Northern Riches and Rangifer Risks: A review of the Impacts of Resource Extraction for Caribou and Reindeer

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ABSTRACT

As the global demand for energy continues to rise rapidly, northern ecosystems—i.e. Arctic, subarctic, and boreal regions—are especially at risk due to their rich mineral and hydrocarbon potential. The expansion of infrastructure associated with extractive industries often impacts species and may ultimately contribute to population declines, particularly for those less resilient to environmental changes like Rangifer tarandus. If we aim to support effective conservation and mitigation measures for Rangifer as resource extraction intensifies, there is an urgent need to compile their range of response recorded toward resource extraction. We present a scoping review of 70 studies addressing the impact of mineral and hydrocarbon extraction on Rangifer to synthesize the evidence currently available in the literature, uncover trends in results, and identify remaining knowledge gaps. We recorded effects for various Rangifer populations impacted by resource extraction, with most of the studies concluding that such activities had a significant negative impact on Rangifer, ranging from impacts on 1) distribution and habitat selection, 2) movement and behaviour, 3) forage, contaminants and body condition, and 4) vital rates and demographic. Our work highlights the need to implement long-term non-invasive contaminant surveys and to uncover mechanisms linking contaminant levels and behavioural responses to vital rates to better understand the long-term impact of these activities on demographic trends.

Keywords: anthropogenic disturbances, mining, fossil fuels, hydrocarbon, behaviour, movement, demography, contaminants

INTRODUCTION

Human population growth and its consequent demand for energy continue to rise, feeding a need to extract more critical minerals and fossil fuels (Boldy et al. 2021; Luckeneder et al. 2021; Simmons et al. 2008). Extracting mineral and hydrocarbon requires extensive roads and infrastructure networks, and a persistent human presence impacting landscapes over a broad spatio-temporal scale (Firozjaei et al. 2021; Jin et al. 2024). The resulting disturbances alter the structure and functioning of ecosystems by stripping soil, releasing dust and contaminants in the environment (Bari et al. 2014; Macklin et al. 2023), and causing deforestation or desertification (Rosa et al. 2017). In time, resource extraction activities can contribute to the global biodiversity crisis via the degradation, loss, and fragmentation of natural habitats (Butt et al. 2013; Harfoot et al. 2018; Lamb et al. 2024).

Animal populations vary in their tolerance toward habitat alteration (Vargas Soto et al. 2022). Although some populations benefit from human-altered landscapes (Laurent et al. 2021), others are more vulnerable and exhibit a range of negative responses toward resource extraction activities (Chalfoun 2021; Martins-Oliveira et al. 2021). The nature and severity of these responses depend on the magnitude and the spatio-temporal scale of the disturbance, ranging from individual level, to population and community level impacts (Johnson & St-Laurent 2011). Behavioural adjustments are one of the first observed responses animals may exhibit, but disturbances can also lead to cascading effects that influence physiology (Selman et al. 2013), nutrition or energetics (Arlettaz et al. 2015), and ultimately vital rates (survival or reproduction, Leclerc et al. 2014). For example, the noise caused by drilling or heavy machinery can have important negative impacts on wildlife (Rutherford et al. 2023) by hindering prey or predator detection, and even limit reproduction opportunities for species relying on acoustic communication (Barber et al. 2010). A spatial or temporal avoidance of the disturbance might allow some individuals to acclimate or cope with changes in their habitat (White & Gregovich 2017). However, increased movements or vigilance behaviour, that come at the expense of foraging, could also be observed (Blum et al. 2015; Lynch et al. 2015). Modified movements or behaviours could result in higher physiological stress levels and consequently energy expenditure (Arlettaz et al. 2015). A failure to access sufficient forage to compensate for higher energetic demands could affect individual survival or reproductive success (Cook et al. 2004, Sutter et al. 2016), ultimately contributing to population decline.

Among the species affected by resource extraction, *Rangifer tarandus* (caribou and reindeer, hereafter Rangifer) are particularly vulnerable, with many populations already experiencing steep declines over the past decades (Festa-Bianchet et al. 2011; Vors & Boyce 2009). Rangifer population declines have been linked to the cumulative and interactive effects of climate change and anthropogenic disturbances, highlighting their vulnerability toward global changes (Vors & Boyce 2009). The increase in resource extraction activities in the circumpolar range of Rangifer is thus a major concern, placing some populations at risk of extirpation by reducing the availability of essential habitat and altering community dynamics (Festa-Bianchet et al. 2011).

Rangifer play an important ecological role and have cultural significance across their circumpolar distribution. They are recognized for shaping ecosystems by increasing heterogeneity in nutrient distribution (Ferraro et al. 2022). Rangifer foraging patterns also influence ecological processes by affecting nutrient cycling in soil and by influencing forest regeneration (Stark et al. 2023). In addition to their ecological importance, Rangifer play a vital cultural and socioeconomic role in many circumpolar communities. In North America, caribou are an essential part of Indigenous culture, as many First Nations still rely on them for subsistence. The decline of caribou populations throughout the continent jeopardizes traditional caribou hunting (Parlee et al. 2018), endangering Indigenous communities' wellbeing, culture, and identity (Borish et al. 2022). In Fennoscandia and Russia, traditional reindeer herding is also crucial to ensure food security and to maintain a traditional way of life (Magga et al. 2011; Mustonen et al. 2021). Although semi-domesticated reindeer populations fluctuate mostly in response to socioeconomic factors and climate change (Rees et al. 2008), the increasing presence of resource extraction activities within the landscape remains a major concern for reindeer herders (Skarin & Åhman 2014). Throughout their range, Rangifer remain an integral part of traditional livelihoods: essential to Indigenous heritage and northern ecosystems.

Because the global demand for energy continues to grow rapidly, we still rely heavily on fossil fuels and on the minerals needed to transition towards renewable energy (Holechek et al. 2022). Therefore, new infrastructure is appearing to meet this ever growing demand (Maus et al. 2022). The increased exploitation of the abundant reserve of mineral and fossil fuel from the Arctic, subarctic, and boreal regions, poses a potential risk to biodiversity in northern ecosystems (Lemieux et al. 2024). Comprehending the impacts of resource extraction activities on Rangifer is crucial to help stop, attenuate, or mitigate further population decline. Previous reviews have compiled the responses of Rangifer toward disturbances, both natural and/or anthropogenic (Festa-Bianchet et al. 2011; Vistnes & Nelleman 2009; St-Laurent et al. 2012; Stevenson et al. 2024; Wolfe et al. 2000). However, a precise focus on the state of knowledge on the impact of long-term resource extraction activities, i.e., mining and fossil fuel exploitation, remains missing. In this scoping review, we qualitatively assessed the current state of knowledge on mining and oil and gas exploitation impacts on Rangifer, identified knowledge gaps, and suggested potential avenues to improve the precision of our knowledge pertaining to Rangifer response to large scale anthropogenic disturbance. The results of this review could help inform policies and orient conservation planning to benefit Rangifer populations.

METHODS

To conduct a scoping review, we followed the PECO framework (by defining Population, Exposure, Comparator, Outcomes; Collaboration for Environmental Evidence 2022) to address:

To what extent do long term resource extraction activities impact Rangifer ?

