Living Lab Program for Climate Change and Conservation - Final Report

Project title: Examining the response of mountain goats to wildfire during the 2023 Crater Creek wildfire in Cathedral Provincial Park, BC

Lead researcher(s): Aimee Chhen, Michael J. Noonan

Research findings

The core aim of this project was to study how mountain goats (*Oreamnos americanus*) in Cathedral Provincial Park responded to the Crater Creek wildfire (K52125). In the summer of 2023, a lightning strike sparked the Crater Creek wildfire in the southern interior of BC on the unceded and ancestral land of Syilx Okanagan Nation near Keremeos, BC. Over the 96 days that it burned (BC Wildfire Service 2023a), the Crater Creek wildfire engulfed a total of 43,504.2 hectares and is considered as a megafire (Linley et al. 2022). Although the fire was initially slow growing, in mid-August the fire spread rapidly towards Cathedral Provincial Park. The fire was eventually extinguished, but over the months that it burned it expanded into the home-ranges of a population of vulnerable mountain goats equipped with GPS tracking collars were being monitored by BC Parks. (Fig. 1). This confluence provided a unique opportunity to study how these animals responded to wildfire in near real-time. Using 6 years of GPS tracking data from the 6 individuals that were continuously monitored before, during, and after the fire, remotely sensed habitat information, and fire spread data, we studied how mountain goats' movement ecology was impacted by the Crater Creek wildfire (Fig. 2). Our key findings are detailed below.

Mountain Goat Movement

- The 6 monitored animals exhibited comparable home-range sizes and diffusion rates across all 6 years (Fig. 4).
- Mountain goat home-range sizes were smaller during the wildfire (July 22nd, 2023 – October 26th, 2023) as compared to their home-range sizes during the same period in the 4 years preceding the fire, and the year after the fire (Table 1; Fig. 3a). However, the fire year/normal year ratio of mean home-range size was estimated as 0.23 (0.01–1.03), which marginally includes 1, implying these differences were not significant.
- Mountain goat diffusion rates, a measure of their movement speed, were greater during the wildfire as compared to the same period in the 4 years preceding the fire, and the year after the fire (Table 1; Fig. 3b). Here the fire year/normal year ratio of mean diffusion rates was estimated as 3.20 (1.80–5.16), which excludes 1, implying a significant difference.

Mountain Goat Habitat-use

- The 6 monitored animals exhibited comparable use of elevation and distance to escape terrain across all 6 years (Fig. 6).
- When restricting our analyses to the June 22nd – October 26th fire period, here again no differences in habitat use were observed (Fig. 7), and resource selection functions (RSFs) further revealed little to no differences in the selection for elevation (Fig. 8a) nor distance to escape terrain (Fig. 8b).
- Near real-time estimates of the mountain goats' distance to the fire perimeter in the year the fire was burning were effectively identical to their distance to the fire perimeter in the years the fire was not burning (Fig. 9), further indicating that the animals did not adjust their habitat use, nor shift their home-ranges in response to the wildfire.

When taken together, our results suggest that managers should not expect mountain goats to proactively adjust their habitat use or movement in response to a nearby wildfire(s). Instead, BC Parks should expect that mountain goats will react only when wildfire represents an immediate threat to their survival. The significantly elevated diffusion rates we observed during the fire suggest that mountain goats may be 'agitated' during wildfire events, however, few other differences were observed. The elevated diffusion rates would result in increased energy expenditures, which these animals would need to adjust for through the consumption of additional food, or the metabolism of fat reserves. The combination of increased energetics and decreased post-fire forage availability can have an additive effect on mountain goats that risk negatively impacting their post-fire survival and fitness. We note, however, that these findings are geographically restricted, and based on a small sample size, and further work is needed to determine the extent to which these findings can be generalised to other mountain goat populations.

Methods summary

- The Crater Creek wildfire was discovered on July 22, 2023, and burned for 96 days (BC Wildfire Service 2023a, 2023b). BC Wildfire Services declared the wildfire out on October 26, 2023 (BC Wildfire Service 2023a, 2023b). We defined this date range as the "wildfire" period in our subsequent analyses.
- Spatial polygons of the spread of the Crater Creek wildfire were obtained from the provincial government via the Freedom of Information and Protection of Privacy Act (FOIPPA), hotspot fire data were obtained from satellite imagery (NASA VIIRS Land Science Team 2020a, 2020b, 2021) elevation data were obtained from the `elevatr` R package (Hollister et al. 2021), slope data was obtained from the terra R package (Hijmans 2024), and 'escape terrain' was defined as locations with a slope greater than 50° (Sarmento and Berger 2020).
- GPS tracking collar data from 6 mountain goats for 6 years (2019 - 2024) were provided by BC Parks. All the tracking data were filtered for outliers prior to analyses, and 671 locations were deemed outliers and removed. The final data set consisted of a total of 13,787 locations.

- To estimate mountain goat diffusion rates we fit continuous-time movement models to the GPS data using the `ctmm` R package (version 1.2.0; Fleming and Calabrese 2022).
- Individual home-range areas were estimated using autocorrelated kernel density estimation (AKDE; Fleming et al. 2015a). We estimated home-ranges during the July 22nd – October 26th wildfire period for all years (2019-2024), and comparisons were made via the `meta` function in `ctmm` (Fleming et al. 2022).
- Individuals' distance to the wildfire perimeter were calculated from the animals' GPS coordinates using the `sf` R package (version 1.0.17; Pebesma 2018, Pebesma and Bivand 2023).
- To examine mountain goat selection for or against elevation and distance to escape terrain in response to the Crater Creek wildfire, resource selection functions (RSFs) were fit via the `rsf.fit` function from the `ctmm` package. RSFs were fit to GPS locations during the July 22nd – October 26th wildfire period for all years (2019-2024).
- We applied a sliding window analysis to detect any dynamic changes in behaviour for the period leading up to and during the wildfire. The GPS location data were subset into a series of 3-day windows, which moved incrementally by 1-day time steps over the duration of the monitoring period. Within each 3-day window, the analyses described above were all conducted, allowing us to see how individuals' movement changed over time.
- Data visualization and analysis were carried out using R (version 4.4.1; R Core Team 2022). All of the scripts involved in this project are openly available in the GitHub repository at https://github.com/QuantitativeEcologyLab/Mountain_Goat.

