Industrial Disturbances in the Ranges of Two Yukon Caribou Herds Approach Critical Levels

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Abstract

Globally, increased land-use for infrastructure and industry development are among the main drivers of biodiversity decline. In Canada, human-caused disturbances are negatively affecting the prospects for the survival of boreal species such as caribou (*Rangifer tarandus*). In the Yukon, those disturbances are mainly caused by the growth of mining exploration and operation. A previous study was made by Yukon Conservation Society (YCS) in 2022 assessing permitted human disturbances within the Yukon's Clear Creek caribou herd range. That work is developed further in this study, using newly available linear and areal surface disturbance data from GeoYukon to assess the current direct habitat loss and indirect human-caused reduced habitat suitability within the Clear Creek and the Klaza caribou herd ranges. The results of this study are comparatively conservative. However, concerns around the health and survival of the two herds remain real and even severe. It was found that, on average, 41% of the herd ranges are disturbed, compared to the maximum limit of 35% as identified in Canada's recovery plan for boreal woodland caribou, and that linear disturbance densities sometimes exceed $0.1km/km^2$. Further, a slightly larger proportion of the caribou habitat is covered by mining claims, i.e., areas that could potentially be disturbed by mining exploration in the future. This proportion of disturbed to undisturbed range is not consistent with continued survival of boreal and southern mountain woodland caribou herds, it is reasonable to assume it is not consistent with the persistence of northern herds either. I.e., these two herds are probably going to decline in the near future.

Executive Summary

Human activities, particularly land alteration and infrastructure development, are significantly impacting global biodiversity. In Western Canada, the northern mountain woodland caribou (*Rangifer tarandus*) faces considerable threats due to anthropogenic disturbances, particularly from the mineral industry. This study focuses on assessing habitat loss and reduced habitat suitability within the Clear Creek and Klaza caribou herds' ranges in Yukon, Canada.

The research utilizes geospatial data to calculate the proportions of direct and indirect disturbances within designated seasonal and general herd ranges. Direct disturbances refer to surface alterations and densities of linear disturbances, while indirect disturbances encompass the zones of influence (ZOIs) around these alterations, affecting caribou behavior and habitat use.

Results indicate that both caribou herds face notable habitat disturbances. Direct disturbances range from 0.05% to 0.4% of the total range area with 0.06 to 0.2 km/km^2 of linear densities, while indirect disturbances span from 3% to 55%, depending on the ZOI size (0.25 km or 4 km). Additionally, the study examines mining claims within the ranges, revealing significant overlaps, particularly with active quartz mining claims.

The findings suggest that current disturbance levels exceed thresholds recommended for caribou habitat sustainability. Specifically, with the upper ZOI buffer, both herds' habitat disturbance surpasses the critical 35% threshold for survival calculated for the boreal woodland caribou. This raises concerns for the long-term viability of these caribou populations, especially when considering additive natural disturbances like wildfires and climate-mediated events.

In conclusion, this study highlights the urgent need for conservation efforts to mitigate anthropogenic impacts on caribou habitat. It underscores the importance of integrating both direct and indirect disturbances into habitat management strategies to ensure the survival of these iconic species and maintain ecosystem health in the boreal region of Canada.

Introduction

The accelerated rate at which humanity is altering the land and developing infrastructures is one of the main drivers behind the global decline in biodiversity (Benítez-López *et al.*, 2010; Newbold *et al.*, 2015). Whether through their presence or their footprint, humans have major impacts on both the abundance (Benítez-López *et al.*, 2010; Torres *et al.*, 2016) and the behavior of wildlife (Tucker *et al.*, 2018; Wilson *et al.*, 2020). In Western Canada, caribou (*Rangifer tarandus*) is one of the species most susceptible to human disturbances; they are designated as special concern, threatened, or endangered (COSEWIC, 2014). Besides having provided vital sustenance and being of critical cultural importance to First Nations for countless generations (Hare *et al.*, 2004), caribou hold significant importance for the boreal ecosystem, functioning as indicators of environmental health (Environment and Climate Change Canada, 2018). The Yukon is home to 30 caribou herds, 26 of which are designated northern mountain woodland caribou (*R. t. caribou;* Hegel & Russell, 2013). Of the herds whose size has been estimated, the majority are considered stable but vulnerable to increasing human pressure from land use, in particular, the mineral industry (Hegel & Russell, 2013), making their conservation a major and pressing challenge.

In order to direct conservation efforts before their situation deteriorates, we assessed the intensity of habitat loss and reduced habitat suitability from current anthropogenic disturbances within two of the northern mountain woodland caribou herds: the Clear Creek and the Klaza caribou herds. To do so, we calculated the proportions of direct and indirect disturbances with zones of influence (ZOIs) and the density of linear disturbances. A ZOI refers to an area around a disturbance feature where its impact is detectable (Niebuhr *et al.*, 2023) and can result in changes in caribou behavior, including avoidance, displacement, or reduction in habitat use (Boulanger *et al.*, 2012). Depending on factors such as location, season, nature, and use, each disturbance feature can have different levels of effects, which can result in ZOIs of various sizes (Gallagher, 2004). For example, a busy highway would have impacts on a larger area than an unused trail (Gallagher, 2004).

Studies have shown the negative effects of linear features on caribou behavior and space use. Nellemann & Cameron (1998) demonstrated that for the barren-ground Central Arctic Herd located near Prudhoe Bay in Alaska, caribou density was inversely related to road density, where caribou density declined by 63% with road density up to 0.3 km/km^2 and by 86% when between

0.6 and 0.9 km/km^2. This decline in density was probably a consequence of a lower use of foraging habitat near human constructions, leading to a displacement of calving activities and a potential decrease in fecundity (Nellemann & Cameron, 1998). A more recent study of this herd found that habitat use decreased as road density increased in post-calving and mosquito harassment season, but road avoidance also increased during high-traffic periods in all seasons (Severson *et al.*, 2023). Similar results were observed in a wild reindeer population of South-Central Norway, where habitat near linear features was completely abandoned when linear density exceeded 1.3 km/km^2 (Vistnes *et al.*, 2001). In the eastern migratory Rivière-aux-Feuilles and Rivière-George herds in Québec, there was clear evidence of avoidance of roads when linear disturbance density exceeded 0.003 km/km^2 (Plante *et al.*, 2018). While there are no established linear disturbance thresholds for the northern mountain woodland caribou herds (Dickie *et al.*, 2023), we can assume that these population densities are also affected by linear features in the landscape.

Disturbances generally interact with other factors to affect an animal's behavior. The effects of disturbances on caribou vary in intensity in relation to changing seasons, stages of life, habitat quality (Gallagher, 2004), as well as age and sex of individuals (Nellemann *et al.*, 2000). Like most wildlife, caribou use certain geographical areas for specific vital and seasonal functions. Those areas are identified as calving, summer, fall rutting, fall and spring migration, and winter ranges. In this study, we calculated the ZOIs and linear density within the snow-free range, which combines calving, summer, and fall rutting seasons, and the winter ranges along with the general herd ranges.