We defined the PECO Population as any wild or semi-domesticated subspecies, population, or herds of *Rangifer tarandus*. We defined the PECO Exposure as the existing or projected presence of mineral and fossil fuel extraction activities (e.g., open or closed mine pit, quarry, oilfield, wellsites, or pads) or active exploration (requiring drilling and/or intensive human presence). We did not include studies recording the impact of “passive” linear features (i.e., seismic lines and pipelines) due to their temporary nature or their lack of continuous human presence. The impact of those structures on caribou have been well documented, especially in Western Canada where oil exploitation has significantly altered the landscape (Dyer et al. 2002; Latham et al. 2011). We retained studies describing the impact of industrial roads because these are often associated with noise, light, and pollution. We defined the PECO Comparator as a measure of the outcome at varying spatio-temporal degrees of exposure (e.g., distance to disturbance, phase of operations, control area, or reference population). We defined the PECO Outcome as any relevant biological response (behaviour, movement, physiology, vital rates, demographics, etc.) or environmental impact having direct relevant implications for Rangifer (e.g., change in forage quality or quantity).

Prior to starting the review, we selected ten studies relevant to our research question, which covered a large range of biological responses and geographic locations, and used them as benchmark papers (see Table S1). Benchmark papers exist as a test to ensure that search parameters are most likely finding their intended papers. We then performed an iterative search on Scopus, Web of science, and SciLit, to refine the combination of terms used (search string) to improve both the sensitivity, i.e. the ability to return most/all relevant studies, and the specificity, i.e. the ability to return only relevant studies, of our searches. Although grey literature can be important sources of information, we focussed our search on peer-reviewed documents as our goal was not to precisely quantify the impact of long term resource extraction, but instead to document the range of responses recorded for Rangifer.

Search terms were grouped based on our PECO criteria in one of the following 3 categories: (1) Population, including “Rangifer”, “caribou”, and “reindeer”; (2) Exposure, specifying terms relating to mineral or oil extraction/exploitation; and (3) Exclusion, used to improve the specificity and eliminate redundant themes or subject considered irrelevant to the review (see Table S2). Terms relating to Comparator and Outcome (i.e. possible biological responses) were excluded in the final search to increase sensitivity. We combined terms within a category using the “OR” operator, while the categories were joined using “AND” (for population and exposure) or “AND NOT” (for exclusion). We confined the search to title, abstract, and keywords to increase the specificity of the search, and decided not to exclude papers based on publication date. We imported all publications from this search into Covidence (2025), a web-based software program used to streamline the scoping review process. After a preliminary title and abstract screening, we performed a full text screening to select only peer-reviewed studies meeting the full PECO inclusion criteria and presenting one or more relevant results. We excluded articles unavailable in French or English, and book chapters (presenting overview of empirical studies). Due to the variety of approaches, environmental setting, and biological responses recorded in the chosen studies, we did not compute a combined effect size to quantify the impact of permanent resource extraction activities. Instead, we reported results in a qualitative manner by categorizing the studies using the type of response recorded: either 1) Distribution and habitat selection; 2) Movement and behaviour; 3) Forage, contaminants and body condition; or 4) Vital rates and demographics.

RESULTS

Following the iterative search on academic databases, we imported 1197 studies into Covidence. Of those, we identified a total of 501 as duplicates. We screened the remaining 696 against title and abstract with 507 studies considered irrelevant (i.e., not specific to Rangifer and resource extraction). During full text screening, we excluded a further 119 studies that did not meet our inclusion or PECO criteria. In total, 70 studies were considered for the review (see

Table S3). Studies were disproportionately distributed in North America (88%), with an overwhelming number of studies conducted in North coastal Alaska oil fields (27 out of 39 hydrocarbon studies, Figure 1). The lack of representation from Fennoscandia and Russia might be partly explained by the fact that studies unavailable in English or French were either not found during the search, or excluded from the review during title and abstract (n = 5), or full text screening (n = 2). Although some studies concluded that resource extraction was not impacting Rangifer in significant ways, most found that these disturbances led to important negative consequences for Rangifer (Figure 1), ranging from changes in behaviour to potential impact on demographic trends. A variety of approaches were used to assess the impacts of extraction activities on Rangifer, with most focussing on distribution or movement responses, and relying on visual surveys or remote sensing technologies (Figure 2). Few papers presented in this review incorporated Indigenous knowledge in their research design, but some studies (n=6) included discussion and interviews with members of First Nations to document the impact of resource extraction activities on Rangifer (Figure 2), with the aim to assess the repercussions for local communities.

Habitat selection and distribution

Mineral and hydrocarbon extraction activities can be perceived as risky by Rangifer, and thus influence their habitat selection and distribution as individuals try to minimize their exposure to such features (Semeniuk et al. 2014). The zone of influence (ZOI) — the area of reduced Rangifer occurrence around resource extraction activities— can vary significantly between herds, season, and years. Temporal variation can be partly explained by differences in environmental conditions affecting forage quality, such as drought conditions (Boulanger et al. 2021) or time of snowmelt (Haskell et al. 2006; Haskell & Ballard 2008). The extent of the ZOI also depends on the nature of the disturbance (Table 1). For operating mines, ZOI up to 23 km have been recorded for wild Rangifer populations (Plante et al. 2018), while ZOI for oilfield infrastructure and industrial roads reached 12.5 km (Johnson et al. 2015) and 17 km (Boulanger et al. 2024), respectively. After road construction in the Prudhoe Bay oilfield, Alaska, USA, caribou and calves abundance within 1 km of roads was 80% lower, but almost triple beyond 4 km (Cameron et al. 1992). Calving females were displaced away from the oilfield, whereas males and yearlings seemed to be more tolerant to resource extraction infrastructure (Cronin et al. 1998; Nelleman & Cameron 1998; Whitten & Cameron 1983). In Newfoundland, Canada, average caribou group size within the ZOI of a gold mine decreased during the operation phase compared to the pre-disturbed study area (e.g. from $\bar{x}$=13.75 to $\bar{x}$=4.81 during late winter; Weir et al. 2007). In Canada, members of different Indigenous communities (Inuit, Nunavut, and Naskapi, Québec) have noted that the noise and vibrations from the mine, and the low flying altitude around operations fragmented caribou herds and drove them away from the area (Blangy & Deffner. 2014; Herrmann et al. 2014).

Rangifer avoidance response can also be modulated by human activity levels, as the ZOI of mines in the Northwest Territories, Canada, varied according to operation phases (Boulanger et al. 2012), and with highest avoidance of a mine in Finnmark, Norway, recorded during workdays, compared to weekends and holidays (Eftestøl et al. 2019). In Alberta, Canada, drilling or producing well sites were also avoided more strongly than inactive ones (MacNearney et al. 2021), similar to roads with more vehicles (Severson et al. 2023) and unrestricted traffic in Alaskan oilfields (Prichard et al. 2022). Haskell et al. (2006) also noted a higher caribou sighting rate at night and in lower activity areas of the oilfield, especially for groups with calves. Some studies concluded that human-wildlife cohabitation was possible by suggesting habituation across years (Noel et al. 2004) or re-habituation within years (Haskell et al. 2006; Haskell & Ballard 2008), but others have concluded that habituation was most likely absent (Boulanger et al. 2012, 2021; Johnson et al. 2020).

The avoidance of large areas around resource extraction activities can lead to significant loss of critical habitat for Rangifer herds (see Table 1) and ultimately impact distribution as individuals abandon part of their range (Joly et al. 2006; Weir et al. 2007). Although petroleum development intensity does not seem to influence range fidelity for caribou in Northeastern Alberta, Canada (Tracz et al. 2010), in-situ oil sand development was expected to decrease caribou home range size due to a loss of landscape permeability (Mulhy et al. 2015). For wild reindeer in Russia, oil and gas exploitation was an important driver of loss of calving habitat, and potential exploitation could further fragment reindeer ranges (Kuemmerle et al. 2014). Domesticated reindeer in Fennoscandia have also been impacted by mining activities as the roads or mine tailings are reducing the availability of high-quality forage areas (Herrmann et al. 2014; Kløcker Larsen et al. 2022). Range loss can eventually lead to overgrazing, degradation of traditional foraging areas, and displacement of individuals to lower quality pastures (Kløcker Larsen et al. 2022).

