

APPLIED ECOLOGY

Undermining subsistence: Barren-ground caribou in a “tragedy of open access”

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Sustaining arctic/subarctic ecosystems and the livelihoods of northern Indigenous peoples is an immense challenge amid increasing resource development. The paper describes a “tragedy of open access” occurring in Canada’s north as governments open up new areas of sensitive barren-ground caribou habitat to mineral resource development. Once numbering in the millions, barren-ground caribou populations (*Rangifer tarandus groenlandicus*/*Rangifer tarandus granti*) have declined over 70% in northern Canada over the last two decades in a cycle well understood by northern Indigenous peoples and scientists. However, as some herds reach critically low population levels, the impacts of human disturbance have become a major focus of debate in the north and elsewhere. A growing body of science and traditional knowledge research points to the adverse impacts of resource development; however, management efforts have been almost exclusively focused on controlling the subsistence harvest of northern Indigenous peoples. These efforts to control Indigenous harvesting parallel management practices during previous periods of caribou population decline (for example, 1950s) during which time governments also lacked evidence and appeared motivated by other values and interests in northern lands and resources. As mineral resource development advances in northern Canada and elsewhere, addressing this “science-policy gap” problem is critical to the sustainability of both caribou and people.

INTRODUCTION

Barren-ground caribou (*Rangifer tarandus groenlandicus*/*Rangifer tarandus granti*) are among the most valued species in the circumpolar arctic/subarctic and one of the world’s last major migratory wildlife species (1). As the human footprint on arctic/subarctic ecosystems grows, so too does the challenge of sustaining many of these caribou herds. Once numbering in the millions, barren-ground caribou populations in northern Canada and Alaska have declined significantly over the last two decades (2, 3). These declines are not new; many Indigenous elders have stories of earlier periods in their own lifetimes and oral histories of “when the caribou did not come.” Scientists also have well-developed models of 40- to 70-year population cycles for most large herds (4). Explanations for these cycles are many; however, as some herds reach critically low levels, human disturbance of the range has become a major focus of debate. We examine the science and traditional knowledge surrounding human stresses on barren-ground caribou and the ways in which this knowledge has and has not informed the governance of this important arctic/subarctic species. The research outcomes point to a “science-policy gap” that is having costly implications for both caribou and people.

As caribou populations have declined in recent years, the governance response has almost exclusively focused on curbing Indigenous subsistence harvesting. The evidence behind such a singular focus, and the lack of attention to other known stresses on populations and habitats, has never been explicit. Drawing on 13 years of harvest data, from two regions of the Northwest Territories and qualitative research on adaptive practices, we demonstrate that perceptions of subsistence harvest as a threat to barren-ground caribou sustainability have little foundation. The alternative hypothesis offered here is that habitat disturbance caused by resource development is the greater stress on caribou populations.

Specifically, we offer the case of the Bathurst caribou herd, where key areas of the summer and fall range have been taken up for mining exploration and development in the last two decades; this disturbance has led to the loss and degradation of key habitat for caribou, thereby exacerbating the decline of the herd. This hypothesis is well supported by a growing body of scientific and traditional knowledge research but has had little influence over decisions about resource development in the Yukon and Northwest Territories. Because governments approve many new mining projects and open up new areas of caribou habitat for mineral exploration, a tragedy of “open access” is unfolding particularly in the Bathurst caribou range, where caribou numbers are at critically low levels and mining activity has boomed since the early 1990s (5). The tragedy, both ecological and socio-economic, mirrors historic periods of wildlife management in northern Canada during which time caribou management was explicitly about advancing private interests in northern lands and resources at the expense of Indigenous cultures and livelihoods (6).

Setting: Barren-ground caribou and Indigenous communities in northern Canada

Barren-ground caribou (*R. tarandus groenlandicus*/*R. tarandus granti*) are an important species to many Indigenous peoples across the circumpolar north. They are known regionally to the Inuvialuit, Gwich’in, and Denesöliné as *tuktu* (Inuvialuitun), *vadzaih* (Teet’it Gwich’in), and *zetthen* (Denesöliné). According to biologists, there are 11 to 13 barren-ground caribou herds or subpopulations in northern Canada and Alaska (Fig. 1). The herds of importance to the Inuvialuit and Gwich’in communities of the Northwest Territories and Yukon are the Porcupine, Cape Bathurst, and Bluenose (east/west); they have been a mainstay of Inuvialuit and Gwich’in cultures and economies for many hundreds, if not thousands, of years. Similarly, the Denesöliné peoples are one of five Indigenous groups in the Northwest Territories with a strong relationship to the Bathurst caribou herd as well as the neighboring Beverly and Ahik herds.