A previous study (Govindaraj *et al.*, 2022) was conducted by YCS to assess permitted disturbances within the Yukon's Clear Creek Caribou Herd (CCCH), using public information from the Yukon Environmental and Socio-Economic Assessment Board (YESAB), the territorial environmental assessment registry, and spatial data from Yukon Government available at the GeoYukon website. The available spatial data has recently been updated to include mapped existing linear and areal surface disturbances based on imagery from 2009 to 2021 (Table A1). While Govindaraj *et al.* (2022) calculated the area of potential disturbance based on permitted disturbances, the new data allowed us to calculate the actual area of disturbance. Moreover, we had access to the most recent Clear Creek caribou annual and seasonal ranges updated with 2017 to 2019 GPS collar locations and 1997 to 2001 aerial survey and VHF collar locations (K. Russell, personal communication, July 14, 2023). This report therefore improves our knowledge of the situation by assessing and mapping the habitat loss from current anthropogenic disturbances within the Clear Creek herd's updated ranges. Using the same methodology, we assessed current disturbances within the Klaza caribou herd's range, which includes surface disturbances from the early stages of several very large, proposed mining projects as well as those from currently operating and abandoned mines.

Methods

Study area

In the Yukon, there are a total of 26 herds that form a part of the northern mountain population of woodland caribou, including the Clear Creek and the Klaza caribou herds. The Clear Creek herd range is within the traditional territories of the Na-Cho Nyak Dun and the Tr'ondëk Hwëch'in First Nations, east of Dawson City and northwest of Mayo (Figure 1). The Klaza herd range is within the traditional territories of the Tr'ondëk Hwëch'in, Selkirk, White River, Kluane, Little Salmon/Carmacks, and Champagne and Aishihik First Nations, north and west of Carmacks (Figure 1). According to the most recent population survey (2018), the Clear Creek population of about 792 animals is considered to be either stable or slowly declining (Russell *et al.*, 2023). A 2012 survey of the Klaza herd estimated a population of about 1,180 individuals and was considered stable at that time (Hegel, 2013).

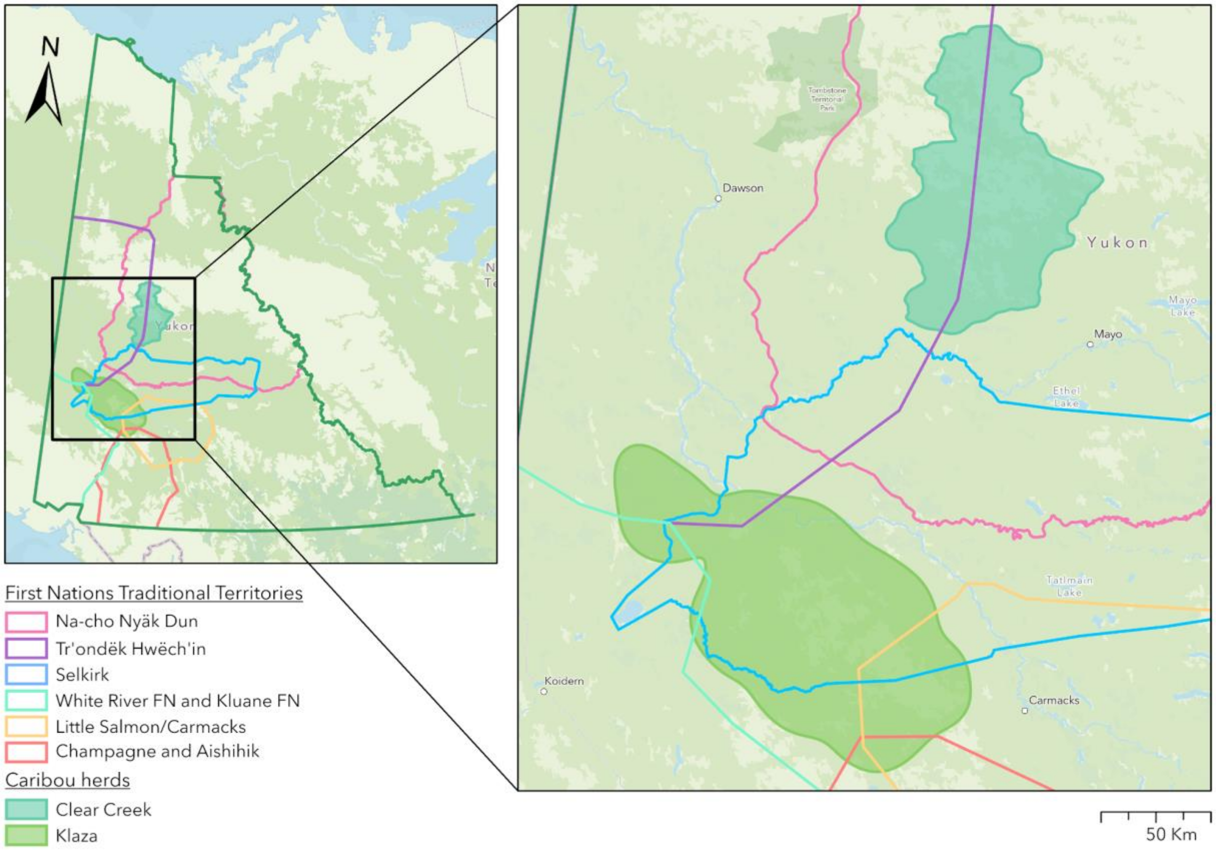

Figure 1. Annual ranges of the Clear Creek and the Klaza caribou herds in central Yukon within First Nations traditional territories. The Clear Creek caribou herd range is within the traditional territories of the Na-Cho Nyak Dun and the Tr'ondëk Hwëch'in First Nations, and the Klaza caribou herd range is within the traditional territories of the Tr'ondëk Hwëch'in, Selkirk, White River, Kluane, Little Salmon/Carmacks and Champagne and Aishihik First Nations.

Disturbance analysis

The area of human/anthropogenic disturbance inside the total annual range was calculated, as well as inside the snow-free and winter ranges (May to October and November to April). The calving, summer, and fall rutting seasons were combined together as the snow-free range since caribou use the same type of habitat during this time of year (Francis & Nishi, 2016). Range boundaries of each caribou herd were obtained with spatial data from several sources: Clear Creek herd annual and seasonal ranges came from 2017 to 2019 GPS collar locations in addition to 1977 to 2001 aerial survey and VHF collar locations (Figure A1, K. Russell, personal communication, July 14, 2023). Klaza herd annual and seasonal ranges were generated using 2012-2019 GPS collar locations (Figure A2, K. Russell, personal communication, March 4, 2024). All range area calculations were performed using the ‘measure feature’ tool in ArcGIS pro 3.0.3 (ESRI, 2011) mapping software. The annual, snow-free, and winter ranges of the Clear Creek caribou herd are respectively 7,557 km^2, 2,968 km^2, and 2,673 km^2 (Figure 2a). Klaza caribou herd areas are 12,496 km^2, 6,394 km^2, and 4,464 km^{2,} respectively (Figure 2b).