Movement and behaviour

Roads associated with mineral or fossil fuels extraction can impact Rangifer movements by reducing landscape permeability (Mulhy et al. 2015), acting as barriers preventing them from reaching certain portions of their range and contributing to habitat loss (Plante et al. 2018). Delays in migration and gradual abandonment of stopover locations have also been noted by Indigenous communities that depend on caribou for subsistence (Herrmann et al. 2014; Kendrick et al. 2005). The roads, which are often constructed on elevated berms for security reasons or to allow for heavy machinery, are sometimes too high to allow safe passage of caribou (Parlee & Manseau 2005), and their barrier effect is known by members of these communities (Blangy & Deffner. 2014). Rangifer can be forced to travel longer distances to get around roads or, when road crossing is inevitable, can delay their migration (Boulanger et al. 2024). While movement rates and directionality of movement decrease when individuals approach the road (Boulanger et al. 2024), faster movement rates and decreased turn angles are usually observed during and after road crossing (Boulanger et al. 2024; Prichard et al. 2020). The presence of traffic on roads could amplify this behavioural response (Boulanger et al. 2024) and reduce crossing frequency (Smith & Johnson 2023). In the Prudhoe Bay oilfield, reduced rates of crossing were observed for both the oilfield itself (Cameron et al. 1995) and roads within the oilfield (Curatolo & Murphy 1986), with males being 66% more likely to cross than females and calves (Whitten et al. 1983). Roads and resource extraction infrastructure can also significantly affect Rangifer activity budget. Caribou spent more time foraging or lying with increasing distance from a mining road (Smith et al. 2023), and spent more time standing (4.8% increase), walking (5.7% increase), and running (12.1% increase) when in close proximity to an oilfield (Murphy & Curatolo 1987). Behavioural responses were stronger for groups with calves and those closer to roads, and more frequent near roads with convoying (Prichard et al. 2022). Traffic levels as low as 5 vehicles/hour were enough to trigger a behavioural response from caribou (Severson et al. 2023).

In contrast to the above findings, Fancy (1983) found no impact of drill sites on movement rates or the activity budget of caribou, but instead suggested caribou seek infrastructure during insect harassment periods to use as relief habitat. Caribou response to insects is a common trend, as the presence of insects seem to attenuate the behavioural response and avoidance of industrial features by caribou (Cameron et al. 1995; Curatolo & Murphy 1986; Murphy & Curatolo 1987; Severson et al. 2023). During moderate or high insect harassment, caribou, which usually avoid oilfields, have been observed moving through them instead to access coastal relief habitat (Pollard et al. 1996b). In Alaska, higher wind velocities were recorded on gravel pads than on adjacent tundra, leading to lower mosquitoes and oestrids abundance (Pollard et al. 1996a). Caribou have been known to use these gravel pads and other infrastructure as relief habitat when insects, especially oestrids, are abundant (Noel et al 1998; Pollard et al. 1996b; Prichard et al. 2020).

Forage, contaminants, and body condition

Resource extraction activities can further affect caribou by impacting forage quality and availability. In Finland, reindeer herders have identified gold mining as being an important threat to reindeer due to the loss of pasture and the potential impact on water quality (Turunen et al. 2024). In Sweden, the physical footprint and estimated ZOI of mineral extraction activities led to an estimated loss of about 1460 metric tonnes of lichen for reindeer (Kater & Baxter 2025). Dust and pollutants resulting from mineral exploitation and mining roads can increase soil pH within 1000m around these areas (Chen et al. 2017), causing a decrease in bryophyte or lichen cover, and an increase in vascular plants (Chen et al. 2017; Watkinson et al. 2021). Mining dust can also lead to an increase in toxic elements concentrations in lichen for up to 8 km around mining operations (Eriksson et al. 1990), with some metals detectable in lichen sampled as far as 40 km (Watkinson et al. 2021). Boulanger et al. (2012) suggested that dustfall could explain the large ZOIs measured around mines, as the modeled air dispersion of finer dust particles was a good predictor of caribou occurrence around a diamond mine.

Thus, by foraging near resource extraction activities, Rangifer may ingest contaminants. Compared to caribou from reference areas, those harvested in the vicinity of a zinc and lead mine (Red Dog Mine, Northwest Alaska, U.S.A.) showed slightly elevated levels of lead in their liver (2.5 versus 2.2 mg/kg) and kidneys (1.6 versus 1.4 mg/kg, Gary et al. 2018), and significantly higher arsenic (0.55 ppm) and copper (11.0 ppm) content in their muscle and rumen tissues, respectively (O'Hara et al. 2003). In contrast, caribou harvested near an abandoned lead/zinc mine in the Northwest territories had cadmium levels comparable to those from other provinces (Kim 1998). In a uranium mining area, high levels of 210Pb were found in the kidneys and on the fur of caribou, potentially indicating a short-term increase in 210Pb intake from contaminated forage or from surface adsorption due to aerial deposition (Thomas et al. 1994; Thomas & Gates 1999). An analysis of toxic polycyclic aromatic hydrocarbons in caribou scat from the Alberta oil sands showed that, although variable between regions, elevated levels were linked to a pyrogenic source, i.e., forest fires, and likely not to in-situ oil production (Lundin et al. 2015). Higher levels of persistent organic pollutants were also found in the tissues of Norwegian reindeer from a region where mining activities were recorded (Hassan et al. 2021). Still, the majority of these studies concluded that individuals harvested near mining operations should not have experienced toxic effects, and were even deemed safe for human consumption (Eriksson et al. 1990; Gary et al. 2021; Hassan et al. 2021; Kim et al. 1998; O'Hara et al. 2003).

Although Smith et al. (2023) found no relationship between distance to a mining road in northern Canada (central N.W. Territories) and the level of stress hormones (cortisol and corticosterone) in fecal samples, other impacts on body condition were probable. For example, higher energy expenditure caused by active seismic petroleum exploration in Alberta, Canada, was found to lead to significant weight loss for individuals experiencing high intensity of disturbances during winter (Bradshaw et al. 1997, 1998). Naskapi hunters also noticed a decrease in body condition of harvested caribou after mining operations started, as they were showing less fat and a lower body weight (Herrmann et al. 2014). In another community, Denésôliné elders noted an increase in injured caribou, probably as they hurt themselves trying to cross boulders on roadside during their migration (Kendrick et al. 2005).

