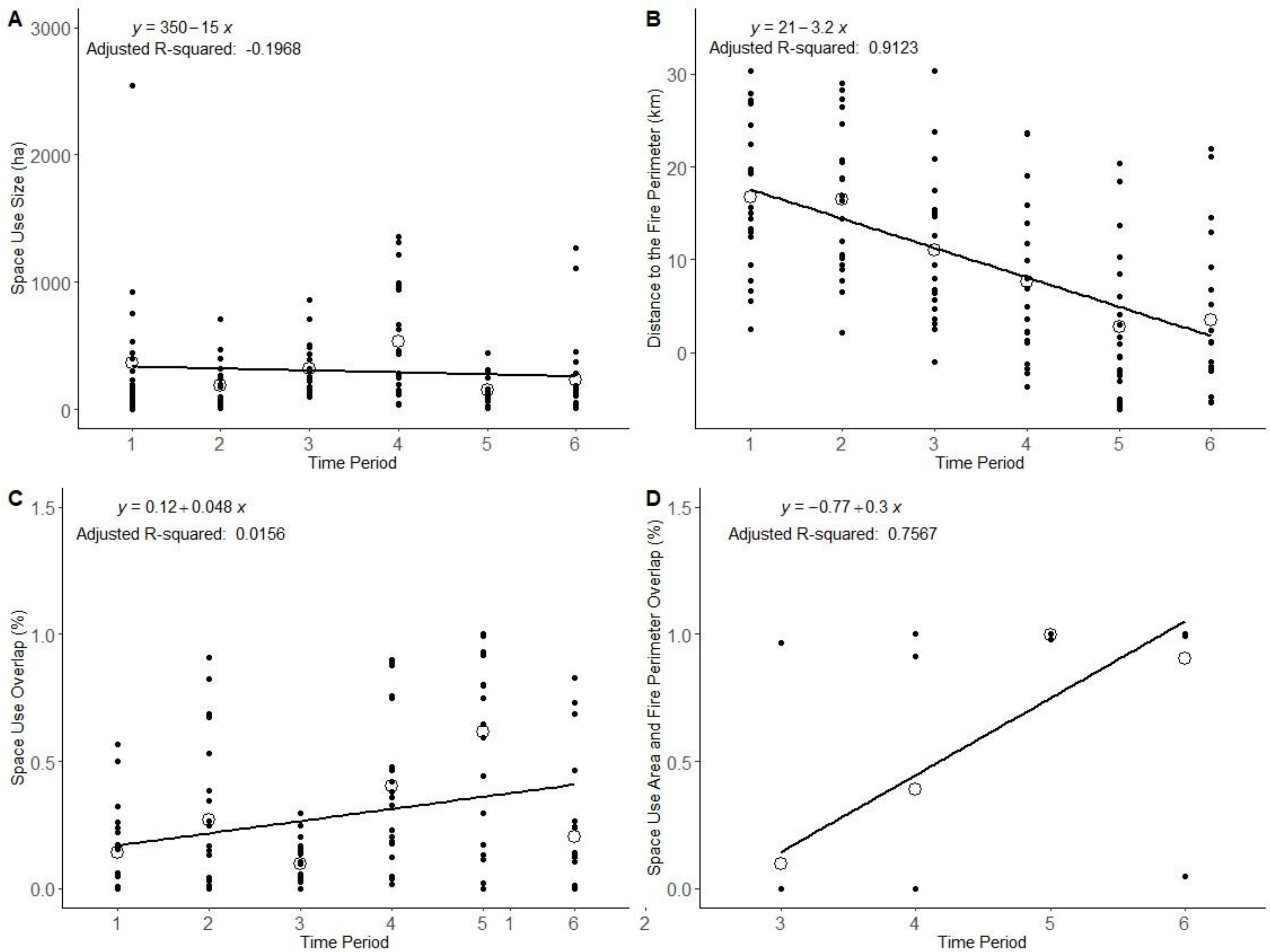

Figure 4. Plot of the results of the regression analysis on the mean values of space use size (A), distance to the fire perimeter (B), space use overlap (C) and space use area and fire perimeter overlap (D) for 20 female moose both Inside and Outside of the Sparks Lake and Tremont Creek wildfires occurring in Interior British Columbia in 2021. Solid data points represent the metrics of each individual (n=20) for each Time Period, with open circles representing the mean value of the metric for each Time Period.