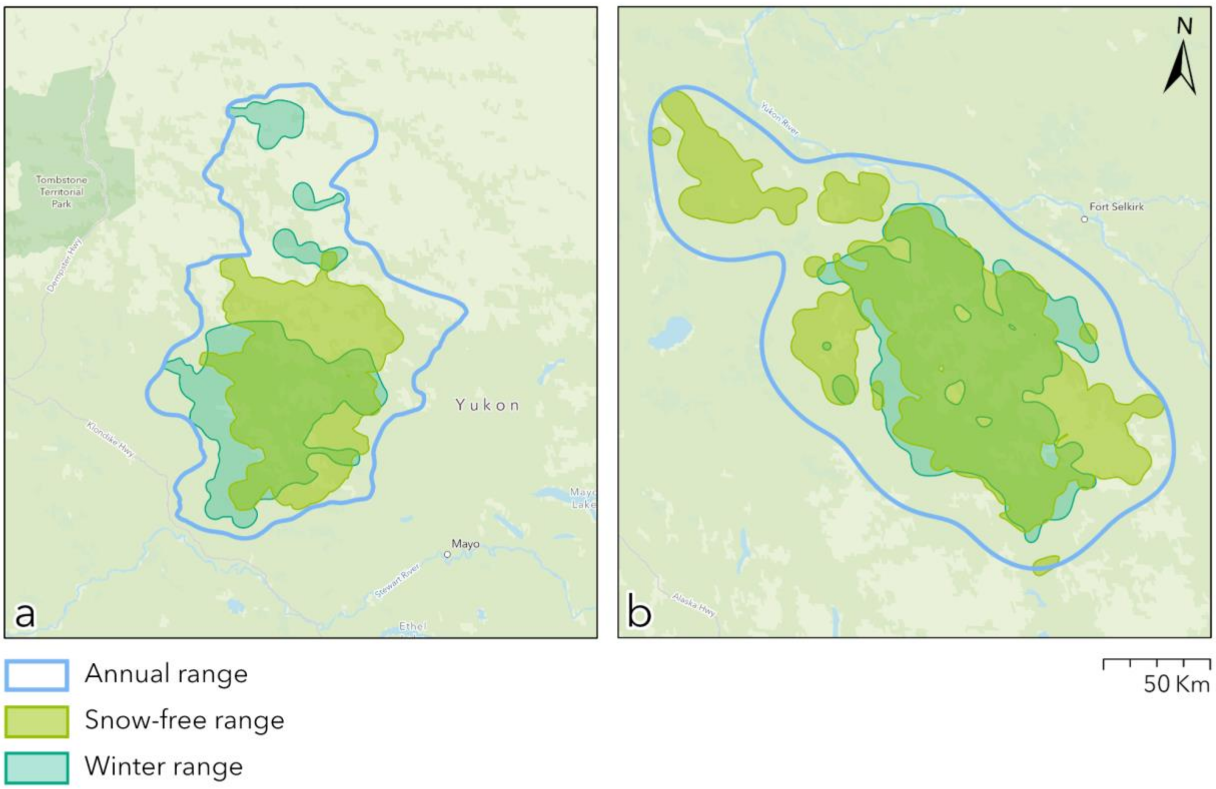

Figure 2. Seasonal ranges within the: a) Clear Creek and the b) Klaza caribou herd annual ranges (indigo). Green polygons represent the snow-free range (calving, summer, and fall rutting seasons), and teal represents the winter range. Both maps have the same scale.

The footprint of human activities was estimated by calculating the proportion of surface disturbances within the Clear Creek and the Klaza herd ranges. To do so, we used the 2009-2021 surface linear and areal disturbance features made available in 2021 (Table A1, Powell, 2023), which comprise mining-related disturbances, including cutlines, trenches, all types of roads and trails, drill pads, gravel pits, camps, mining sites, etc. Each feature represents either a line or a polygon with a corresponding measurement (length or area). The ArcGIS ‘clip’ tool allowed for the separation of all disturbances within each range type. The measurements obtained were then exported in an Excel sheet for calculation purposes. We calculated the total length (km) of linear disturbances by adding together all the length measurements and the total area (km^2) of disturbances by multiplying linear features by their width and adding them to the area measurements. We then calculated the proportion of direct disturbance by dividing its total area by the range area and the linear disturbance density by dividing the total length by the range area.

Spatial data allows for direct caribou habitat loss assessment but does not address the indirect anthropogenic disturbances of ZOIs. We thus applied a low and high buffer zone around each of the linear and areal disturbances to allow calculation of a range of areas where a variety of caribou behaviors can be altered, up to and including avoidance by caribou. When applying the buffer using the 'buffer' tool in ArcGIS, the dissolve parameter was selected, which creates a single feature and removes any overlap. To be consistent with the 2022 report and with the original science used to establish these values, the same low and high ZOIs values were kept, i.e. 0.25 km and 4 km (Francis & Nishi, 2016). The areas of the lower and upper buffers were obtained with the 'measure feature' tool, and the corresponding proportions of disturbed areas within each range type were therefore calculated by dividing the buffer zone area by the range area. To avoid any double-counting when calculating the total indirect disturbances, the 'combine' and the 'merge' tools were used to create a new layer. As the spatial data do not allow the identification of the majority of disturbances by type of mining activity, we decided to combine anthropogenic, quartz, and placer-related disturbances in each ZOI calculated.

To visualize potential future disturbances, the proportion of claims (active and pending) for each type of mining activity (quartz and placer) within the ranges of both herds were calculated using the Government of Yukon's mining claims data (Government of Yukon, 2023) and the 'clip' tool to separate claims within each range type. The measurements were then exported in an Excel sheet. The proportions of quartz and placer claims for each status (active and pending) within each range were calculated by dividing the claim area by the range area.

Results

The Clear Creek caribou herd faces the most disturbances during winter: 0.4% of the winter range is directly disturbed, while between 7 and 55% is indirectly disturbed, depending on the ZOI calculated (0.25 and 4 km, Table 1). The linear density is about 0.2 km/km^2. Disturbances are least frequent in areas where caribou spend their time outside of winter, such as during calving, summer, and fall rutting (snow-free). Here, direct disturbances are 0.1%, and indirect disturbances range from 4 to 40%, with a linear density of 0.08 km/km^2.