Key outcomes for BC Parks

Decades of fire suppression and fuel accumulation, paired with the pressures from human-induced climate change, are leading to longer fire seasons comprised of more frequent and severe wildfires (Parisien et al. 2023). Managers at BC Parks will need to contend with the threat that these fires pose to BC's forests and wildlife. From our analyses, we found that mountain goats did not appear to proactively adjust their habitat-use or movement in response to a nearby wildfire. Managers should therefore expect mountain goats to react only when a wildfire presents an immediate threat to their survival. Although based on a small sample size, these findings are consistent with patterns observed in other species throughout the province (Adam T. Ford, *pers. comm.*).

Although the monitored mountain goats did not adjust the size or location of their home-ranges, we did observe significantly elevated diffusion rates during the wildfire. This suggests that individuals may have been 'agitated' during the wildfire. If wildfires drive increased movement rates, they would result in increased energy expenditures that these animals would need to compensate for through the consumption of additional food, or the catabolism of fat reserves. The additive effects of increased energetics and decreased post-fire forage availability risk negatively impacting their post-fire survival and fitness.

Relevance to BC Parks management

Although the crater creek fire moved through areas that these mountain goats were known to occupy (Fig. 1), all of the GPS tracked individuals survived the fire. This is promising, as it suggests that mountain goats have the capacity to escape fast moving megafires. Notably, however, these animals did not preemptively adjust their habitat use in any statistically identifiable way in response to the wildfire, but continued to occupy their core habitat up until the point at which a fire became an imminent threat to their survival. This has two main implications for managers at BC parks. First, this implies that when faced with a potentially threatening wildfire, employees at BC Parks should be able to contrast real-time fire spread predictions against maps of mountain goat habitat to assess the risk the fire poses to mountain goat populations without needing to factor in fire-induced behavioural changes. Second, because managers cannot expect mountain goats to respond proactively to wildfires, we recommend that, in the event of a potentially threatening wildfire, they work to ensure that mountain goats have the space and freedom of movement needed to flee from approaching fires. Access to flight or escape paths should be protected from recreational encroachment and/or physical barriers, such as a fence as best as possible. Although further work is needed to determine the landscape features mountain goats' use during any fine-scale flight responses, ensuring good habitat connectivity is an important component of proactive wildfire management. Individuals only seem to respond when a fire becomes an immediate threat, placing them at risk of becoming trapped if there is poor habitat connectivity. Notably, park managers will also need to consider the vagility of mountain goats, or wildlife in general. If a wildfire is projected to move quickly, it may risk outpacing mountain goats. Given that fires are spreading at faster rates (Balch et al. 2024), this will be increasingly important going forward.

Project's challenges/opportunities

The core aim of this project was to study how mountain goats in Cathedral Provincial Park responded to the Crater Creek wildfire. Although the mountain goat tracking data were made available by partners at BC Parks, obtaining access to accurate fire spread data was a substantial challenge in this project. BC Wildfire Services only provides the initial ignition point and final perimeters of past wildfire. The dynamic perimeter data are not readily available to researchers, despite news media and wildfire services being able to report the fire perimeters as wildfires progress. In an attempt to obtain real-time fire spread information, we assessed the viability of remotely sensed data; however, only hotspot points were available, and significant effort is required to convert these hotspots to fire perimeters. In addition, the satellite imagery data were either fine-scale temporally (~15 minutes) and coarse-scale spatially (2km; geostationary satellite, GOES-West) or coarse-scale temporally (twice a day) and fine-scale spatially (250-375m; polar-orbiting satellite, MODIS and VIIRS). Unfortunately, much of the remotely sensed fire data could not be used due to their relatively poor quality, and the challenges associated with working with them. Our eventual approach was to obtain data via the Freedom of Information and Protection of Privacy Act (FOIPPA), in which fire boundaries were requested from the BC government records. Again, the data were limited, and there were only 15 perimeters included in the request. With five of the most destructive

wildfire years occurring in the past eight years in BC (BC Wildfire Service 2023b), critical data on wildfire should and needs to be made available to researchers.

The small sample size of 6 mountain goats makes it difficult to generalise our findings beyond the Cathedral Provincial Park population. It is effectively impossible to plan a study around wildfires, as they are stochastic and unpredictable in nature. This analysis was only possible because we happened to know that mountain goats in Cathedral Provincial Park were being monitored during the Crater Creek fire. However, there are hundreds, if not thousands of GPS monitored animals throughout the province. If there whereas better coordination in terms of understanding which animals are collared, when and where for all the animals across the province, researchers would be better able to study the effects of wildfire on animal movement and habitat use. If such a database existed, it would be advantageous for those tasked with stewarding BCs wildlife and the habitats the live in.

In both cases, data limitations were the primary challenges we faced with this project. Through various agencies, there appears to be a lack of coordination on how these data are collected and stored. In addition, the data were difficult to work with and required substantial effort to process before any analyses could be done. Improving data curation practices would help reduce the effort required to work with these data. Improved accessibility is greatly needed to increase the usage of these incredibly valuable data. We anticipate that it would lead to more collaborations between BC Parks and researchers, a more efficient use of research time, and undoubtedly more actionable findings.