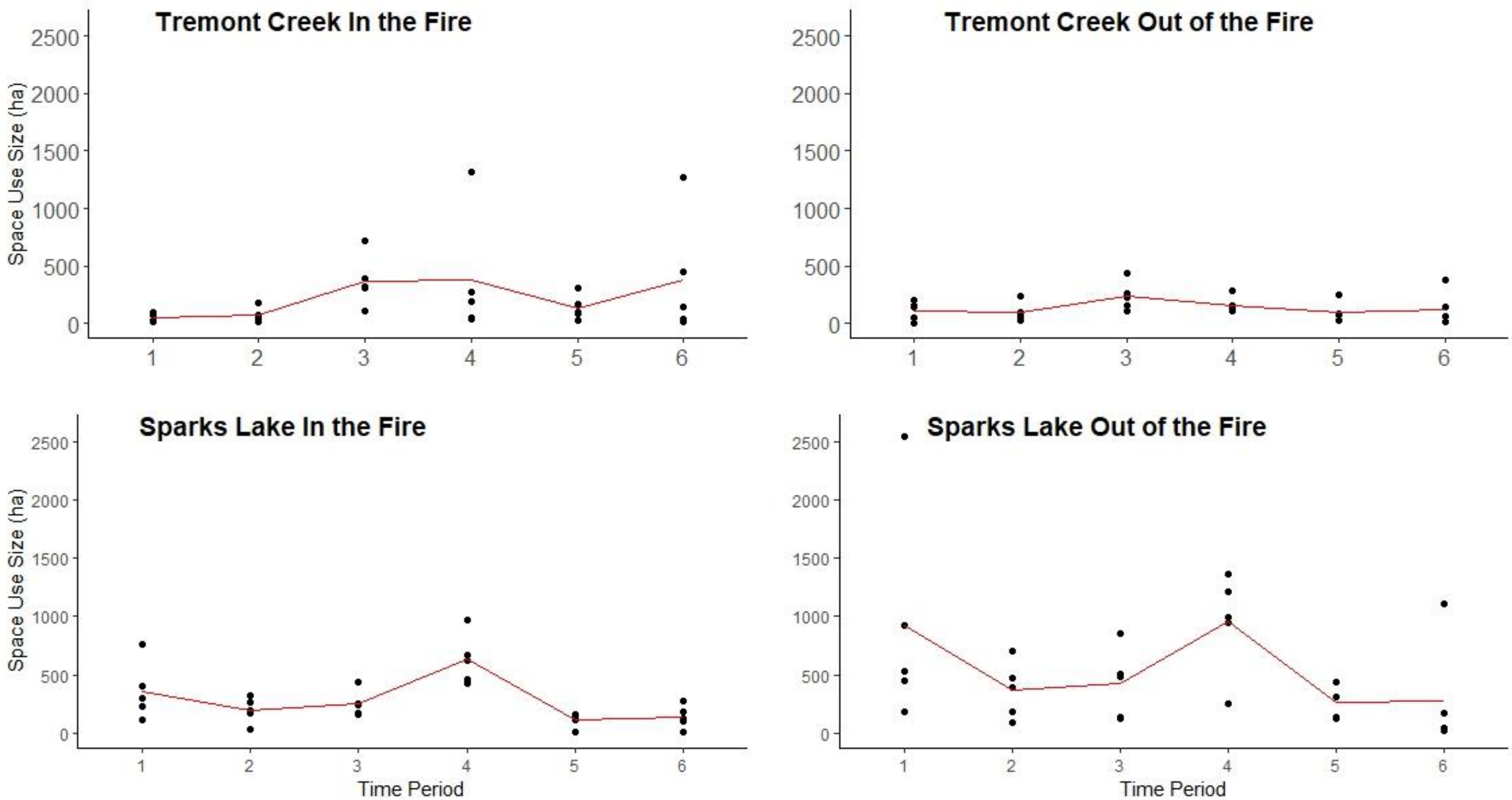

Figure 5. Space use size (ha) of female moose in and out of the Tremont Creek and Sparks Lake wildfires, with both fires occurring in south-central British Columbia in 2021. Data points represent the space use size of each individual moose (n=5) during each time period, with the mean space use size in red.