Vital rates and demographics

Although Cronin et al. (2000) suggested large-scale resource extraction could coexist with Rangifer with no impact on caribou demographics, other studies argued that industrial development would reduce survival and reproductive success, potentially leading to population declines. Plante et al. (2020) found that exposure to industrial disturbances (i.e. mines and mining exploration) increased daily mortality risk for caribou from the Rivière-aux-Feuilles herd during winter but the effect during summer, for the Rivière-George herd, or at other temporal scale seemed to be either negligible compared to non-anthropogenic factors, or indistinguishable from the effect of latitude. Females of the Central Arctic herd exposed to petroleum development also had lower parturition rate (64.3% versus 82.5%), lower autumn body condition, and more frequent reproductive pauses (i.e. years without calf production; 36% versus 19%) than those not exposed to these developments (Cameron et al. 2005). For the Porcupine caribou herd, calf mortality increases with distance from the traditional calving area, located near the coastal plain of the Arctic National Wildlife Refuge (Whitten et al. 1992). Projected petroleum development in their range was expected to displace maternal females from the calving ground, reducing their access to quality forage during peak lactation and increasing predation on calves (Kruse et al. 2004; McCabe 1994). Coupled with the effect of climate change, disturbance-induced displacement could lead to an 85% decline of the Porcupine herd over 40 years, while climate change alone was unlikely to cause such a drastic decline (Kruse et al. 2004). Similarly, Rempel et al. (2021) simulated the combined effect of climate change and mining for caribou in Ontario's Ring of Fire and found that, at the local project scale (encompassing three mining projects), populations would be resilient to climate change alone, but that proposed mining development would cause significant population decline (29%) over 50 years.

DISCUSSION

Exponential increases in the demands for minerals and fossil fuels, abundant in the northern environments that comprise the circumpolar range of Rangifer, have put important pressures on a species known to be sensitive to environmental change (Vors & Boyce 2009, Wittmer et al. 2007). It is, however, very likely that mineral and fossil fuel exploitation is going to accelerate, with considerable impacts for Rangifer populations subjected to expanding exploration and extraction activities. To synthesize and better position what is empirically known about the effects, or lack thereof, of mineral and fossil fuel extraction on Rangifer, we conducted a repeatable and transparent scoping review of relevant peer-reviewed literature. While the magnitude of the effect of mineral and fossil fuel extraction observed varied between study systems and resource extracted, the vast majority (76% or 53/70) of the studies included in this review recorded substantial negative impact for Rangifer, at various biological scales (e.g., delays in migration, habitat loss, forage contamination, etc.). Long-term or repeated studies indicated Rangifer did not habituate nor acclimate to disturbance, because avoidance and behavioural responses were still observed decades after resource extraction commenced (e.g., Boulanger et al. 2021; Johnson et al. 2020). Some herds even abandoned part of their range as undisturbed areas were becoming too fragmented (Joly et al. 2006). Most studies that recorded non-significant or absence of impact of petroleum extraction on Rangifer were local scale, short-term studies, usually performed before 1990. Some studies had their control plots within the probable ZOI of infrastructure or relied on temporally limited visual surveys, most likely resulting in a failure to detect significant effects of resource extraction activities on Rangifer (Vistnes and Nellemann 2008). It is important to highlight that failing to detect an effect, particularly with studies that occurred at small temporal or spatial scales, is not equivalent to there being no effect of disturbance on Rangifer, especially as most studies identified effects over longer time scales and broader spaces. A few studies claimed that caribou could actually benefit from petroleum infrastructure. Readers should interrogate those studies, paying careful attention to the strength of inference given the design: use of industrial infrastructure as relief habitat from insects may be plausible, but appears to have little support compared to studies that found industrial infrastructure was a barrier that reduced access to other habitats, which may have included natural insect relief i.e, coastal plains (Wilson et al. 2012).

A current gap in our understanding of the impacts of mineral and fossil fuel extraction on caribou is long-term exposure and accumulation of toxic elements released by these activities. While studies looking into possible intake of toxic elements and pollutants by Rangifer concluded that resource extraction activities should not lead to significant toxic effects, most studies still found elevated levels of contaminants in various organs and tissues. Cadmium, arsenic, lead, and mercury can have pervasive effects on reproductive functions, even at low concentration (Massányi et al. 2020). Indeed, the natural distributions of these toxic elements have been linked with lower reproductive success in other large ungulates (see van Beest et al. 2023). Because lichen bioaccumulates toxic elements, radionuclides, and other atmospheric contaminants (Conti and Cecchetti 2001), and are an important part of Rangifer's diet (Webber et al. 2022), they could contribute to an increased intake of contaminants by Rangifer. Impacts on health and reproduction are thus concerning for Rangifer populations impacted by mineral extraction activities. The need to harvest animals to assess contaminant levels in organs and tissues also limited temporal reach and sample sizes (but see O'Hara et al. 2003 collecting from mass death event), and only two studies relied on feces collection as a non-invasive method to assess health impact (Lundin et al. 2015; Smith et al. 2023). Feces collection could allow for more extensive, long term biomonitoring to help track variations in contaminant intake and could potentially increase our ability to detect toxic effects for individuals (Pacyna et al. 2019; Stavridris et al. 2024). Hair sampling also represents an effective and non-invasive alternative to organ collection (Jutha et al. 2022; van beest et al. 2024) and could be an effective method to assess toxic elements or contaminants accumulation in response to resource extraction (Li et al. 2025). Non-invasive contaminant survey of Rangifer hair or fecal could help monitor the long term effect of dust deposition and toxic elements possibly impacting Rangifer health.

Although most of the studies included in the review looked either at Rangifer's distribution and habitat selection, or movement and behavioural responses, very few assessed the impacts on fitness, e.g., survival and reproductive success (but see McCabe 1994; Plante et al. 2020). Because behavioural responses can vary significantly, both between (Lafontaine et al. 2019; Lessard et al. 2025) and within herds (Leclerc et al. 2014; Mumma et al. 2017), it is crucial to articulate how different behavioural strategies impact survival and reproductive success. For example, studies looking into the impact of forestry on woodland caribou showed that their behavioural responses and adjustments could be either fitness rewarding (Derguy et al. 2025; Lafontaine et al. 2017) or maladaptive (Dussault et al. 2012; Losier et al. 2015), with important implications for population trends. Thus, linking Rangifer's habitat use and movement with variation in fitness, while assessing the level of plasticity individuals can display, are important steps in disentangling the full range of impacts anthropogenic disturbances have on individuals. If avoidance of infrastructure can positively influence survival (Plante et al. 2020), or decrease intake of toxic elements (Watkinson et al. 2021), it can also limit access to nutritious forage or increase predation (McCabe et al. 1994). Precise knowledge of how different strategies towards mineral and hydrocarbon infrastructure affect Rangifer vital rates could help better understand the mechanisms of population decline, accurately predict population trends, and implement efficient conservation strategies to promote human-wildlife cohabitation.

While this review focussed on the specific effect of mineral and fossil fuel extraction, these are but one of many threats to Rangifer populations. Evaluating the individual impacts of disturbances is a key step in trying to quantify their cumulative effect. Still, studies assessing the combined impacts of various disturbances present essential knowledge on the responses of Rangifer (Beauchesnes et al. 2014, Johnson et al. 2015) and can help us understand demographic trends (see Stewart et al. 2020; Rudolph et al. 2017) when herds are facing a range of natural and anthropogenic stressors. Land changes associated with anthropogenic activities are known to be an important cause of Rangifer's population decline around the globe, but climate change is also a considerable threat for Rangifer and could interact with habitat alteration to accelerate their decline (Mallory & Boyce 2018). Weather and disturbances can interact to influence Rangifer's behaviour (Lessard et al. 2025) and demography (St-Laurent et al. 2022), highlighting the importance to consider such synergistic effects. A warming climate could affect access to forage during winter, put thermal stress on individuals and alter community dynamics. Out of all the studies included in this review, only four directly modeled the effects of climate change on population trends, while ten studies included a measure of weather or vegetation changes (e.g., temperature, snow cover, drought index, NDVI), allowing partial inference on how a warming climate might affect the study systems (see table S3). Climate changes are expected to exacerbate human-wildlife conflicts, and failure to consider their impact could decrease the efficiency of conservation and mitigation measures (Abrahms et al. 2023).

