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Human disturbance effects and cumulative habitat loss in endangered migratory caribou

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ABSTRACT

As human development intensifies in northern ecosystems, negative impacts of anthropogenic disturbances on wildlife could increase. Many caribou and reindeer populations are declining across the northern hemisphere, and human disturbances have been suggested as a potential cause for these declines. We evaluated the effects of human disturbances in the summer and winter ranges of two migratory caribou herds in northern Québec and Labrador, Canada. We captured and collared 510 caribou between 2009 and 2015. We first assessed caribou avoidance of human disturbances at a large spatial scale by comparing the density of mines, mining exploration sites, power lines, roads and human settlements within seasonal ranges to their density within available ranges. We estimated the area avoided by caribou (ZOI; zone of influence) around disturbances located within seasonal ranges and evaluated the resulting cumulative habitat loss. We also evaluated the barrier effect of roads and their influence on caribou movement rates. The density of many disturbance types was lower within caribou seasonal ranges than within available ranges, suggesting they avoided disturbances over a large spatial scale. Within seasonal ranges, caribou avoided all disturbance types except power lines. ZOIs were highly variable among disturbance types and years, ranging from no avoidance to 23 km. Cumulative habitat loss could reach as much as 30% of seasonal ranges and 38% of high-quality caribou habitat. We demonstrate that human disturbances have broad negative effects on caribou behavior, but whether this could translate into population decline remains to be investigated.

1. Introduction

Human disturbances are encroaching wildlife habitat at an unprecedented rate, especially in northern ecosystems where mining, oil and gas industries are expanding (UNEP, 2001). Adverse effects of human disturbances may affect wildlife distribution, population dynamics, and ability to thrive in changing environments (Trombulak and Frissell, 2000; UNEP, 2001). As many wildlife populations decline, effects of human disturbances on behavior and vital rates are increasingly investigated (Johnson and St-Laurent, 2011).

Human disturbances are generally non-lethal, but can cause risk-averse responses which could lead to fitness costs for animals (Frid and Dill, 2002). These responses have been reported at multiple spatio-temporal scales (Benítez-López et al., 2010; Fahrig and Rytwinski, 2009), ranging from increased vigilance over short periods of time and flight movements of a few meters (Benhaiem et al., 2008; Côté, 1996; Hansen and Aanes, 2014), to avoidance over several km or even desertion of disturbed areas (Harju et al., 2010; Hovick et al., 2014). Disturbances can also disrupt migration routes (Seidler et al., 2015), increase movement rates (Dussault et al., 2007) or delay crossing of linear infrastructures (Wilson et al., 2016), potentially increasing energy expenditure or reducing the time animals spend in suitable habitat. It can also prevent animals from reaching portions of their range (Sawyer et al., 2013), or maintaining synchrony with vegetation availability (Lendrum et al., 2013). The energetic costs of risk-averse responses and habitat loss caused by avoidance may appear insignificant for a single disturbance. At the scale of the animal lifetime or range, however, repeated risk-averse responses and cumulative habitat loss resulting from the avoidance of all disturbances encountered by the animal may be considerable (Bradshaw et al., 1998; Dyer et al., 2001). As negative effects of disturbances accumulate, they may reach a critical point where consequences are observed on fitness, survival and population dynamics (Johnson and St-Laurent, 2011).

Human disturbance was suggested to contribute to the generalized

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decline of caribou and reindeer (*Rangifer tarandus*) across northern regions (Vors and Boyce, 2009). These ungulates could be particularly sensitive to human disturbances and their cumulative effects because of their broad distribution and long-ranging movements (Bergerud et al., 2008). They are reported to consistently avoid human disturbances such as cabins (Polfus et al., 2011), roads (Leblond et al., 2013), resorts (Nellemann et al., 2010), human settlements (Anttonen et al., 2011), and mines (Boulanger et al., 2012). Avoidance of disturbances by caribou and reindeer were found to range from ≤1 km (roads; Dussault et al., 2012; Dyer et al., 2001) to 14 km (diamond mine; Boulanger et al., 2012). Linear features, such as roads, are also known to alter caribou movements or compromise access to portions of their range (Leblond et al., 2013; Wilson et al., 2016). For example, Leblond et al. (2013) showed that 77% of individuals in a forest-dwelling caribou population did not cross a highway, resulting in a potential loss of > 50% of their range and limiting their access to protected areas. In the same study, caribou willing to cross the highway showed increased movement rates within 5 km of the roadway, potentially reducing time spent in risky habitat. Although human disturbances have unequivocal effects on caribou and reindeer behavior and habitat use, quantifying cumulative effects remains a challenge (Gunn et al., 2011).

The study of habitat selection constitutes a powerful tool to assess individual and cumulative effects of human disturbances on wildlife. Distinguishing disturbance effects from environmental effects can, however, be challenging due to their confounding influences on habitat use (Boulanger et al., 2012). If a disturbance is located in low-quality habitat, for example, it may be difficult to determine whether animals are avoiding low-quality habitat or the disturbance. Similarly, animals may avoid crossing a road either because of the absence of suitable habitat on the other side, or because of the human activity on the road. Comparing habitat use near disturbances to predicted use based on habitat quality constitutes a robust approach to untangle environmental and disturbance effects (Polfus et al., 2011; White and Gregovich, 2017).