Distance to the fire perimeter

The distance to the fire perimeter demonstrated by the moose differed between the combination of Site and Time Period ($F_{1.4, 22.41} = 19.50$, $P < 0.001$). However, upon further evaluation, there were no significant differences between exact Site and Time Periods. Not surprisingly, moose that were in the 'Outside' category generally were farther (M = 14.9km) from the fire perimeter than those that were Inside the fire perimeter (M = 4.5km; ANOVA, $F_{1, 16} = 21.68$, $P < 0.001$; Games Howell, $P < 0.001$). Moose demonstrated significant differences in the distance to the fire perimeter as Time Periods progressed (ANOVA, $F_{1.4, 22.41} = 95.23$, $P < 0.001$; Games Howell, all Ps ≤ 0.02; Regression, $F_{1,4} = 52.98$, $P < 0.001$, $R^2 = 0.91$, Figure 4), with moose becoming closer to the fire perimeter throughout the progression.

Consecutive space use overlap

Moose in both the Outside and Inside categories did not have different degrees of consecutive space use overlap (Figure 6, $F_{1, 16} = 0.17$, $P = 0.68$), however Site and Time Period showed a significant interaction during Time Period 3 and Time Period 5 ($F_{3.54, 56.67} = 3.07$, $P = 0.03$; Simple main effects, all Ps ≤ 0.03; Pairwise comparison, all Ps ≤ 0.03). There were significant differences in consecutive space use overlap between some Time Periods (ie. Time Periods 1 and 4, 1 and 5, 2 and 5, 3 and 4, 3 and 6, 5 and 6; ANOVA $F_{3.54, 56.67} = 12.57$, $P < 0.001$; Games Howell, all Ps ≤ 0.03), however no significant differences in space use overlap were identified as Time Periods progressed (Regression, $F_{1,4} = 1.08$, $P = 0.36$, $R^2 = 0.02$, Figure 4), regardless of whether moose were Inside or Outside the wildfire (Figure 6).

Space use and fire perimeter overlap

Overlap between space use areas and the fire perimeter significantly increased for Inside moose as the fire progressed (ANOVA, $F_{3,24} = 22.24$, $P < 0.001$). Notable differences in these measurements occurred between Time Periods 3 and 5, 3 and 6, and 4 and 5, however there was no significant change as Time Periods progressed (Games Howell, all Ps < 0.02; Regression, $F_{1,2} = 10.33$, P =0.08, $R^2 = 0.76$, Figure 4). Once the fire perimeter overlapped with the space use of moose and they became impacted by the wildfire, all moose aside from one individual remained within the fire perimeter.