In contrast, the Klaza caribou herd experiences the highest level of disturbances throughout their annual and snow-free range: 0.2% of the snow-free range is directly disturbed, while indirect disturbances span from 4 to 39% depending on the ZOI calculated (0.25 and 4 km, Table 1). The corresponding linear density is 0.1 km/km^2. The lowest disturbance levels occur during the winter, with direct disturbance at 0.05% and indirect disturbances ranging from 3 to 34%. Here, the linear density measures 0.06 km/km^2.

Table 1. Proportions of area directly and indirectly disturbed and linear density in the annual, snow-free, and winter ranges of the Clear Creek and the Klaza herd. Results were calculated using the Government of Yukon's surface linear and areal disturbance features data. Lower (0.25 km) and upper (4 km) buffer zones, representing the ZOIs, were applied to linear and areal disturbance features using ArcGIS 'buffer' tool.

Herd	Range type	% area disturbed	% area disturbed (lower bound)	% area disturbed (high bound)	Linear density (km/km^2)
Clear Creek	Annual	0.2	4.2	38.2	0.2
	Snow-free	0.1	3.8	39.1	0.08
	Winter	0.4	7.0	55.2	0.2
Klaza	Annual	0.3	4.7	39.9	0.1
	Snow-free	0.2	3.5	38.9	0.1
	Winter	0.05	2.5	33.7	0.06

Active quartz mining claims outweigh active placer mining claims in the Clear Creek caribou herd ranges. Active quartz claims cover 13 to 22% of all ranges, while active placer claims cover 2 to 3%. Pending quartz mining claims cover less than 0.4% of all ranges, with no pending placer claims within the herd range (Table 2). Similarly, in the Klaza caribou herd ranges, active quartz mining claims surpass active placer mining claims. Active quartz claims range from 14 to 25% of all ranges, while active placer claims cover 1 to 3%. Pending mining claims are below 0.3% for all ranges, and there are no pending quartz placer claims within the Clear Creek herd range (Table 3).

Table 2. The claim footprint and proportions of the quartz and placer mining claim according to their status (active and pending) within each range of the Clear Creek caribou herd.

Range type	Range area (km^2)	Status	Mining	Claim footprint area (km^2)	% of range staked
Annual	**7 557**	Active	Quartz	998.4	13.2
			Placer	121.9	1.6
		Pending	Quartz	12.6	0.2
			Placer	0	0
Snow-free	**2 397**	Active	Quartz	386.7	16.1
			Placer	70.0	3.0
		Pending	Quartz	8.6	0.4
			Placer	0	0
Winter	**2 673**	Active	Quartz	582.2	21.8
			Placer	80.0	3.0
		Pending	Quartz	9.3	0.4
			Placer	0	0

Table 3. The overlap areas and proportions of the quartz and placer mining claim according to their status (active and pending) within each range of the Klaza caribou herd.

Range type	Range area (km^2)	Status	Mining	Overlap area (km^2)	% of range staked
Annual	**12 496**	Active	Quartz	2883.7	23.1
			Placer	323.3	2.6
		Pending	Quartz	0	0
			Placer	16.3	0.1
Snow-free	**6 394**	Active	Quartz	1566.1	24.5
			Placer	183.6	2.9
		Pending	Quartz	0	0
			Placer	16.0	0.3
Winter	**4 464**	Active	Quartz	629.4	14.1
			Placer	62.0	1.4
		Pending	Quartz	0	0
			Placer	0.05	0.001

Discussion

The objective of this study was to assess direct habitat loss and indirect reduced habitat suitability within the Clear Creek and the Klaza caribou herd ranges using newly available disturbance data as well as the most recent Clear Creek and Klaza herd's range data from K. Russell (personal communication, July 14, 2023, March 4, 2024). It allowed for adjusting the results obtained in the 2022 report (Govindaraj *et al.*, 2022) and adding new knowledge about the Klaza caribou herd.

Zones of influence

We used high and low buffer ZOIs to evaluate the proportion of human-caused disturbances and to reflect effective caribou habitat loss within the Clear Creek and the Klaza caribou herds. We found that the proportions of indirect disturbances constitute a concern for the future of both herds. While the results obtained with the lower buffer (0.25 km) indicate that, on average, 4% of the habitat of both herds (annual and seasonal ranges included) is disturbed, the results for the upper buffer (4 km), show that on average 41% of the habitat of both herds is disturbed. The current metrics for boreal populations of woodland caribou (no metric has yet been calculated for northern mountain woodland caribou, we employ it in this context as it represents the only available measure at present) require that 65% of its habitat must remain undisturbed (35% disturbance) for a population to have a 60% chance of survival (Environment Canada, 2012; Environment Canada, 2014). While this threshold has not been exceeded in any ranges with the low buffer ZOI, it has been exceeded in both annual and snow-free ranges, especially in the Clear Creek winter range, with the upper buffer ZOI (Table 1). Furthermore, this threshold includes all types of disturbances (Environment Canada, 2011). Given that we have found that direct and indirect anthropogenic disturbances alone already exceed the 35% disturbance threshold, it seems highly likely that the addition of natural disturbances such as recent fires (Environment Canada, 2011) and climate-mediated landslides will push the proportion of disturbance even further past the 35% threshold. Indeed, a study found that wildfires were the major source of habitat loss for the boreal and northern mountain caribou in Alberta and British Columbia (Nagy-Reis *et al.*, 2021), meaning that all types of disturbances must be considered.

In the Clear Creek caribou herd, the winter range witnesses higher disturbances than the snow-free range. Conversely, in the Klaza herd, disturbances are slightly more pronounced in the snow-free period compared to winter. Mountain woodland caribou exhibit distinct habitat preferences across these two periods (Francis & Nishi, 2016; MacNearney *et al.*, 2016; Theoret *et al.*, 2022). During the snow-free season, they prefer alpine and subalpine habitats but then migrate to lower altitudes in forested areas for wintering (Francis & Nishi, 2016). This behavioral pattern characterizes them as partially migratory, capable of traveling short distances, an average of fifty kilometers, to transition between summer/fall and winter habitats (Theoret *et al.*, 2022). However, anthropogenic habitat degradation in seasonal areas can prompt behavioral shifts, leading some individuals to become residents, confining themselves to a specific location year-round (Williams *et al.*, 2021). This strategy can be suboptimal as it may compel individuals to use habitats of lower quality, resulting in decreased survival prospects (Johnson *et al.*, 2015). For example, with more severe disturbances at lower altitudes, individuals may alter their behavior to avoid such areas, favoring higher elevations during winter (MacNearney *et al.*, 2016). Disturbances do not have the same effects in all seasons. For instance, in winter, inaccessible roads result in fewer levels of human activity, hence lower impacts on caribou (Francis & Nishi, 2016). In our case, disturbances exceed the 35% threshold across all snow-free ranges. This indicates that although the winter season may be relatively calm, snow-free periods remain significantly disturbed and can affect migratory behaviors. The potential addition of all-season roads in those ranges may also increase concerns in the future (Francis & Nishi, 2016).