Conclusions/next steps

Our findings allowed us to describe mountain goats' coarse-scale response to the Crater Creek wildfire. With wildfire being projected to increase in frequency and severity, it is recommended that BC Parks make use of these findings to understand how mountain goat movement patterns and habitat use are expected to change in the coming years. Although our results were at a relatively coarse temporal scale, they represent a starting point for park managers to help guide their day-to-day decisions. Due to the challenges mentioned above, time constraints became a limiting factor, and fine-scale analyses could not be performed. Further work on the fine-scale responses of mountain goats is needed in order to better understand their response to wildfire. In addition, a finer-scale re-creation of the Crater Creek wildfire is essential for such analyses. Mountain goats seem to only acknowledge the presence of wildfire when it becomes an immediate threat and not when a situation may become dangerous. Despite these acute responses, they maintain their area-use patterns with increased movement. Therefore, area-based conservation is crucial in protecting the vulnerable population of mountain goats in Cathedral Provincial Park. Collectively, our findings can help park managers throughout the province to make informed decisions about wildlife in protected areas and how they are expected to respond in a future of induced-climate increases in wildfire.

References and links

Balch, J. K., V. Iglesias, A. L. Mahood, M. C. Cook, C. Amaral, A. DeCastro, S. Leyk, T. L. McIntosh, R. C. Nagy, L. St. Denis, T. Tuff, E. Verleye, A. P. Williams, and C. A. Kolden. 2024. The fastest-growing and most destructive fires in the US (2001 to 2020). Science 386:425–431.

BC Wildfire Service. 2023a, November 29. Crater Creek. Government. https://wildfiresituation.nrs.gov.bc.ca/incidents?fireYear=2023&incidentNumber=K52125.

BC Wildfire Service. 2023b, December 7. Wildfire Season Summary - Province of British Columbia. Government, Province of British Columbia. https://www2.gov.bc.ca/gov/content/safety/wildfire-status/about-bcws/wildfire-history/wildfire-season-summary.

Fleming, C. H., and J. M. Calabrese. 2022. ctmm: Continuous-Time Movement Modeling.

Fleming, C. H., I. Deznabi, S. Alavi, M. C. Crofoot, B. T. Hirsch, E. P. Medici, M. J. Noonan, R. Kays, W. F. Fagan, D. Sheldon, and J. M. Calabrese. 2022. Population-level inference for home-range areas. Methods in Ecology and Evolution 13:1027–1041.

Fleming, C. H., W. F. Fagan, T. Mueller, K. A. Olson, P. Leimgruber, and J. M. Calabrese. 2015. Rigorous home range estimation with movement data: a new autocorrelated kernel density estimator. Ecology 96:1182–1188.

Hijmans, R. J. 2024. terra: Spatial Data Analysis.

Hollister, J. W., A. L. Robitaille, M. W. Beck, M. Johnson, and T. Shah. 2021, December 29. elevatr: Access elevation data from various APIs. Zenodo.

Linley, G. D., C. J. Jolly, T. S. Doherty, W. L. Geary, D. Armenteras, C. M. Belcher, R. Bliege Bird, A. Duane, M. Fletcher, M. A. Giorgis, A. Haslem, G. M. Jones, L. T. Kelly, C. K. F.

Lee, R. H. Nolan, C. L. Parr, J. G. Pausas, J. N. Price, A. Regos, E. G. Ritchie, J. Ruffault, G. J. Williamson, Q. Wu, and D. G. Nimmo. 2022. What do you mean, 'megafire'? Global Ecology and Biogeography 31:1906–1922.

NASA VIIRS Land Science Team. 2020a. VIIRS (NOAA-20/JPSS-1) I Band 375 m Active Fire Product NRT (Vector data). NASA LANCE MODIS at the MODAPS.

NASA VIIRS Land Science Team. 2020b. VIIRS (S-NPP) I Band 375 m Active Fire Product NRT (Vector data). NASA LANCE MODIS at the MODAPS.

NASA VIIRS Land Science Team. 2021. VIIRS (NOAA-21/JPSS-2) I Band 375 m Active Fire Product NRT (Vector data). NASA LANCE MODIS at the MODAPS.

Parisien, M.-A., Q. E. Barber, M. L. Bourbonnais, L. D. Daniels, M. D. Flannigan, R. W. Gray, K. M. Hoffman, P. Jain, S. L. Stephens, S. W. Taylor, and E. Whitman. 2023. Abrupt, climate-induced increase in wildfires in British Columbia since the mid-2000s. Communications Earth & Environment 4:309.

Pebesma, E. 2018. Simple Features for R: Standardized Support for Spatial Vector Data. The R Journal 10:439.

Pebesma, E., and R. Bivand. 2023. Spatial Data Science: With Applications in R. First edition. Chapman and Hall/CRC, New York.

R Core Team. 2022. R: A language and environment for statistical computing. R, Vienna, Austria.

Sarmento, W., and J. Berger. 2020. Conservation implications of using an imitation carnivore to assess rarely used refuges as critical habitat features in an alpine ungulate. PeerJ 8:e9296.
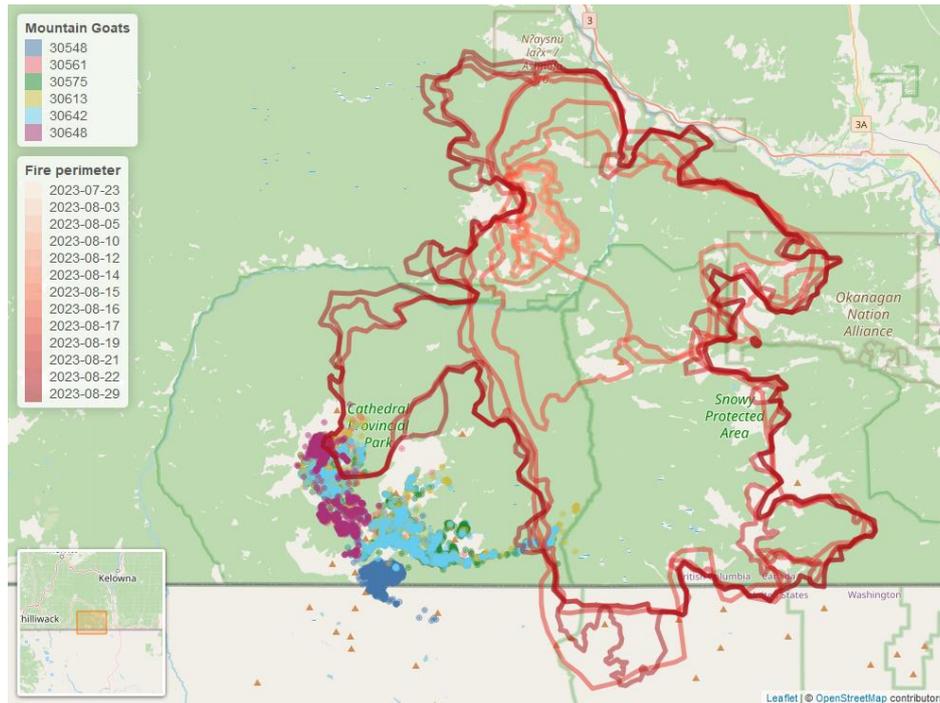
Figures