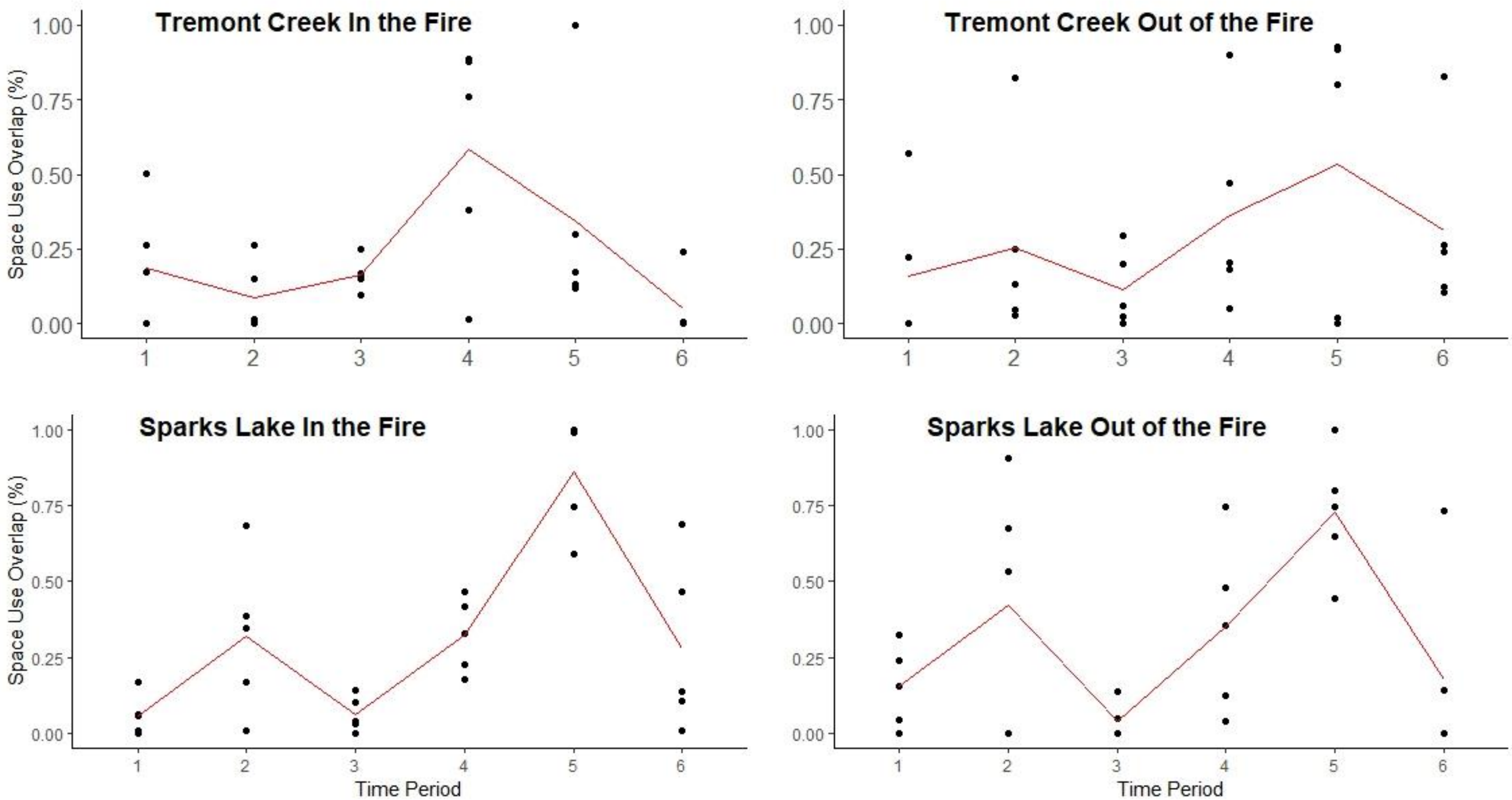

Figure 6. Consecutive space use overlap (%) of female moose in and out of the Tremont Creek and Sparks Lake wildfires, with both fires occurring in south-central British Columbia in 2021. Data points represent the consecutive space use overlap of each individual moose (n=5) during each time period, with the mean consecutive space use overlap in red.

Step length

Inside and Outside Moose did not show differences in the distances in their step lengths between Time Periods (ANOVA, $F_{1, 16} < 0.01$, $P = 0.96$, Figure 7), although there was a significant interaction between Site and Time Period ($F_{3.03, 48.52} = 3.72$, $p = 0.02$). Step length for moose at the Sparks Lake site was greater during multiple Time Periods (1, 2, and 3) compared to the Tremont Creek site (Simple main effects, all Ps ≤ 0.01; Pairwise comparison, all Ps ≤ 0.01), however no discernable trend in step length occurred throughout the progression of time periods (Figure 7).