The Porcupine caribou range roughly covers an area of 250,000 km²; the calving grounds are in Alaska, but the migration follows a path

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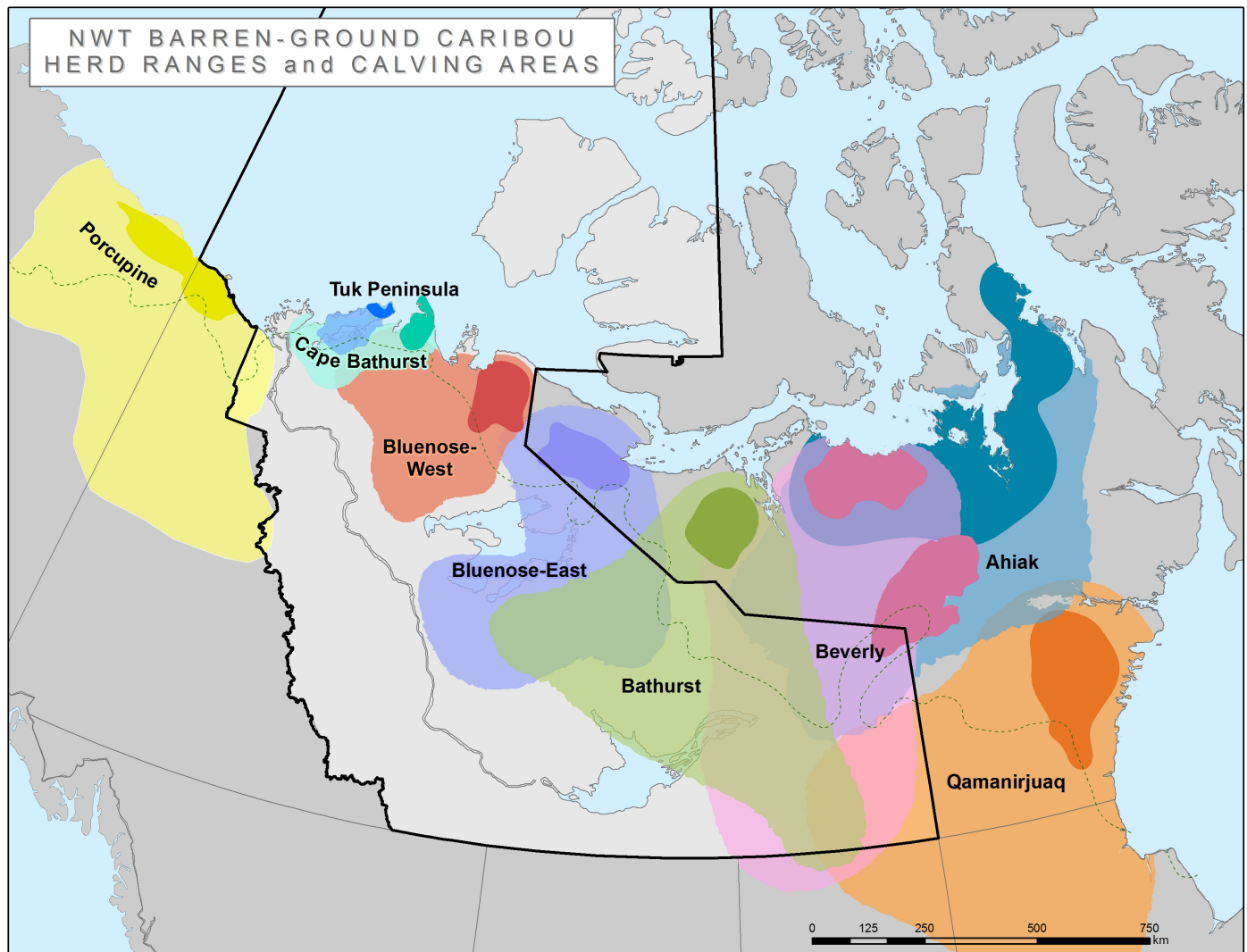


Fig. 1. Caribou herds in Northwest Territories (NWT) and Yukon.

through the Yukon and into the Northwest Territories (7). Although a key focus of the paper is on the Porcupine caribou herd, data for adjacent herds are also presented as a context for the discussion on harvesting data (that is, harvesters do not necessarily differentiate their harvest by herd). The Bathurst caribou range is considered to be over 400,000 km²; their migration begins in the calving grounds near Bathurst Inlet in Nunavut and follows south into central Northwest Territories to the Saskatchewan border. Both the Bathurst and Porcupine herds are characterized by 40- to 70-year population cycles (Figs. 2 and 3) (4). Forage quality and quantity are theorized as the central regulating factors in population size and cycles. Because caribou numbers increase and impacts on habitat grow, carrying capacity is exceeded and the associated nutritional stress of lost or degraded forage leads to poor calf recruitment (8). Recovery of these herds is considered a reflection of the speed and spatial extent of habitat regeneration (that is, given that arctic subarctic vegetation is slow to regenerate, so too is caribou population recovery) (9).