Rangifer are sensitive to environmental change and human-caused environmental disturbance has been implicated directly (Lamb et al. 2025) and indirectly (via habitat-mediated apparent competition, Wittmer et al. 2007) to caribou population declines and large-scale range contraction (Vors et al. 2007). While specific responses by Rangifer depend on environmental settings, extraction method, spatial footprint of infrastructure, and activity levels, our review affirms that mineral and hydrocarbon extraction have caused significant impacts for Rangifer populations. The impacts on caribou herds are expected to further decrease hunting opportunities for many First Nations that depend on them for subsistence (Herrmann et al. 2014; Kruse et al. 2004) and reduce traditional reindeer herding opportunities, endangering indigenous livelihood and culture (Kløcker Larsen et al. 2022). Indeed, as the global demand for mineral and fossil fuels accelerates, Rangifer will likely pay the cost of expanding resource extraction. Because there is limited sociopolitical appetite to put the intrinsic and instrumental value of caribou ahead of human extractive interest, compiling detailed knowledge on the precise consequences of mineral and fossil fuel resource extraction is a critical step to mitigate the impact of future development.

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Table 1: Zone of influence (ZOI) recorded for different infrastructure types with their corresponding habitat loss when available.

Infrastructure type	Recorded avoidance (ZOI) or habitat loss	Study
Mineral extraction		
Mine	1.5 km in late winter and summer/fall, habitat loss of 306 km^2 (11.9%)	Anttonen et al. 2011
	14 km (aerial surveys), 11 km (GPS locations), habitat loss of 3551 km^2 (6.7%)	Boulanger et al. 2012
	7.2 km (6.1–18.7 km)	Boulanger et al. 2021
	1.5 km (work days) 0.9 km (3 week holidays)	Eftesol et al. 2019
	10 km (based on interviews with reindeer herders)	Kløcker Larsen et al. 2022
	20–23 km in summer	Plante et al. 2018
	0.25 km (winter) and 2 km (summer)	Polfus et al. 2011
	4 km	Weir et al. 2007
	0–3 km	Johnson et al. 2015
Mineral exploration	6 km	Johnson et al. 2005
	2–4 km (summer) and 3–21 km (winter)	Plante et al. 2018
Mining Roads	0–8 km (summer) and 0–15 km (winter)	Plante et al. 2018
	16–17 km prior to crossing 3 km after crossing	Boulanger et al. 2024
Proposed mining road	Habitat loss of 151–848 km^2 (1.5-8.5%) modeled with potential ZOI ranging from 1 to 5 km	Wilson et al. 2014
Mineral potential	High mineral potential overlapping with 11% (winter) to 21% (growing season) of quality habitat	Suzuki &Parker 2016
Hydrocarbon extraction		
Oilfield infrastructure	No avoidance recorded	Cronin et al. 1998
	1 km (mosquito season: 7475 km^2, 17%), 2 km (post-calving: 4627 km^2, 15%), 5 km (calving: 3859 km^2, 12%)	Johnson et al. 2020
	4 km	Nelleman & Cameron 1996
	5 km (calving)	Prichard et al. 2020
Well sites	0.25 km (early and late winter, summer, rut) to 1 km (calving), habitat loss of 83–910 km^2 (1.4–14.8%)	Dyer et al. 2001

	0–2 km (winter) to 0–12.5 km (summer)	Johnson et al. 2015
	0.5 km (inactive or producing wellsites) to 1 km (drilling)	MacNearnet et al. 2021
	1 km (but displacement of up to 4km)	Cameron et al. 1992
	0.25 km (late winter to rut), loss of 113.57 km^2 (1.8%)	Dyer et al. 2001
	4 km	Joly et al. 2006
	No avoidance recorded	Noel et al. 2004
	2 km (convoying*) 4 km (unrestricted traffic)	Prichard et al. 2022
Oilfield roads	1–3 km	Severson et al. 2023
	20–40% reduction in habitat Effectiveness index	Francis & Hamm 2011
	12–15% (TCH) and 2-4% (WAH) according to development scenarios	Fullman et al. 2021
	High hydrocarbon potential overlapping with 21% (growing season) to 42% (winter) of quality habitat	Suzuki &Parker 2016
Oil and gas development scenarios	Simulated loss of 9–34% of high quality calving habitat according to different management alternatives	Wilson et al. 2013

*all vehicles travelling together during scheduled periods to reduce frequency of disturbances

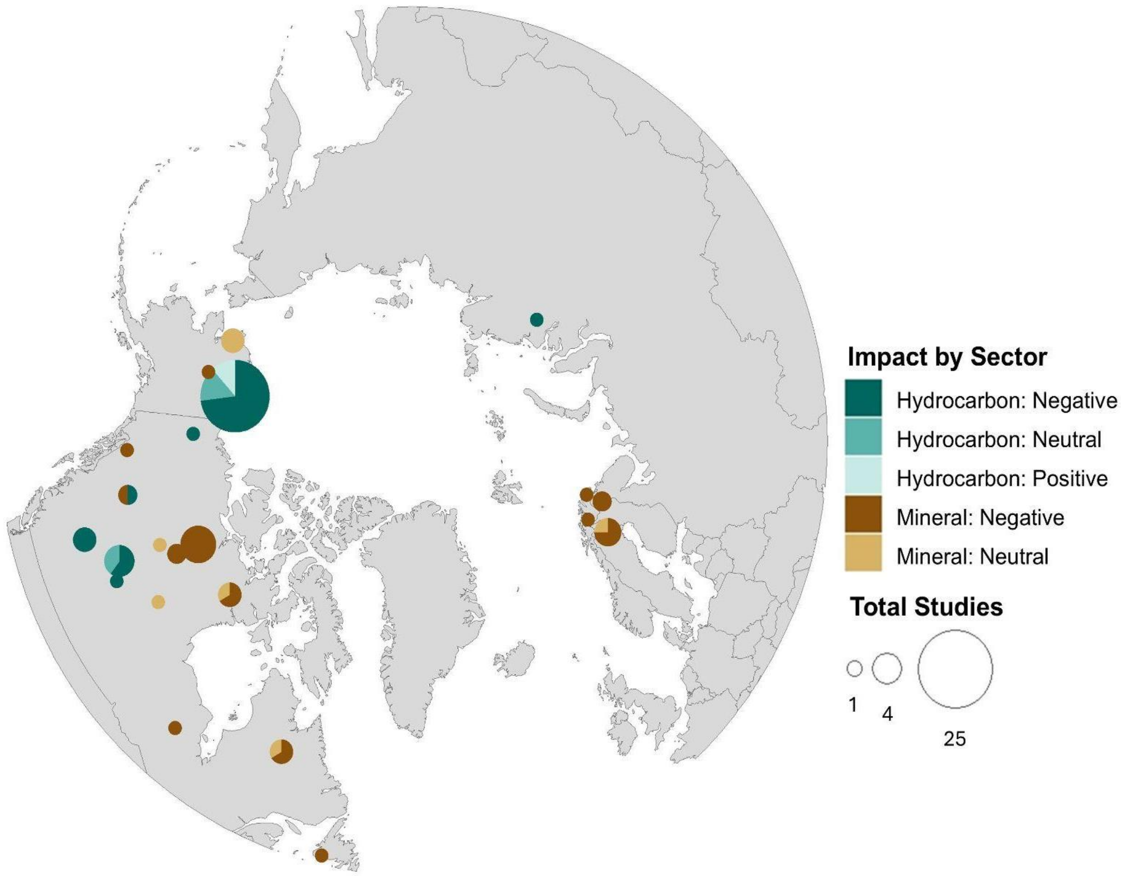

Figure 1: Distribution of the 70 studies looking at the impacts of hydrocarbon and mineral exploitation on Rangifer. Studies assessing the impact of both resource extraction (n=1) or in different studies areas (n=1) are represented twice.