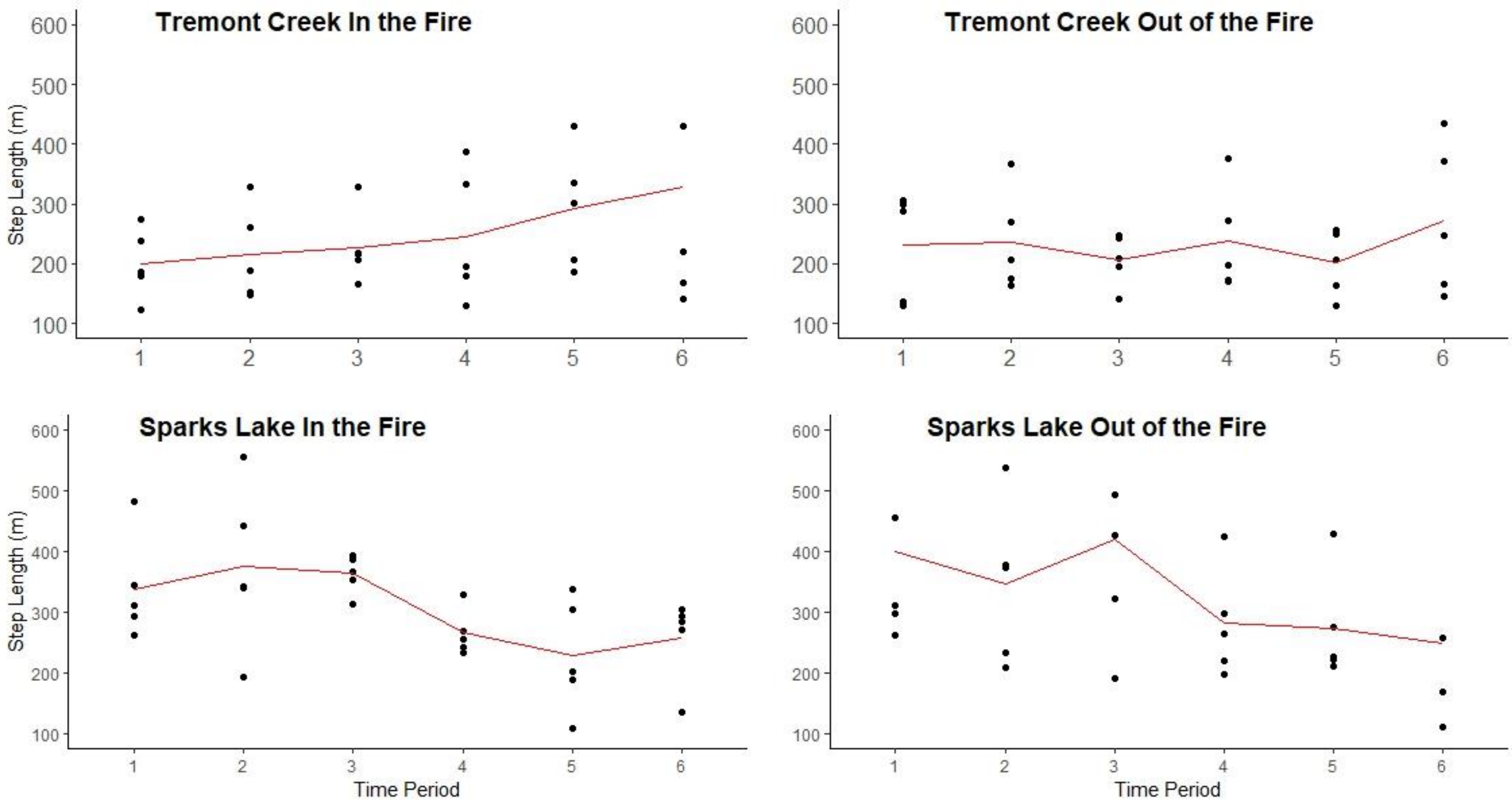

Figure 7. Step length (m) of female moose in and out of the Tremont Creek and Sparks Lake wildfires, with both fires occurring in south-central British Columbia in 2021. Data points represent the step length of each individual moose (n=5) during each time period, with the mean step length in red.