Here, we evaluated the individual and cumulative effects of human disturbances on an Arctic ungulate, the eastern migratory caribou of the Rivière-aux-Feuilles (RFH) and Rivière-George (RGH) herds in northern Québec and Labrador. Like most caribou and reindeer herds, the RFH and RGH have been declining in the last decades. In northern Québec, the RFH peaked at > 500,000 individuals around 2001 (Couturier et al., 2004) and declined to ca. 199,000 (± 16,000) individuals in 2016 (Taillon et al., 2016). The RGH, distributed over parts of Québec and Labrador, peaked at ca. 800,000 (± 104,000) individuals in 1993 (Couturier et al., 1994), and rapidly decreased to < 9000 (± 670) individuals in 2016 (MFFP, 2016). In 2017, both herds were listed as endangered by conservation authorities (COSEWIC, 2017), which stressed the importance of caribou sensitivity to human disturbances. Evaluating the effects of human disturbances and their cumulative effects on migratory caribou is thus critical to implement effective management and conservation measures.

Our goal was to evaluate the effects of human disturbances on migratory caribou habitat and space use. Because caribou are sensitive to human disturbances, we hypothesised that they would avoid approaching sites with human activity or infrastructures. We first predicted that caribou would avoid disturbances at a large spatial scale, by establishing seasonal ranges where the density of industrial disturbances (mines, mining exploration), power lines, human settlements and roads was lower than in other potential seasonal ranges. We also predicted that caribou would avoid disturbances at a finer spatial scale, by reducing occupancy around disturbances found within their seasonal ranges, termed the zone of influence or ZOI. We expected that industrial disturbances would be avoided over larger distances than other types of disturbances, due to the use of heavy machinery and the noise they produce. We evaluated cumulative habitat loss for caribou caused by the avoidance of all disturbances in caribou ranges. We finally assessed whether roads could affect caribou movements, by either acting as a barrier to movements or by modifying movement rates during crossing.

2. Study site

The study area is located north of the 51st parallel and encompassed northern Québec and Labrador, including Nunavik and Nunatsiavut territories, Canada (Fig. 1A). Every year, caribou of the RFH and RGH undertake a migration of several hundreds of kilometers between their summer and winter ranges (mean migration distance 2000–2011: RFH = 615 km; RGH = 350 km; Le Corre et al., 2017). Summer ranges are located in the northern part of the herds' annual distribution range and are mainly covered by arctic tundra dominated by shrubs (*Salix* sp. and *Betula* sp.), grasses, herbaceous plants, and terrestrial lichens (Latifovic and Pouliot, 2005). Transition areas between open tundra and taiga forests are composed of shrubs and conifer trees (mainly black spruce, *Picea mariana*), and are also found in the southern part of the summer ranges. Caribou winter ranges, located in the southern portion of their annual distribution, are dominated by black spruce stands with tamarack (*Larix laricina*), interspersed with low vegetation composed of shrubs and lichens. Natural fires occur mainly on winter ranges, and decrease in frequency and size from west to east, as well as from south to north (MRN, 2014). Elevation of the study area ranges from sea level to 1652 m. Arctic and subarctic climates prevail, with short, cool summers followed by long, cold winters. Annual temperatures averaged −3.6 °C (mean of −27.4 °C and 11.0 °C for the coldest and warmest trimesters, respectively; 1981–2010; Berteaux et al., 2018) across the annual range of the RGH and the winter range of the RFH. On the summer range of the RFH, temperatures for the warmest trimester (summer) averaged 9.7 °C. Precipitations averaged 1077 and 718 mm·year^{-1}, for the southern and northern parts of the study area, respectively, with most precipitations falling as snow between October and March.

We focused our analyses on caribou summer and winter ranges. Disturbances were rare in the summer ranges of both herds, but included human settlements located on the coast, mining exploration sites, and mines (Fig. 1B). RFH and RGH winter ranges were more disturbed than summer ranges, and included human settlements, main roads stretching outside settlements, power lines, and mining exploration sites. The Raglan mine (Glencore; 61°41′08″N, 73°40′49″W; Fig. 1C) was the only mine in operation on the summer range of the RFH during our study. The mine operated three to four underground pits, and an airfield during the study period. The RGH summer and winter ranges included one and two mines in operation, respectively, located at the periphery of the ranges. Three major roads crossed caribou ranges (Fig. 1C). The Raglan road connected the Raglan mine to the shipping port (93 km), and crossed the northern portion of the RFH summer range from southeast to northwest. This road was not paved and was mainly used for ore transportation. The Trans-Taiga and the Trans-Labrador roads respectively crossed the RFH and the RGH winter ranges from east to west. The unpaved Trans-Taiga road connected the hydroelectric infrastructures along the La Grande River, and was mainly used by workers, as well as sport and traditional hunters during winter. The Trans-Labrador road was partially paved and served as the only terrestrial link between Labrador and Québec. Human settlements, power lines and roads did not develop significantly in the last decades, but the number of mining exploration sites varied among years and the number of mines increased over the last 15 years (Appendix 1).

3. Methods

3.1. Caribou data

We captured caribou between 2009 and 2015 using a net-gun shot from a helicopter and fitted them with GPS (Vectronic Aerospace, Berlin, Germany) or Argos (Telonics, ARGOS platform, Mesa, Arizona) collars programmed to record a location every 1 h to 7 d (1 h, 2 h, 7 h, 13 h, or 1 to 7 day-schedule). We used location data of 360 individuals of the RFH (113 M, 247 F) and 150 of the RGH (38 M, 112 F). We removed locations with an estimated error > 1500 m (Argos LC score of 0; GPS PDOP score > 10) from analyses (Christin et al., 2015). We only used caribou equipped with a GPS collar recording locations at high frequencies (1 h to