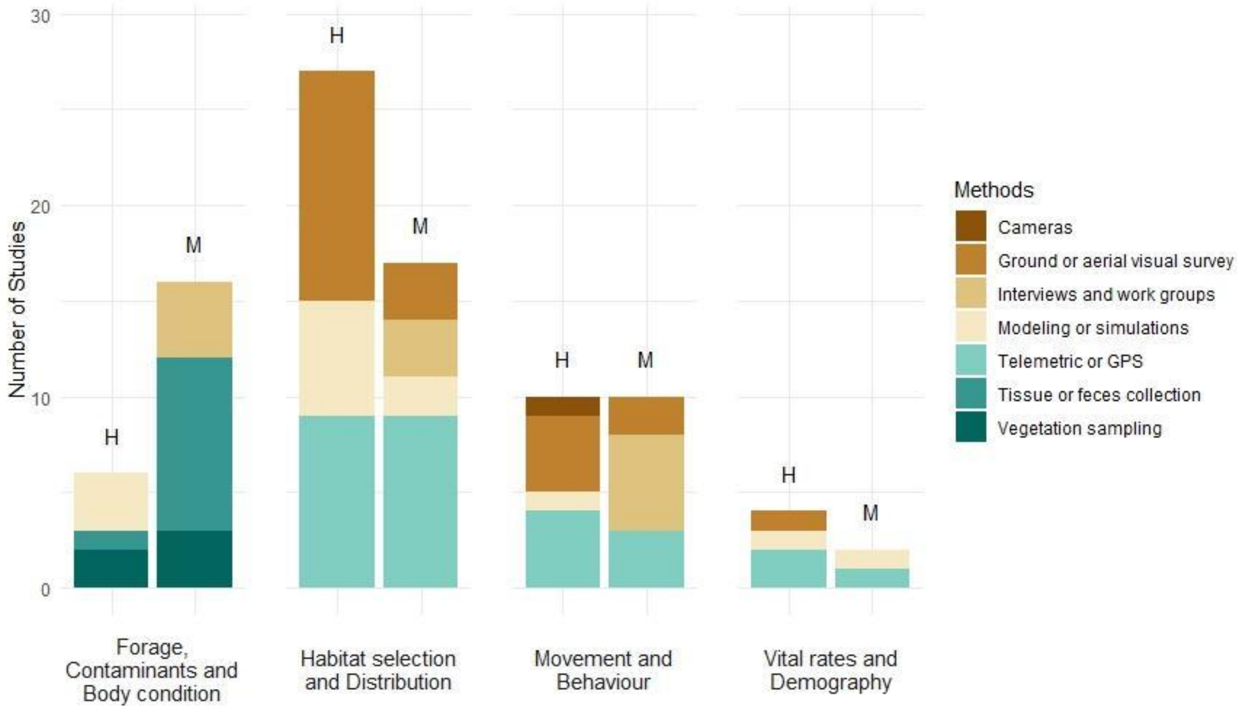

Figure 2: Methods and categories of response recorded in the 70 studies looking at the impact of hydrocarbon (H) and mineral (M) exploitation over Rangifer. Studies assessing the impact of both resource extraction (n = 1), relying on various methods (n = 8) or addressing multiple response categories (n = 14) are represented more than once.

Table S1: List of benchmark paper relevant to the review

Citations	Indexed in WoS	Indexed in Scopus	Indexed in SciLit
MacNearney, D., Nobert, B., & Finnegan, L. (2021). Woodland caribou (*Rangifer tarandus*) avoid wellsite activity during winter. *Global Ecology and Conservation*, 29:e01737.	yes	yes	yes
Plante, S., Dussault, C., Richard, J.H., Garel, M. & Côté, S.D. (2020). Untangling Effects of Human Disturbance and Natural Factors on Mortality Risk of Migratory Caribou. *Frontiers in Ecology and Evolution*, 8:154.	yes	yes	yes
Watkinson, A. D., Virgl, J., Miller, V. S., Naeth, M. A., Kim, J., Serben, K., Shapka, C. & Sinclair, S. (2021). Effects of dust deposition from diamond mining on subarctic plant communities and barren-ground caribou forage. *Journal of Environmental Quality*, 50(4):990-1003.	yes	yes	yes
Weir, J.N., Mahoney, S.P., McLaren, B. & Ferguson, S.H. (2007). Effects of Mine Development on Woodland Caribou Rangifer Tarandus Distribution. *Wildlife Biology*, 13(1):66–74.	yes	yes	yes
Chen, W., Leblanc, S.G., White, H.P., Prevost, C., Milakovic, B., Rock, C., Sharam, G., O'Keefe, H., Corey, L., Croft, B., Gunn, A., van der Wielen, S., Football, A., Tracz, B., Snortland Pellissey, J. & Boulanger, J. (2017). Does Dust from Arctic Mines Affect Caribou Forage? *Journal of Environmental Protection*, 8(3):258–76.	no	no	yes
Eftestøl, S., Flydal, K., Tsegaye, D. & Colman, J.E. (2019). Mining activity disturbs habitat use of reindeer in Finnmark, Northern Norway. Polar Biology, 42(10):1849–58.	yes	yes	yes
Smith, A., Johnson, C.J. & Clark, K. (2023). Behavioral and physiological stress responses of barren-ground caribou (*Rangifer tarandus groenlandicus*) to industrial ice roads. *Polar Biology,* 46:1053–1067.	yes	yes	yes
Muhly, T., Serrouya, R., Neilson, E., Li, H. & Boutin, S. (2015) Influence of *In-Situ* Oil Sands Development on Caribou (*Rangifer tarandus*) Movement. *PLoS ONE*, 10(9):e0136933.	yes	yes	yes
Fancy, S.G. (1983). Movements and activity budgets of caribou near oil drilling sites in the Sagavanirktok River floodplain, Alaska. *Arctic*, 36(2):193-197.	yes	no	yes
Kuemmerle, T., Baskin, L., Leitão, P.J., Prishchepov, A.V., Thonicke, K. & Radeloff, V.C. (2014). Potential impacts of oil and gas development and climate change on migratory reindeer calving grounds across the Russian Arctic. *Diversity and Distributions*, *20*(4), 416-429.	yes	yes	yes

Table S2: Combination of terms used for the search on Scopus, Web of Science, and SciLit with the number of papers returned by each search.