Figure 1. Mountain goat location in and around Cathedral Provincial Park, British Columbia. Map of 6 mountain goat GPS locations from July 22 to October 26, 2023. The solid grey line marks the Canada-USA international border.
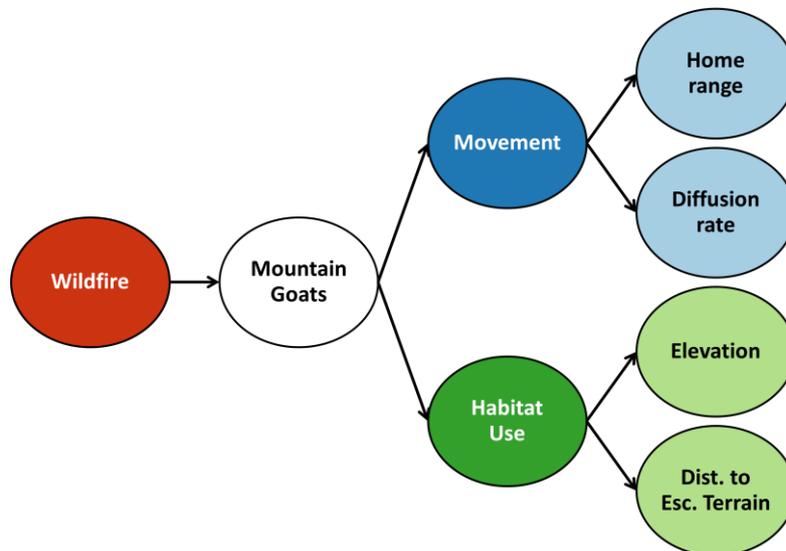