Discussion

My study suggests that moose in the paths of two wildfires did not appreciably alter individual movement behaviour and space use, although there were differences in the metrics between the two sites (Sparks Lake and Tremont Creek).

Moose inside the fire area did not appear to shift their space use areas to access unburnt areas outside the periphery and were able to survive and sustain themselves within their original space use areas. Had an increase in space use size occurred within the Inside moose, it would have suggested the moose attempted to leave the area in response to the progressing wildfires, however this was not the case. Instead, space use size was the same between moose both Inside and Outside the wildfire at both sites, with moose at the Sparks Lake site having larger space use sizes compared to those at Tremont Creek. Similarly, Inside moose at both sites did not display longer step lengths as a result of the wildfire meaning they did not increase their movement as a result of the wildfire, and were able to find all the required resources such as forage, water, and thermal shelter. Comparatively, all moose at the Sparks Lake site displayed longer step lengths compared to moose at the Tremont Creek site. Unsurprisingly, Outside moose were situated farther from the fire perimeter, compared to those inside the fire perimeter, with overall distance of moose to the wildfire perimeter decreasing throughout the fire progression. Lastly, for the 10 Inside moose, overlap between their space use areas and the fire perimeter increased as the wildfire progressed, with only one of these 10 Inside moose reducing its space use within the fire perimeter once it was impacted by the fire. Overall, it appears the moose maintained the same movement rates, space use size, and locations during these wildfire events. This contradicts the Bambi image of animals racing ahead of the fire front. The overall undetectable response of moose to wildfire progression, in combination with the lack of mortality during the wildfire, indicates that the moose were able to meet all their immediate needs despite the occurrence of wildfires.

While there were limited differences in the moose metrics between Inside and Outside individuals, differences did occur in the step length and space use size of moose between the two fire sites (Sparks Lake and Tremont Creek). Moose space use is a function of resource availability and habitat heterogeneity across landscapes (Van Beest et al. 2010). The differences between the two sites could be attributed to differences in topography and resource availability, with moose at Sparks Lake having larger space use areas to ensure all survival requirements are fulfilled, while requiring additional step lengths to access resources. Despite the two sites being in close proximity and within similar forest types it appears a larger landscape level effect apart from the fire was influencing moose movement and behaviour. At this larger scale, differences in landscape characteristics may lead to differences in moose response during events such as wildfires.

As previously outlined, the forests in which the moose were inhabiting fell under the IDF, MS, and SBPS ecosystems. Historically, these areas had frequent low-severity fires to maintain their vegetation composition, however this now appears to be shifting to more high-severity fires (Heyerdahl et al. 2012, Parisien et al. 2020). In the case of the Sparks Lake wildfire, the areas in which the moose were inhabiting experienced relatively low-severity burning (Giles T 2021A); in comparison, the moose at Tremont Creek were situated in high-severity sites (Giles T 2021B). Lower severity may correlate with larger fire 'skips' and/or less fire crowning, allowing moose to more easily avoid flames and heat. Yet, there was no difference in moose response between individuals inside and outside the wildfires at both sites, suggesting that severity was not directly responsible for moose behaviour during burning. Of note is the fact the study fires coincided with an extreme, record-breaking heat event in the BC interior (Surviving the heat … 2023); prior to the fire, there was little suggestion moose were relocating to thermal refugia (including wetlands) (Roberge et al. *in progress*). At this time, it is difficult to predict whether the combination of extreme weather heat and the heat/danger from the wildfire would have interacted to influence moose movement.