Source	String	Papers
Scopus	TITLE-ABS-KEY (Rangifer OR reindeer* OR caribou*) AND TITLE-ABS-KEY (mine OR mining OR drilling OR oilfield OR ((extract* OR develop* OR explor* OR road OR wells*) AND (mineral* OR oil OR gas OR bitumen OR petroleum))) AND NOT TITLE-ABS-KEY (*fossil* OR "greenstone belt" OR *terrane OR paleo* OR "caribou mine" OR "caribou creek" OR "caribou bog" OR "caribou county" OR colorado)	403
Web of Science	TS=(Rangifer OR reindeer* OR caribou*) AND TS=(mine OR mining OR drilling OR oilfield OR ((extract* OR develop* OR explor* OR road OR wells*) AND (mineral* OR oil OR gas OR bitumen OR petroleum))) AND NOT TS=(*fossil* OR "greenstone belt" OR *terrane OR paleo* OR "caribou mine" OR "caribou creek" OR "caribou bog" OR "caribou county" OR colorado)	350
SciLit	Common fields [Title, Abstract, Keyword]: (Rangifer OR reindeer* OR caribou*) AND Common fields [Title, Abstract, Keyword]: (mine OR mining OR drilling OR oilfield OR ((extract* OR develop* OR explor* OR road OR wells*) AND (mineral* OR oil OR gas OR bitumen OR petroleum))) AND NOT Common fields [Title, Abstract, Keyword]: (*fossil* OR "greenstone belt" OR *terrane OR paleo* OR "caribou mine" OR "caribou creek" OR "caribou bog" OR "caribou county" OR colorado)	442

Table S3: Peer-reviewed papers used to review the impacts of resource extraction activities on *Rangifer* , along with the informations extracted from each