While applying ZOIs is a useful tool in evaluating the potential impacts of human infrastructure on caribou behavior or displacement, two approaches to calculating ZOIs lead to different results (Figure 3).

First, consider that anthropogenic disturbances can be caused by a variety of infrastructure, such as a house or a road, which are often represented on maps by spatial units such as points, polygons, or lines (Niebuhr *et al.*, 2023). ZOIs are commonly expressed as the radius of a circle with the disturbance feature as its center (Figure 3; Niebuhr *et al.*, 2023). In this study, we used buffers to estimate the ZOIs around linear and areal features. This first approach only considers the distance to the nearest feature, which means that it does not account for cumulative impacts of overlapping ZOIs (Figure 3a; Niebuhr *et al.*, 2023). Cumulative impacts of overlapping ZOIs are more severe because their effects are additive (Niebuhr *et al.*, 2023). For example, a single, isolated house will not only have a smaller ZOI than a road lined with multiple houses, but if the homes are close enough so that their ZOIs overlap, the areas with overlapping ZOIs will have more severe effects on caribou than separate ZOIs that do not interact (Figure 3b; Niebuhr *et al.*, 2023). Accounting for the cumulative, overlapping ZOI of multiple features is thus an approach that considers how interactions between more than one feature have the potential to lead to more severe impacts (Niebuhr *et al.*, 2023). Because we only used ArcGIS Pro tools, we decided not to quantify the additive effects of overlapping ZOIs.

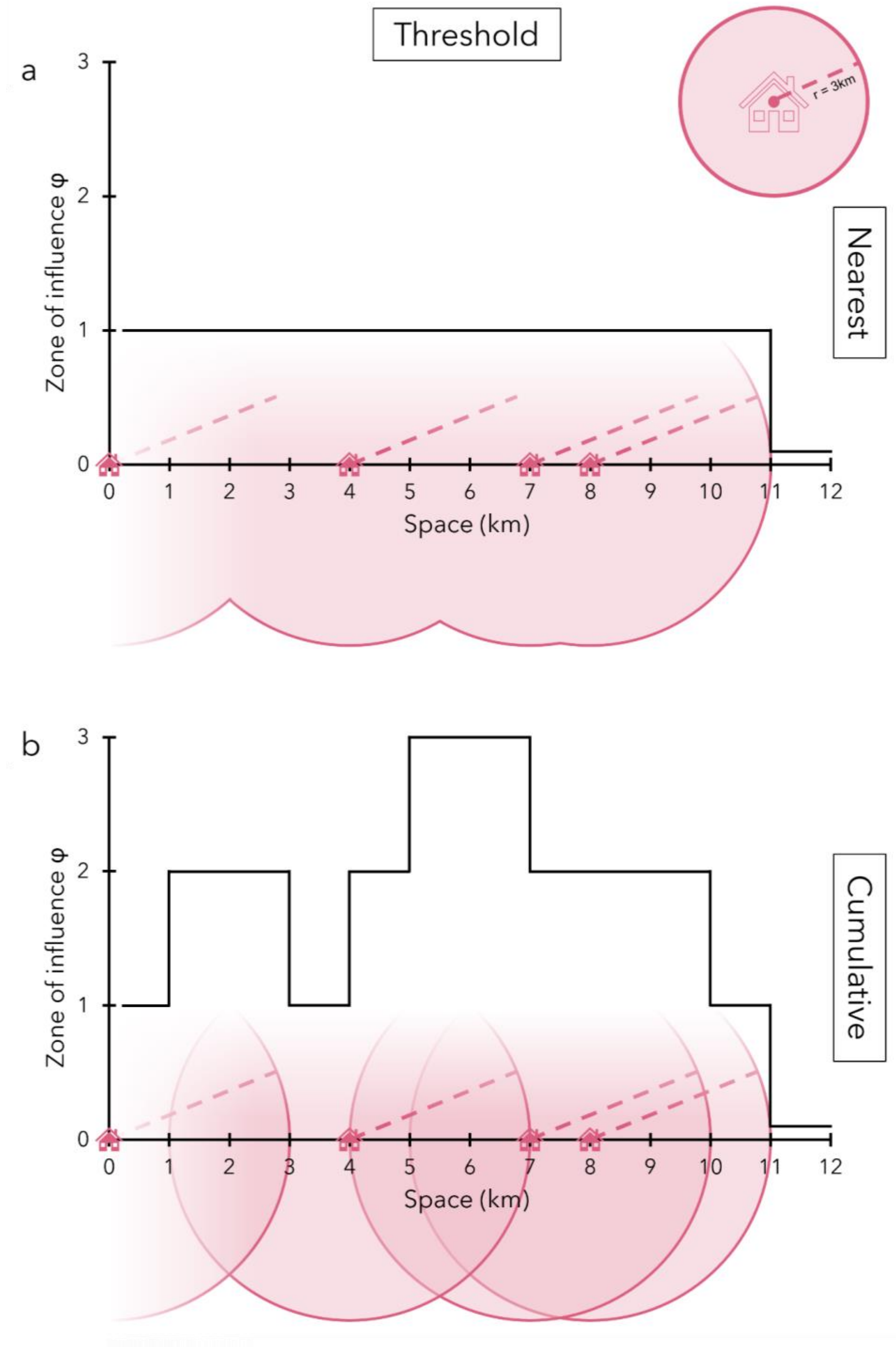

Figure 3. Two approaches to evaluating the ZOI of multiple features (houses): the distance to the nearest feature where the areas around the feature merge together and the cumulative ZOI of multiple features where the areas around the feature stack one on top of the other.

Note. Adapted from Estimating the cumulative impact and zone of influence of anthropogenic features on biodiversity, by Niebuhr *et al.*, 2023, *Methods in Ecology and Evolution*, p. 4

In both herds, linear and areal disturbances are concentrated in the southern, northern and eastern parts of the ranges (Figure 4 and 5). Thus, the upper buffer ZOI, which already exceeds the sustainability threshold, likely underestimates the real, additive cumulative impacts of overlapping ZOIs in key caribou habitats. Moreover, the buffer ZOIs that ranged from 0.25 km to 4 km, were chosen to follow the Francis and Nishi (2016) study. Those numbers are rather conservative, considering that, depending on factors such as the disturbance type and the environment, the distance of caribou avoidance or displacement can be up to 10 km (Francis & Nishi, 2016). Given that the 4 km threshold is conservative and does not include the adverse cumulative effects of clustered disturbances, we consider that this distance should be the established threshold used for impact assessment of future mining exploration and activation.