The results of this study illustrate the ability of moose to survive wildfires, even in areas that they are not commonly associated with. Moose are generally a boreal species, with their range being almost identical to the expansion of boreal forests, and are adapted to the conditions and events that occur within these ecosystems, including prevalent wildfire (Pastor et al. 1988). Fire in boreal ecosystems clearly plays a dominant role in structuring and maintaining a mosaic of vegetation across the landscape which in turn helps to support a diversity of wildlife, including moose (Bergeron et al. 2001, Flannigan et al. 2001, Weber and Stocks 1998). Boreal forests have evolved under the influence of fire, and lose much of their structure and characteristics without these natural fire events (Kelsall et al. 1977). In Canada, boreal forests cover a large portion of the land base from Newfoundland to the Yukon, and into the northern portion of British Columbia, which supports the majority of BC's moose population (Blancher et al. 2006, Moose 2023). Despite this, moose are still found within Southern Interior BC in other forest types including IDF, SBPS, and MS and are able to survive, especially under the conditions created by wildfire.

The results of this study suggest moose may be well-adapted to deal with advancing wildfires, although further research, under a wider range of ecological conditions, is needed to reveal the full scope and 'repertoire' of moose behaviour. Also, the longer-term effects of exposure to wildfire (e.g. smoke inhalation, heat exposure) need to be considered when examining the impacts to this species. The increase of wildfires within Southern Interior BC is often associated with an increase in overall temperatures during critical summer period which is traditionally when moose struggle to stay cool (Lenarz et al. 2009, Carstensen et al. 2016, Haughian et al. 2012). Moose will be faced not only with avoiding wildfire, but also dealing with hotter and drier temperatures. Additionally, moose are a relatively new species within Southern Interior BC, and it is unknown how rapidly these changes within the environment may impact this species.

In this study, the observed moose behaviour demonstrates that moose are able to survive wildfire events, and further studies could determine the benefit of the abundant high-quality forage present following wildfires (Maier et al. 2005, Joly et al. 2016). Moose increase their use of burns immediately following wildfire, continuing until approximately 25 years post-burn to take advantage of the early seral stage in which herbaceous plant species continue to increase (Fisher and Wilkinson 2005). With increasing wildfires, these areas will be more abundant, and due to historic fire suppression have an increased burn severity which contributes to improved summer browse for moose (Brown et al. 2018, Parisien et al. 2020). At first glance, the effects of wildfires appear to create short term detrimental impacts such as habitat loss, however may provide improved longer-term habitat and forage for moose.

Several factors may have introduced bias into this study. Inconsistent wildfire progression perimeters made for time periods of varying lengths, leading to differences in the amount of GPS data points used to create the minimum convex polygons (MCPs). However, the overall lack of change in space use observed throughout the fire progression suggests this bias, if it existed, was likely inconsequential. In addition, GPS collars for moose at the Sparks Lake site collected data points every four hours as opposed to two hours at the Tremont Creek site; space use at the latter therefore was more detailed due to the larger amount of data points available for MCP calculations. In addition, the smaller numbers of data points for Sparks Lake moose required using MCPs for depicting space use, as opposed to Kernel Density Estimations (KDEs). KDEs encompass clustering of data points and therefore identify areas of importance and highlight resource selection, as opposed to MCPs which create the smallest polygon possible around data points and may be less beneficial in ecological studies (Nilson et al. 2008, Vang 2017). This study also was limited in that burn severity was not available as an overlay on moose locations. Burn severity likely plays a vital role in how moose respond during wildfire events, as high impact burns have been proven to alter moose behaviour and space use post-wildfire (Brown et al. 2018, Lord and Kielland 2015). It is possible that the areas inhabited by the moose in this study were areas of 'fire skips', therefore contributing to their ability to survive, however it is unlikely that all 10 of the moose Inside the fires were within these types of skip areas. Additionally, any large movements or increases in step length could have indicated a shift to a fire skip area and would have been detected during analysis. Future studies should be conducted to examine the use of skips under additional scenarios.

Overall, my study suggests moose are capable, in at least some circumstances, to survive wildfires without substantially altering their movement and space use. However, the specific tactics used by the moose to survive and position themselves on a landscape being burned by wildfire needs more detailed work, especially in regard to habitat type and burn severity, in addition to collecting data that can be used to determine or assume behaviour during wildfires. Increased knowledge on this subject will aid in our understanding of the species and aid managers in conservation and management efforts for moose related to wildfires.

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