Figure 2. Project schematics of the workflow examining the response of mountain goats to wildfire. The dark blue circle represents the movement response of mountain goats. Movement was evaluated by home-range size and diffusion rate (light blue circles). The dark green circle represents the habitat-use of mountain goats. Habitat-use was investigated based on elevation and distance to escape terrain (light green circles).
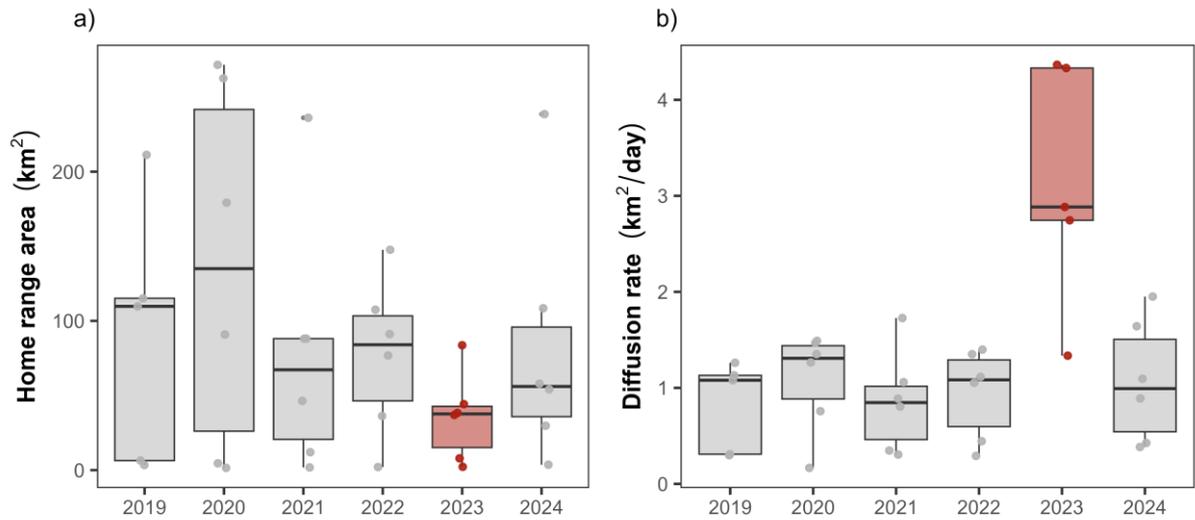
Figure 3. Mountain goat home-range and movement during the 2023 Crater Creek wildfire in Cathedral Provincial Park, British Columbia. Panel a) shows boxplots of individual home-range sizes from July 22 to October 26 wildfire period across all years (2019-2024), with 2023 being the year of the Crater Creek wildfire. The width of each bar indicates the 95% confidence intervals on the home-range estimates across all years during this period. Panel b) shows boxplots of diffusion rate for these same individuals for the wildfire period across all years. The width of each bar indicates the 95% confidence intervals on the diffusion rate across all years during this period. The points depict the underlying data, with red indicate the year of the Crater Creek wildfire.
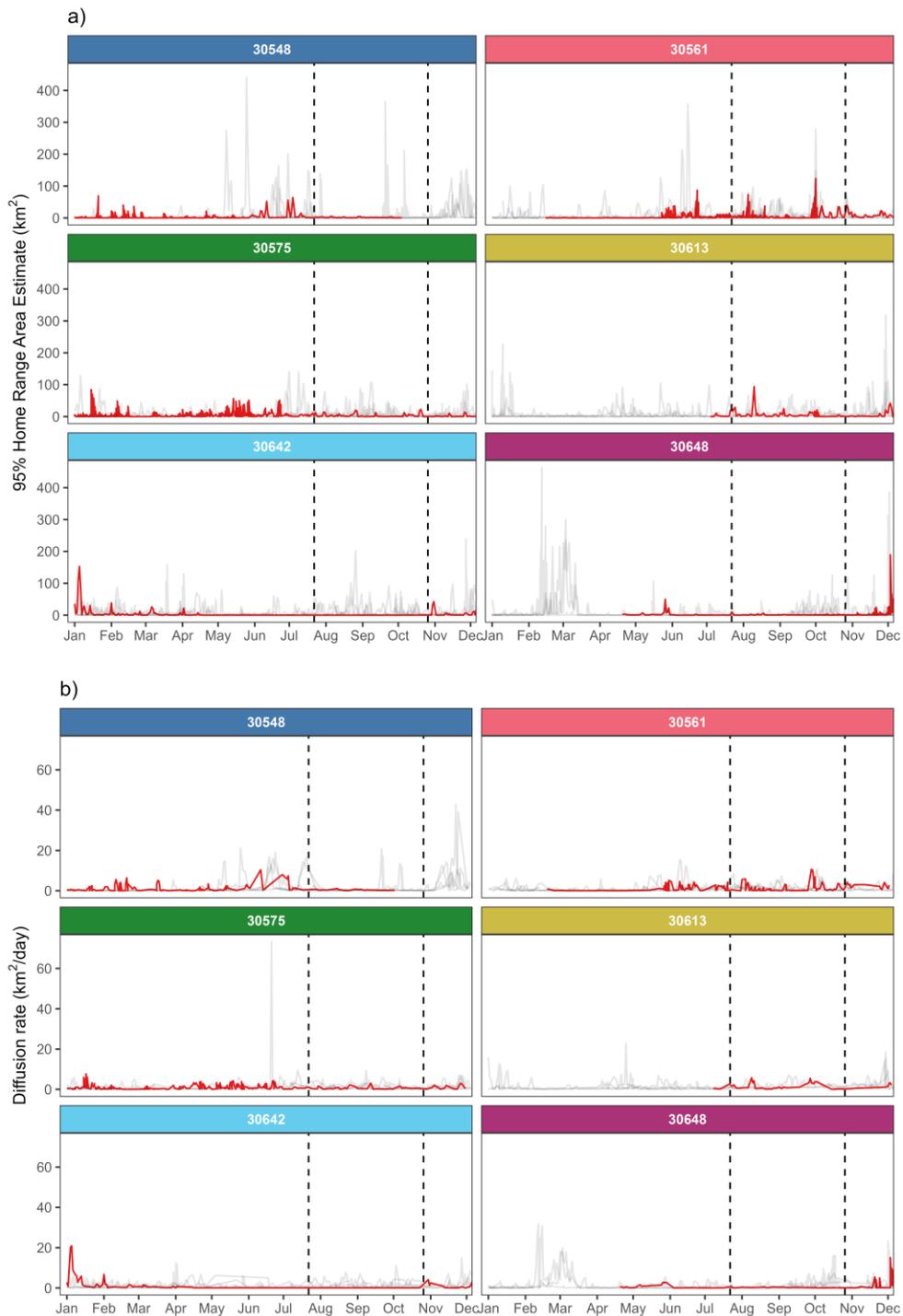