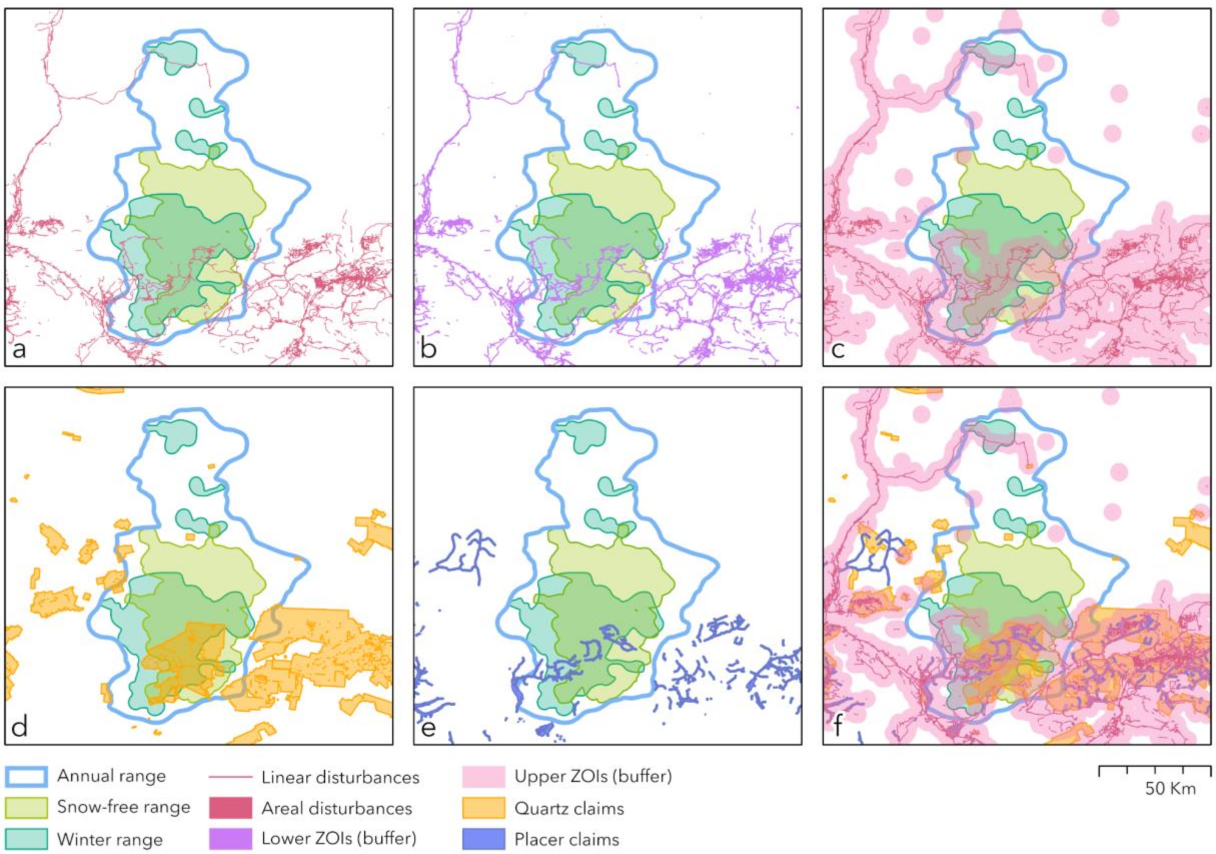

Figure 4. Annual range of the Clear Creek caribou herd, including its snow-free and winter ranges and its main disturbances: a) linear and areal surface disturbances, b) lower ZOIs (0.25 km buffer), c) linear and areal disturbances and their upper ZOIs (4 km buffer), d) quartz claims, e) placer claims and f) all disturbances, buffers, and claims.

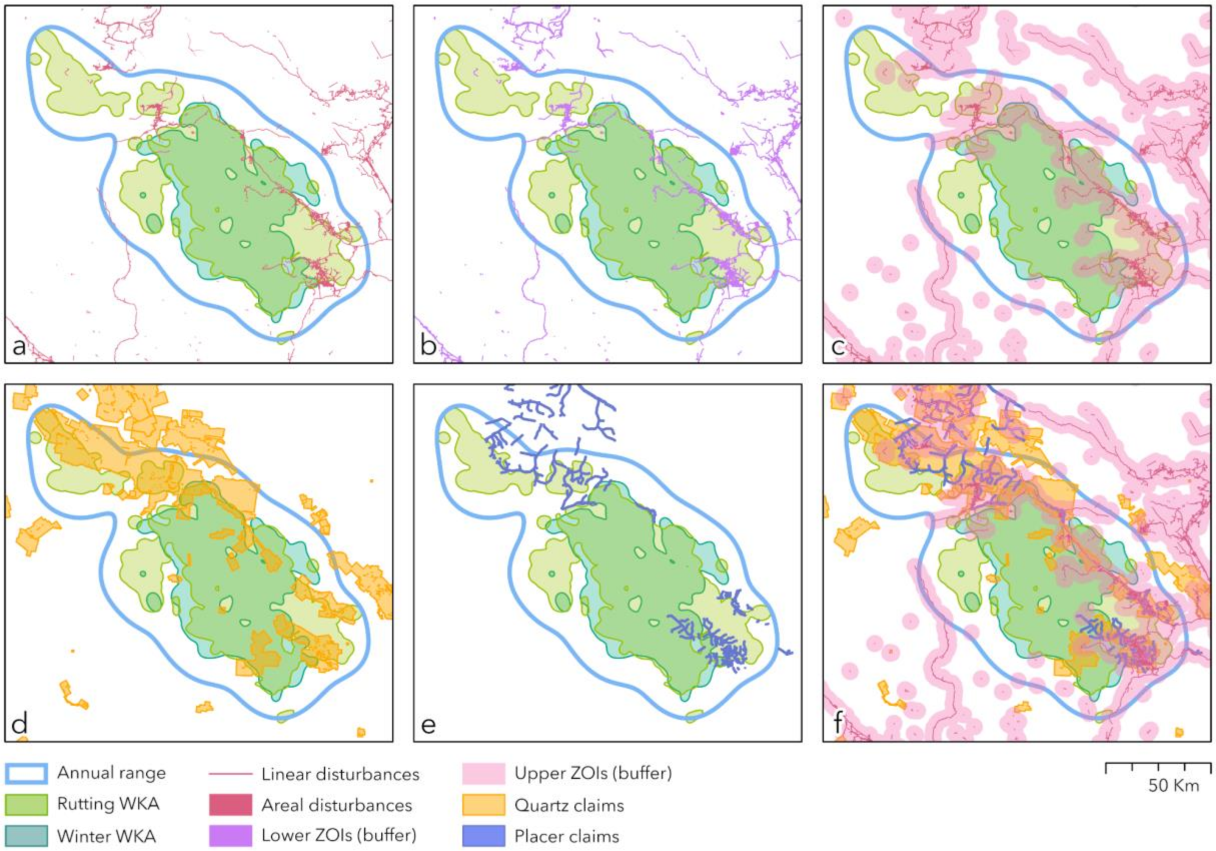

Figure 5. Annual range of the Klaza caribou herd, including its snow-free and winter ranges and its main disturbances: a) linear and areal surface disturbances, b) lower ZOIs (0.25 km buffer), c) linear and areal disturbances and their upper ZOIs (4 km buffer), d) quartz claims, e) placer claims and f) all disturbances, buffers, and claims.