Study.ID	Country	Region	Subspecies/Ecotype	Herd/Population	Resource	Methods	Trend	Climate change/weather considered	Response Category
Anttonen et al. 2011	Finland	Northern Lapland	Semi-domesticated reindeer (R.t. tarandus)	NA	Mineral	Telemetric or GPS	Negative	No	Distribution or habitat selection
Blangy & Deffner 2014	Canada	Central Nunavut	Barren ground caribou (R.t. groendlandicus)	Beverly and Qamanirjuaq herds	Mineral	Interview	Negative	No	Movement or behaviour; Forage, contaminant, or body condition
Boulanger et al. 2012	Canada	Central Northwest Territories	Barren ground caribou (R.t. groendlandicus)	Bathurst herd	Mineral	Aerial or ground visual survey; Telemetric or GPS	Negative	Plant phenology (NDVI) included	Distribution or habitat selection
Boulanger et al. 2021	Canada	Central Northwest Territories	Barren ground caribou (R.t. groendlandicus)	Bathurst herd	Mineral	Aerial or ground visual survey; Telemetric or GPS	Negative	Drought index included	Distribution or habitat selection
Boulanger et al. 2024	Canada	Central Nunavut	Barren ground caribou (R.t. groendlandicus)	Lorillard and Wager Bay herds	Mineral	Aerial or ground visual survey; Telemetric or GPS	Negative	Temperature and frozen water bodies included	Movement or behaviour
Bradshaw et al. 1997	Canada	Northeast Alberta	Boreal woodland caribou (R.t. caribou)	East Side Athabasca River herd	Hydrocarbon	Telemetric or GPS	Negative	No	Movement or behaviour
Bradshaw et al. 1998	Canada	Northeast Alberta	Boreal woodland caribou (R.t. caribou)	East Side Athabasca River herd	Hydrocarbon	Modelling or simulation	Negative	No	Forage, contaminant, or body condition
Cameron et al. 1992	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Negative	Snowmelt included (late or early)	Distribution or habitat selection
Cameron et al. 1995	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Telemetric or GPS; Other: Aerial telemetry	Negative	No	Distribution or habitat selection; Movement or behaviour
Cameron et al. 2005	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Negative	No	Vital rates and demography
Chen et al. 2017	Canada	Central Northwest territories	Barren ground caribou (R.t. groendlandicus)	Bathurst herd	Mineral	Vegetation survey	Negative	No	Forage, contaminant, or body condition
Cronin et al. 1998	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Null or n.s.	No	Distribution or habitat selection
Cronin et al. 2000	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Null or n.s.	No	Vital rates and demography
Curatolo & Murphy 1986	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Negative	No	Movement or behaviour
Dyer et al. 2001	Canada	Northern Alberta (Athabasca)	Boreal woodland caribou (R.t. caribou)	West Side Athabasca River herd	Hydrocarbon	Telemetric or GPS	Negative	No	Distribution or habitat selection
Eftestøl et al. 2019	Norway	Finnmark	Semi-domesticated reindeer (R.t. tarandus)	NA	Mineral	Telemetric or GPS	Negative	No	Distribution or habitat selection
Eriksson et al. 1990	Sweden	Norrbotten	Semi-domesticated reindeer (R.t. tarandus)	NA	Mineral	Tissue collection; Vegetation survey	Null or n.s.	No	Forage, contaminant, or body condition
Fancy 1983	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Null or n.s.	No	Movement or behaviour
Francis & Hamm 2011	Canada	Northern Yukon (Eagle plain bassin)	Barren ground caribou (R.t. groendlandicus)	Porcupine herd	Hydrocarbon	Modelling or simulation	Negative	Climate change modelling	Forage, contaminant, or body condition
Fullman et al. 2021	U.S.A	National Petroleum Reserve, Alaska	Barren ground caribou (R.t. granti)	Teshekpuk and Western Arctic Herd	Hydrocarbon	Modelling or simulation	Negative	No	Distribution or habitat selection
Garry et al. 2018	U.S.A	Red dog mine, Alaska	Barren ground caribou (R.t. granti)	Western Arctic and Teshekpuk herd	Mineral	Telemetric or GPS; Tissue collection	Null or n.s.	No	Distribution or habitat selection; Forage, contaminant, or body condition
Garry et al. 2021	U.S.A	Red dog mine, Alaska	Barren ground caribou (R.t. granti)	Western Arctic herd	Mineral	Tissue collection	Null or n.s.	No	Forage, contaminant, or body condition
Haskell & Ballard 2008	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Negative	Snowmelt included	Distribution or habitat selection
Haskell et al. 2006	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Negative	Snowmelt included	Distribution or habitat selection
Hassan et al. 2021	Norway	Finnmark, Troms, Nordland and Sør-Trøndelag	Semi-domesticated reindeer (R.t. tarandus)	NA	Mineral	Tissue collection	Negative	No	Forage, contaminant, or body condition
Herrmann et al. 2014	Canada and Sweden	Northern Québec and central Lapland	Boreal migratory caribou (R.t. caribou); Semi-domesticated reindeer (R.t. tarandus)	Rivière-aux-feuilles and Rivière-George herds (Qc)	Mineral	Interview	Negative	No	Distribution or habitat selection; Movement or behaviour; Forage, contaminant, or body condition
Johnson et al. 2005	Canada	Nunavut and Northwest Territories border	Barren ground caribou (R.t. groendlandicus)	Bathurst herd	Mineral	Telemetric or GPS	Negative	No	Distribution or habitat selection
Johnson et al. 2015	Canada	Eastern British Columbia	Boreal woodland caribou (R.t. caribou)	Central mountain populations	Hydrocarbon	Telemetric or GPS	Negative	No	Distribution or habitat selection
Johnson et al. 2020	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Telemetric or GPS	Negative	No	Distribution or habitat selection
Joly et al. 2006	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Negative	No	Distribution or habitat selection
Kater & Baxter 2025	Sweden	Norrbotten	Semi-domesticated reindeer (R.t. tarandus)	NA	Mineral	Modelling or simulation	Negative	Snow included	Distribution or habitat selection
Kendrick & Lyver 2005	Canada	Central Northwest territories	Barren ground caribou (R.t. groendlandicus)	Beverly and Bathurst herds	Mineral	Interview	Negative	No	Movement or behaviour
Kim et al. 1998	Canada	South of Northwest Territories	Barren ground caribou (R.t. groendlandicus)	NA	Mineral	Tissue collection	Null or n.s.	No	Forage, contaminant, or body condition
KløckerLarsen et al. 2022	Sweden	Norrbotten	Semi-domesticated reindeer (R.t. tarandus)	NA	Mineral	Interview	Negative	No	Distribution or habitat selection; Movement or behaviour; Forage, contaminant, or body condition
Kruse et al. 2004	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Porcupine herd	Hydrocarbon	Modelling or simulation	Negative	Climate change modelling	Vital rates and demography
Kuemmerle et al. 2014	Russia	Northern Russia	Migratory wild reindeer (R.t. tarandus)	NA	Hydrocarbon	Modelling or simulation	Negative	Climate change modelling	Distribution or habitat selection
Lundin et al. 2015	Canada	Central Alberta	Boreal woodland caribou (R.t. caribou)	Algar, Egg pony and Wiau herds	Hydrocarbon	Feces collection	Null or n.s.	No	Forage, contaminant, or body condition
MacNearney et al. 2021	Canada	West-Central Alberta	Boreal woodland caribou (R.t. caribou)	Central mountain populations	Hydrocarbon	Telemetric or GPS	Negative	No	Distribution or habitat selection
McCabe 1994	U.S.A	Arctic National Wildlife Refuge, Alaska	Barren ground caribou (R.t. granti)	Porcupine herd	Hydrocarbon	Telemetric or GPS; Vegetation survey	Negative	Snowmelt and plant phenology included	Forage, contaminant, or body condition; Vital rates and demography
Muhly et al. 2015	Canada	Northeast Alberta	Boreal woodland caribou (R.t. caribou)	East Side Athabasca River herd	Hydrocarbon	Telemetric or GPS; Modelling or simulation	Negative	No	Distribution or habitat selection; Movement or behaviour
Murphy & Curatolo 1987	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central arctic herd	Hydrocarbon	Aerial or ground visual survey	Negative	No	Movement or behaviour
Nellemann & Cameron 1996	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central arctic herd	Hydrocarbon	Aerial or ground visual survey	Negative	No	Distribution or habitat selection
Nellemann & Cameron 1998	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Negative	No	Distribution or habitat selection
Noel et al. 1998	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey; Cameras	Positive	No	Distribution or habitat selection; Movement or behaviour
Noel et al. 2004	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Null or n.s.	Snowmelt included (late or early)	Distribution or habitat selection
O'Hara et al. 2003	U.S.A	Red dog mine, Alaska	Barren ground caribou (R.t. granti)	Western Arctic and Teshekpuk herd	Mineral	Tissue collection	Null or n.s.	No	Forage, contaminant, or body condition
Parlee & Manseau 2005	Canada	Central Northwest territories	Barren ground caribou (R.t. groendlandicus)	Bathurst, Beverly and Ahiak herd	Mineral	Interview	Negative	No	Movement or behaviour
Plante et al. 2018	Canada	Northern Québec	Boreal migratory caribou (R.t. caribou)	Rivière-aux-Feuilles and Rivière-George herds	Mineral	Telemetric or GPS	Negative	No	Distribution or habitat selection; Movement or behaviour
Plante et al. 2020	Canada	Northern Québec	Boreal migratory caribou (R.t. caribou)	Rivière-aux-feuille and Rivière-George herds	Mineral	Telemetric or GPS	Null or n.s.	weather variables included	Vital rates and demography
Polfus et al. 2011	Canada	Northwest British Columbia	Boreal woodland caribou (R.t. caribou)	Atlin herd, Northern Mountain population	Mineral	Telemetric or GPS	Negative	No	Distribution or habitat selection
Pollard et al. 1996a	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central arctic herd	Hydrocarbon	Aerial or ground visual survey	Positive	No	Distribution or habitat selection
Pollard et al. 1996b	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Vegetation survey	Positive	Temperature and wind velocity included	Forage, contaminant, or body condition
Prichard et al. 2020	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Telemetric or GPS	Negative	No	Distribution or habitat selection; Movement or behaviour
Prichard et al. 2022	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Aerial or ground visual survey	Negative	No	Distribution or habitat selection; Movement or behaviour
Rempel et al. 2021	Canada	Northern Ontario	Boreal woodland caribou (R.t. caribou)	NA	Mineral	Modelling or simulation	Negative	Climate change modelling	Vital rates and demography
Semeniuk et al. 2014	Canada	West-Central Alberta	Boreal woodland caribou (R.t. caribou)	Little Smoky herd	Hydrocarbon	Modelling or simulation	Negative	No	Distribution or habitat selection; Forage, contaminant, or body condition
Severson et al. 2023	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	Central Arctic herd	Hydrocarbon	Telemetric or GPS	Negative	No	Distribution or habitat selection; Movement or behaviour
Smith & Johnson 2023	Canada	Central Northwest Territories	Barren ground caribou (R.t. groendlandicus)	Bathurst, Bluenose-East, and Beverly/Ahiak herds	Mineral	Telemetric or GPS	Negative	No	Movement or behaviour
Smith et al. 2023	Canada	Central Northwest territories	Barren ground caribou (R.t. groendlandicus)	Bathurst, Bluenose-East, and Beverly/Ahiak herds	Mineral	Aerial or ground visual survey; Feces collection	Negative	No	Movement or behaviour; Forage, contaminant, or body condition
Suzuki & Parker 2016	Canada	Northeast British Columbia	Boreal woodland caribou (R.t. caribou)	Northern mountain population	Hydrocarbon and Mineral	Modelling or simulation	Negative	No	Distribution or habitat selection
Thomas & Gates 1999	Canada	Northern Saskatchewan	Barren ground caribou (R.t. groendlandicus)	Beverly herd	Mineral	Tissue collection	Null or n.s.	No	Forage, contaminant, or body condition
Thomas et al. 1994	Canada	Central Northwest territories	Barren ground caribou (R.t. groendlandicus)	Beverly, Wager bay and Qamanirjuaq herds	Mineral	Tissue collection	Null or n.s.	No	Forage, contaminant, or body condition
Tracz et al. 2010	Canada	Northeast Alberta	Boreal woodland caribou (R.t. caribou)	West Side Athabasca River herd	Hydrocarbon	Telemetric or GPS	Null or n.s.	No	Distribution or habitat selection
Turunen et al. 2024	Finland	Northern Lapland	Semi-domesticated reindeer (R.t. tarandus)	NA	Mineral	Interview	Negative	No	Distribution or habitat selection; Forage, contaminant, or body condition
Watkinson et al. 2021	Canada	Central Northwest Territories	Barren ground caribou (R.t. groendlandicus)	Bathurst herd	Mineral	Vegetation survey	Negative	No	Forage, contaminant, or body condition
Weir et al. 2007	Canada	Southwestern Newfoundland	Boreal woodland caribou (R.t. caribou)	La poile herd	Mineral	Aerial or ground visual survey	Negative	No	Distribution or habitat selection
Whitten & Cameron 1983	U.S.A	Prudhoe Bay, Alaska	Barren ground caribou (R.t. granti)	central arctic herd	Hydrocarbon	Aerial or ground visual survey; Telemetric or GPS	Negative	No	Distribution or habitat selection
Whitten et al. 1992	U.S.A	Arctic National Wildlife Refuge, Alaska	Barren ground caribou (R.t. granti)	Porcupine herd	Hydrocarbon	Telemetric or GPS	Negative	No	Vital rates and demography
Wilson et al. 2013	U.S.A	National petroleum reserve, Alaska	Barren ground caribou (R.t. granti)	Teshekpuk Herd	Hydrocarbon	Modelling or simulation	Negative	No	Distribution or habitat selection
Wilson et al. 2014	U.S.A	Northwest alaska	Barren ground caribou (R.t. granti)	Western Arctic herd	Mineral	Telemetric or GPS	Negative	No	Distribution or habitat selection