Figure 4. Mountain goat home-range sizes and diffusion rates from 2019 to 2024 in Cathedral Provincial Park, British Columbia. Results of a sliding window analysis estimating individuals' mean a) home-range size, and b) diffusion rates across all 6 years (2019-2024), with 2023 being the year of the Crater Creek wildfire. Panel a) shows each mountain goat's home-range size (km²) across all 6 years. Panel b) shows each mountain goat's diffusion rates (km²/day) across all 6 years. The red line indicates the year of the Crater Creek wildfire, and the grey lines are all the other years. The black dashed line represents the Crater Creek wildfire period.
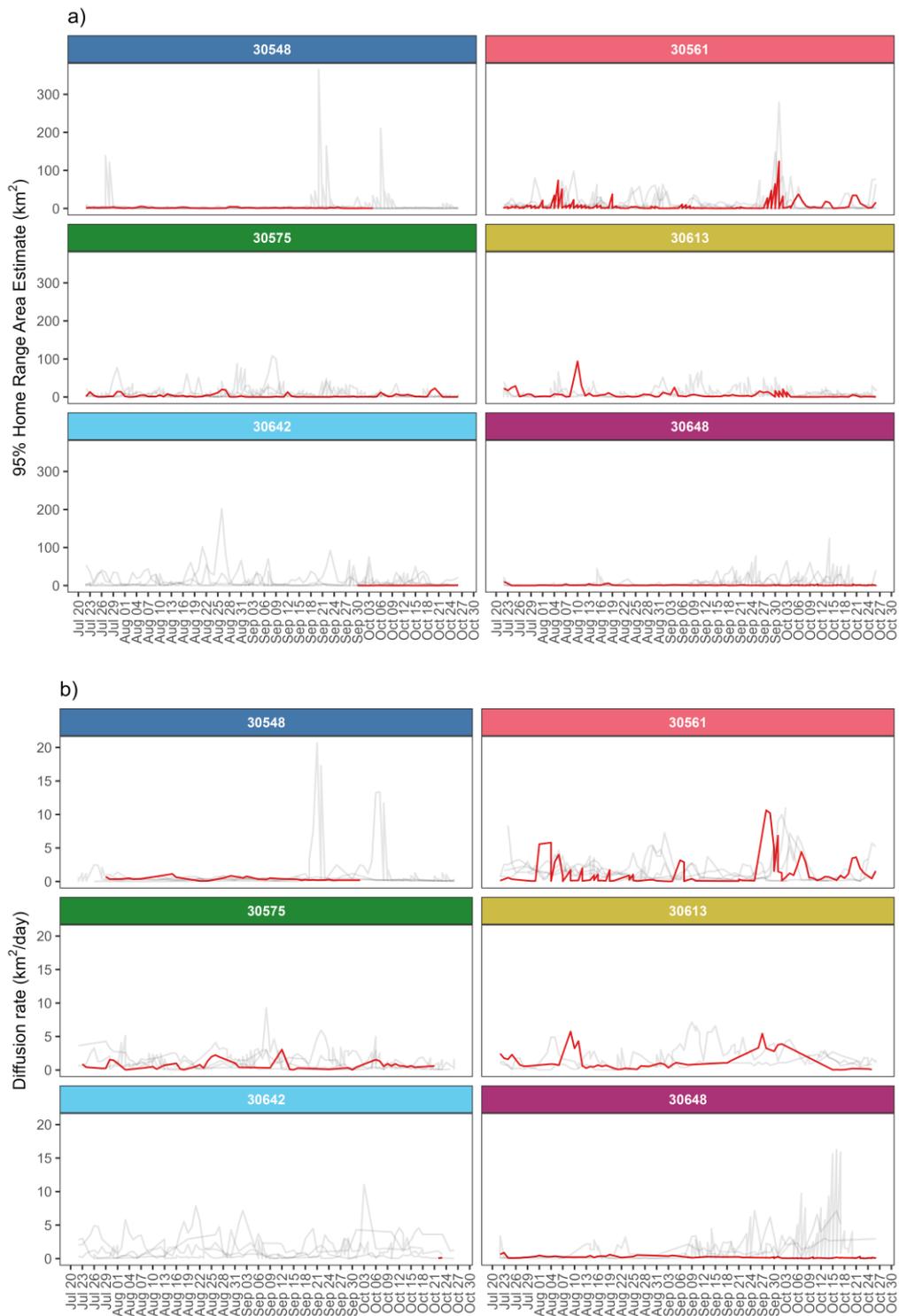
Figure 5. Mountain goat movement during the 2023 Crater Creek wildfire in Cathedral Provincial Park, British Columbia. Results of a sliding window analysis estimating individuals' mean a) home-range size, and b) diffusion rates during the wildfire period (July 22 to October 26) across all 6 years (2019-2024), with 2023 being the year of the Crater Creek wildfire. Panel a) shows each mountain goat's home-range size (km^2) during the Crater Creek wildfire (red line) compared to their home-range sizes in all the other years over the same period (grey lines). Panel b) shows each mountain goat's diffusion rates (km^2/day) during the Crater Creek wildfire (red line) compared to their diffusion rates in all the other years over the same period (grey lines).
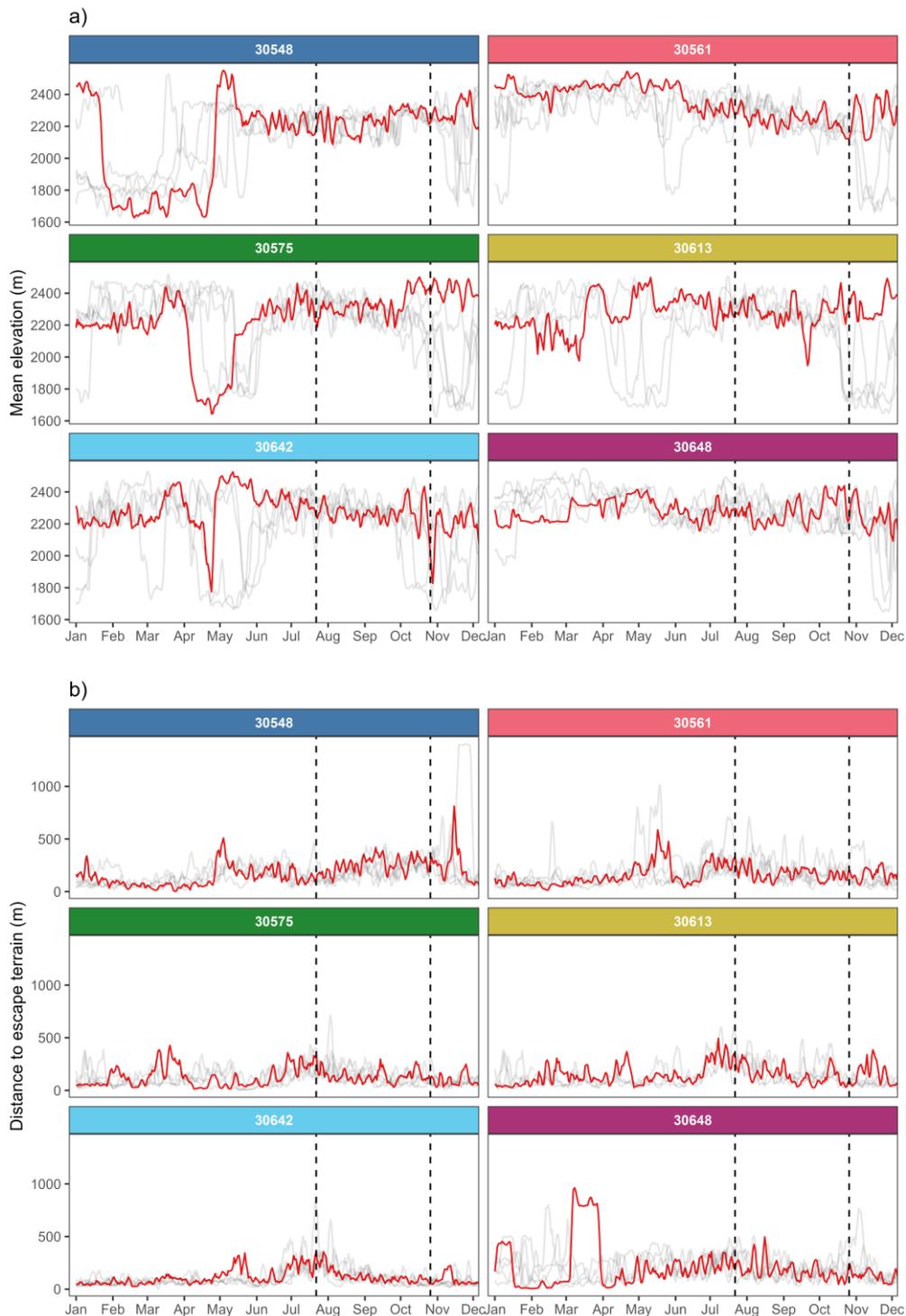