Linear density

We found that linear density for all ranges of both caribou herds is between 0.1 and 0.2 km/km^2. Nellemann and Cameron (1998) showed that caribou density is inversely related to road density, where caribou density declines by 63% with a road density of up to 0.3 km/km^2 and by 86% when between 0.6 and 0.9 km/km^2. Caribou density is thus affected when linear features such as roads or trails are present in their habitat. In the case of the Clear Creek and the Klaza herds, road density has approached 0.3 km/km^2 in some of the ranges, which is a concern and will become a bigger concern if mining projects continue to expand and lead to the creation of new linear disturbances.

Linear features can also lead to habitat fragmentation (Environment Canada, 2012). In many species, habitat fragmentation reduces gene flow and genetic diversity and can lead to inbreeding depression (lower survival and fertility; Loxterman, 2011; Rivera-Ortíz *et al.*, 2015). However, this lack of connectivity in boreal caribou populations was linked to a decline in population size related to their reduced ability to utilize their entire range, especially important in fire disturbance-dominated boreal forests (Environment Canada, 2012).

Quartz and placer mining claims

In addition to the actual disturbances, the proportion of mining claims within the different ranges was estimated. Even though they are at different stages of approval (pending or active), they represent zones that could eventually be used for future mining projects. Already approved claims account for a non-negligible proportion of the snow-free and winter range. Some of the actual disturbances overlap the estimated mining claims, but portions of yet undisturbed claims area could eventually be used for exploration or mining and added to the list of disturbances. In addition, some of the permitted disturbances we used in the CCCH report (see Govindaraj *et al.*, 2022) may not have resulted in the mapped disturbance. In other words, additional disturbances to those used in this report have been permitted and could be created at any time.

Conclusion

The aim of this study was to assess the direct human-caused habitat loss and the indirect habitat suitability loss within the Clear Creek and the Klaza caribou herds using current and accurate disturbance data. The results showed that the proportion of disturbances (ZOIs and linear density) within each range is a cause of concern for the natural survival of both herds. Indirect disturbances account for a great proportion of the habitat and exceed the sustainable threshold for herd survival. The approach taken to estimating disturbance was conservative in that we used a small range of potential ZOIs and did not calculate additive cumulative effects. However, it is clear that all the disturbance features combined together account for much stronger cumulative effects. Caribou behavior and displacement can also be affected by habitat quality (Gallagher, 2004) and natural disturbances such as wildfire (Environment Canada, 2012, 2014), which was not taken into account in this study.

Considerable portions of most caribou herd ranges are still being actively explored by mineral companies (Hegel & Russell, 2013), and each year, disturbance accumulates while more claims are being staked. Meanwhile, it can take decades before habitat recovers and foraging areas are restored (Lee & Boutin, 2006), and it is important to remember that reclaimed disturbances remain disturbances from a caribou perspective (Ray, 2014). This study thus brought into focus the urgent need for current caribou herd range assessments and key habitat protection. While we had access to the ranges and spatial data for both the Clear Creek and the Klaza caribou herds, many Yukon herds do not have recent population estimates, or data are not publicly available (K. Russell, personal communication, January 19, 2024). This lack of data makes it difficult to conduct a rigorous environmental assessment of large-scale projects.

Two important parts of recovering caribou populations are habitat restoration and protection (Schneider *et al.*, 2010). Some studies have shown that restoring old trails and roads positively affects caribou (Schneider *et al.*, 2010; van Rensen *et al.*, 2015; Pigeon *et al.*, 2016). A linear feature takes time to restore naturally (Lee & Boutin, 2006), especially if it has been used several times as the soil has been well compacted and the vegetation damaged (Lee & Boutin, 2006; van Rensen *et al.*, 2015). In that case, restoring old unused trails and roads might help reduce their negative impacts on caribou, such as avoidance (Boulanger *et al.*, 2012), easy access for predators (Latham *et al.*, 2011), and humans, habitat fragmentation (van Rensen *et al.*, 2015), and habitat loss (Dyer *et al.*, 2001). However, this strategy can be long and expensive (Lee & Boutin, 2006; van Rensen *et al.*, 2015) and, therefore, should be done along with habitat protection because new trails and roads will be created as long as the minerals industry continues (Schneider *et al.*, 2010). Creating protected areas where land disturbance is not allowed is an established method of preventing habitat loss and decline in caribou populations (Schneider *et al.*, 2010), along with land use planning as a tool for better adapting to fluctuations in population ranges. That said, it is important to select key caribou habitats where disturbances have the most impact on the species' survival to identify effective protected areas and to inform land use planning.

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Appendix

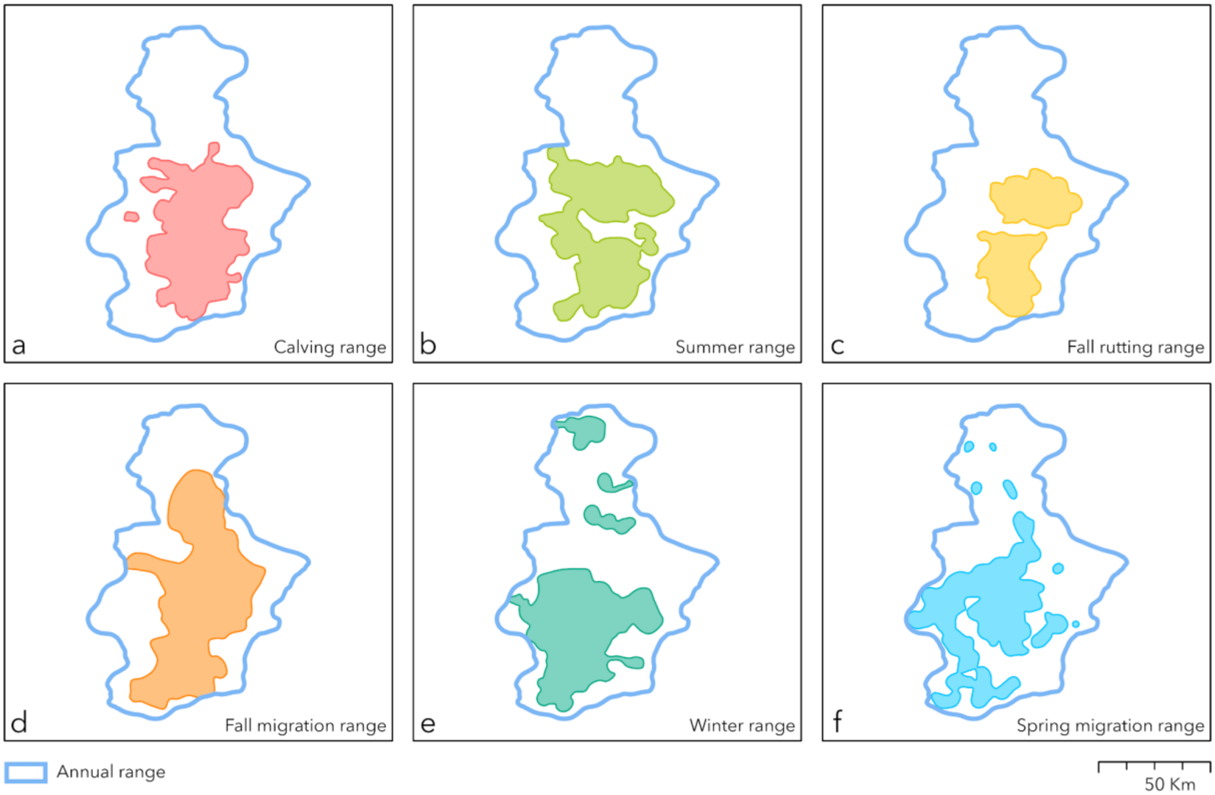

Figure A1. Different seasonal ranges within the Clear Creek annual range. In this study, we only used a) calving, b) summer, and c) fall rutting seasons as the snow-free range and e) winter range.

The calving range is from May 17 to June 16, the summer range is from June 17 to September 17, the fall rutting range is from September 18 to October 6, the Winter range is from December 6 to April 11, the spring migration range is from April 12 to May 16, and the fall migration range is from October 7 to December 5.

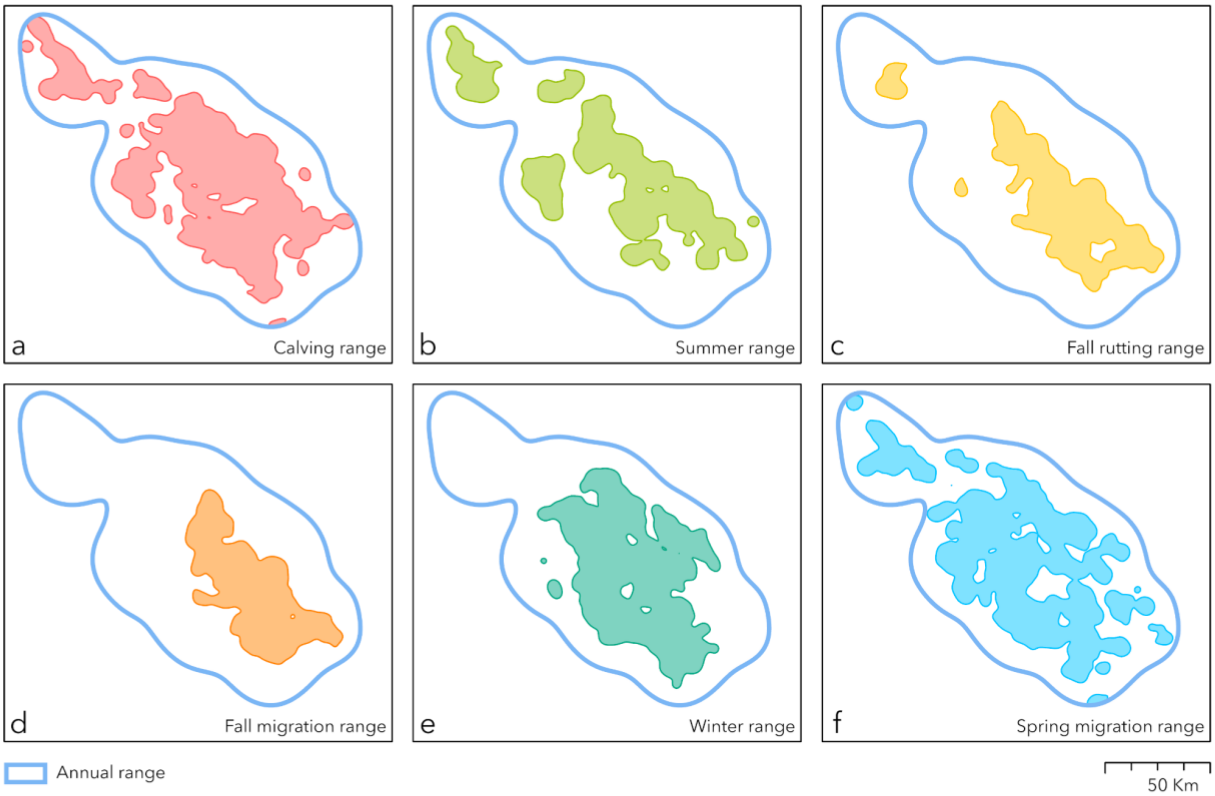

Figure A2. Different seasonal ranges within the Klaza annual range. In this study, we only used a) calving, b) summer, and c) fall rutting seasons as the snow-free range and e) winter range.

To generate the annual and seasonal ranges, we used the R package 'adehabitatHR' with the 2012-2019 GPS radio-collar location provided by the Yukon Government (K. Russell, personal communication, March 4, 2024). The data were subsampled by randomly selecting one location per animal per day (Hegel & O'Donoghue, 2015). We determined smoothing parameters (h) by adjusting the href from Hegel & O'Donoghue, 2015 to better fit the spatial data. The annual range was generated with all locations (n = 23 151, 42 animals) with a smoothing parameter of h = 8000. Seasonal ranges were all generated with different dates, and h = 2000. The calving range was generated with locations from May 1st to June 14 (n = 2344, 37 animals), the summer range was generated with locations from June 15 to September 10 (n = 4258, 35 animals), the fall rutting range was generated with locations from September 11 to October 31 (n = 3036, 39 animals), the winter range was generated with locations from November 1st to April 30 (n = 13513, 42 animals), the spring migration range was generated with locations from April 15 to May 15 (n = 1901, 39 animals), the fall migration range was generated with locations from October 15 to November 30 (n = 3130, 40 animals).

Table A1. Year of imagery data for each disturbance type, range, and herd.

Disturbance type	Range	Clear Creek	Klaza
Linear	Annual	2013, 2015-2017, 2019, 2021	2009, 2011-2014, 2019
	Snow-free	2013, 2015-2017, 2019	2011-2013, 2019
	Winter	2013, 2015-2017, 2019	2011-2013
Areal	Annual	2015-2020	2012-2013, 2019
	Snow-free	2015, 2017-2020	2012-2014, 2019
	Winter	2015, 2018-2019	2012-2013