Figure 6. Mountain goat habitat-use from 2019 to 2024 in Cathedral Provincial Park, British Columbia. Results of a sliding window analysis estimating individuals' mean a) elevation, and b) distance to escape terrain across all 6 years (2019-2024). Panel a) shows each mountain goat's mean elevation (m) across all 6 years. Panel b) shows each mountain goat's distance to escape terrain (m) across all 6 years. 'Escape terrain' was defined as locations with a slope greater than 50° (Sarmento and Berger 2020). The red line indicates the year of the Crater Creek wildfire, and the grey lines are all the other years. The black dashed line represents the Crater Creek wildfire period.
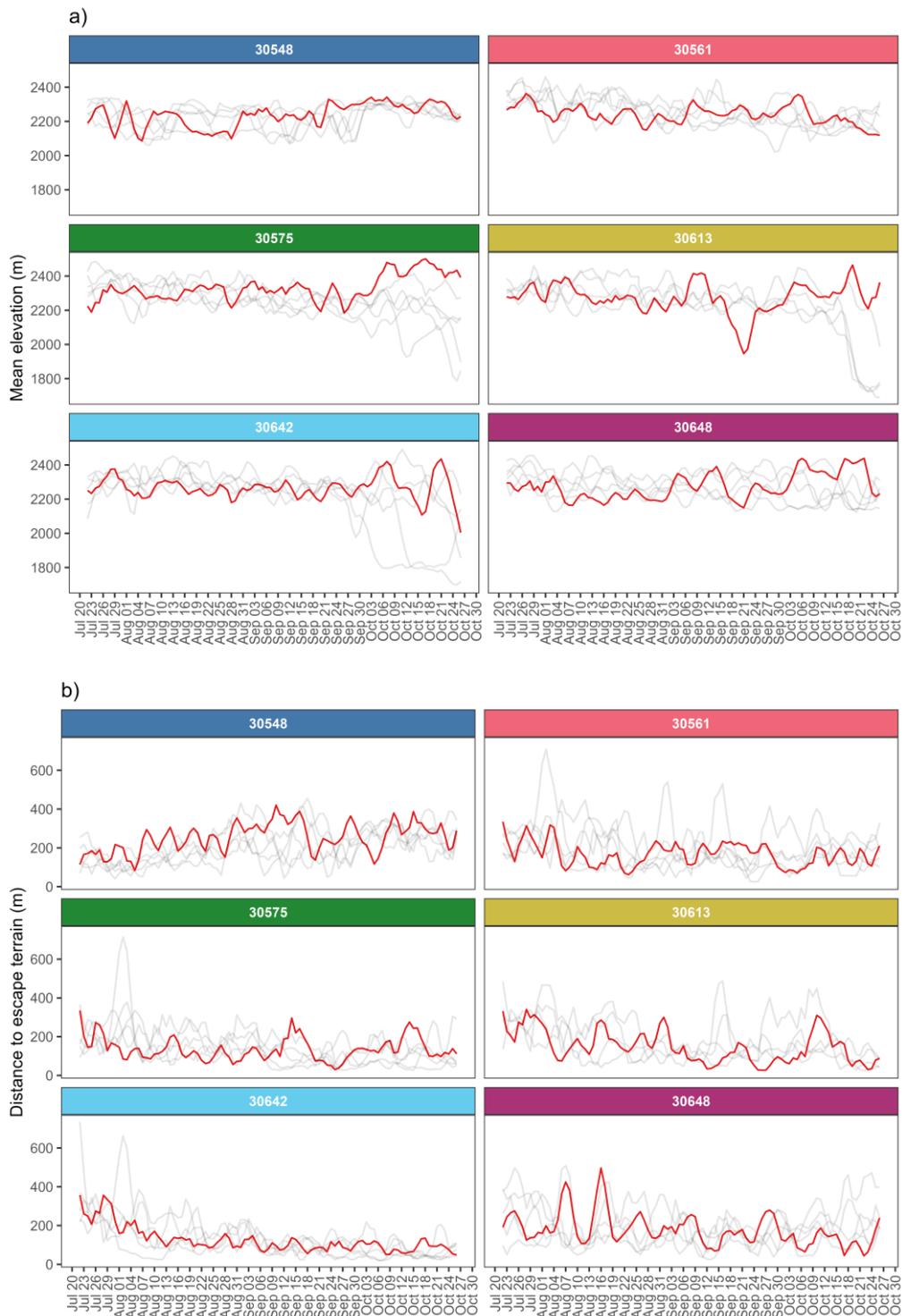
Figure 7. Mountain goat habitat-use during the 2023 Crater Creek wildfire in Cathedral Provincial Park, British Columbia. Results of a sliding window analysis estimating individuals' mean a) elevation, and b) distance to escape terrain during the wildfire period (July 22 to October 26) across all 6 years (2019-2024), with 2023 being the year of the Crater Creek wildfire. Panel a) shows each mountain goat's mean elevation (m) during the Crater Creek wildfire (red line) compared to their elevation in all the other years over the same period (grey lines). Panel b) shows each mountain goat's distance to escape terrain (m) during the Crater Creek wildfire (red line) compared to their distance to escape terrain in all the other years over the same period (grey lines). 'Escape terrain' was defined as locations with a slope greater than 50° (Sarmento and Berger 2020).
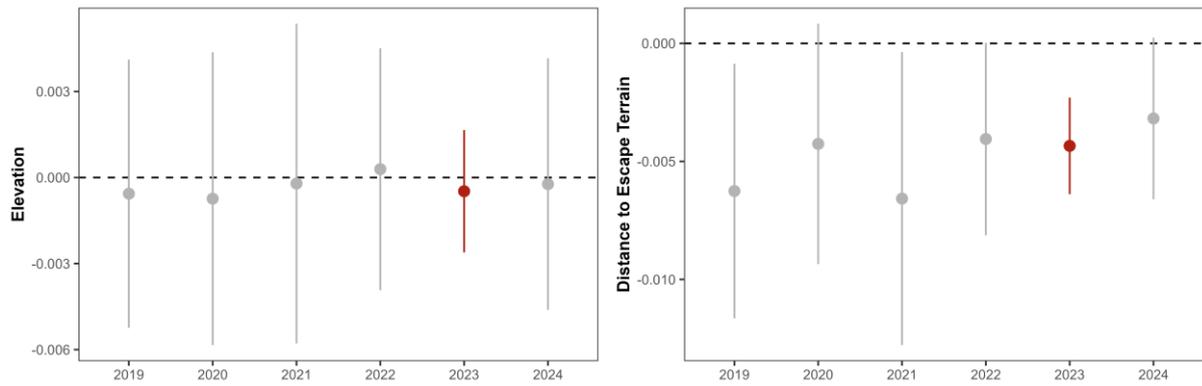
13

Figure 8. Mountain goat habitat selection during the 2023 Crater Creek wildfire in Cathedral Provincial Park, British Columbia, compared to non-fire years. Estimates for parameters used to fit a resource selection function (RSF) to mountain goat home-range size to examine habitat-use patterns based on resource selection Individuals selected for or against the habitat variables according to year. Panel a) shows the elevation coefficient (β) during the Crater Creek wildfire (red point) and all the other years over the same period (grey points). Panel b) shows distance to escape terrain coefficient (β) during the Crater Creek wildfire (red point) and all the other years over the same period (grey points).
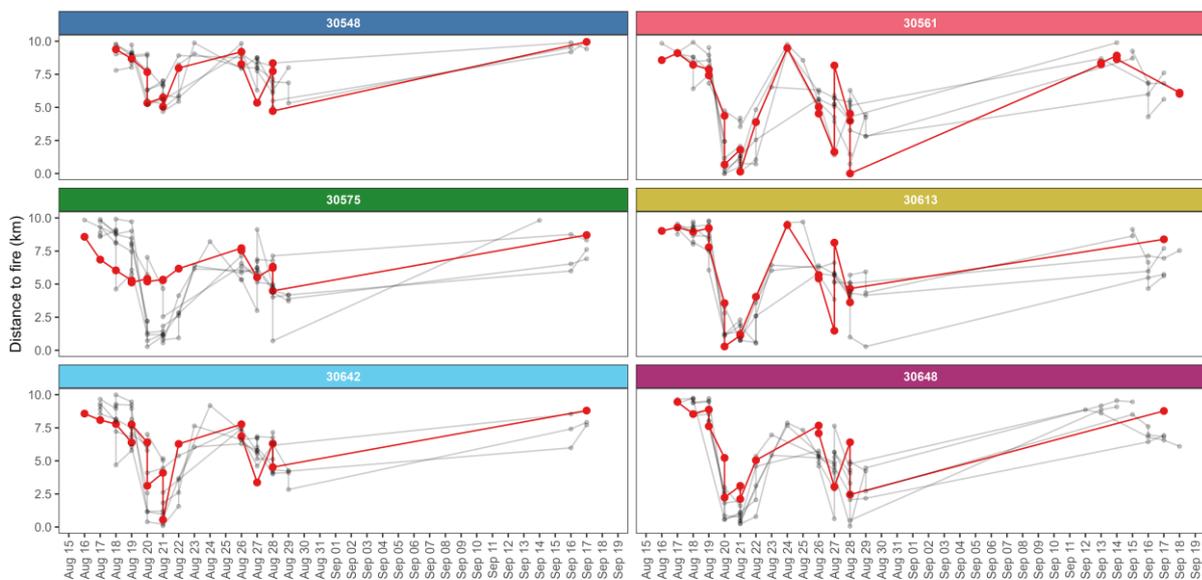

Figure 9 Mountain goat distance over time to the 2023 Crater Creek wildfire perimeter in Cathedral Provincial Park, British Columbia. Euclidean distance was calculated between the GPS position of individuals the Crater Creek wildfire perimeter during the Crater Creek wildfire period (red line) and all the other years of the same period (grey lines). Note the lack of any clear differences between years.

Tables

Table 1. The average home-range size and diffusion rates for 6 mountain goats from July 22 to October 26. The asterisk indicates the year of the Crater Creek wildfire.

Year	Home-range size (km^2)	Home-range 95% CI (km^2)	Diffusion rate (km^2/day)	Diffusion rate 95% CI (km^2/day)
2019	96.76	7.17 - 494.07	0.81	0.39 - 1.51
2020	153.21	5.94 - 1019.23	1.08	0.47 - 2.17
2021	85.26	6.85 - 415.88	0.85	0.46 - 1.46
2022	82.54	9.32 - 350.83	095	0.53 - 1.58
2023*	35.85	7.60 - 111.30	3.13	1.98 - 4.72
2024	85.88	12.75 - 311.01	1.06	0.57 - 1.81