Literature review

We are guided by common-pool resource theory and previous research on Indigenous resource management practices and institutions (that is,

rules and social norms) (10); this body of work, including that in northern Canada, demonstrates how Indigenous peoples have sustained both their natural resources and subsistence economies despite significant ecological variability (11, 12). We also situate our work in the body of historical research on wildlife management (6, 13) and subsistence harvesting (14–16). We challenge stereotypes about Indigenous harvesters as indiscriminate hunters by presenting data and trends about Indigenous caribou harvesting that, coupled with case studies of harvester and community adaptation, provide evidence that subsistence harvest presents little threat to caribou. By doing so, we also advance insights around subsistence as a livelihood practice that is inextricably linked with conservation (that is, conservation hunting) (17). Although historical accounts of subsistence in arctic ecosystems are detailed and well theorized in the anthropology, geography, and economics literature, there has been relatively limited attention paid to longitudinal trends and patterns in contemporary subsistence harvesting, particularly in the last two decades and in relation to barren-ground caribou population dynamics in Canada.

The paper weaves together both science and traditional knowledge research about the issue of human disturbance in arctic ecosystems (18).

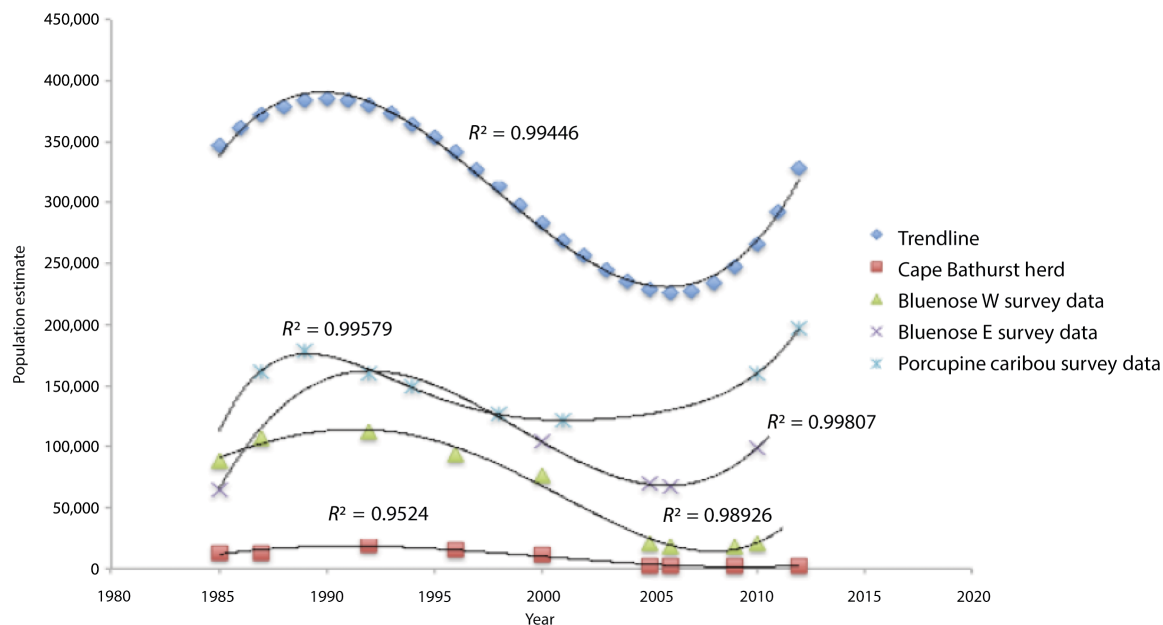


Fig. 2. Population trends for four barren-ground caribou herds (111).

Compared with the significant body of work on “climate change,” relatively little critical attention has been paid to the cumulative effects of mining activity in the arctic and its impacts on caribou systems (caribou and people) (19). To address this gap, we offer the theory of open access to help explain the ways in which governance arrangements related to mineral resource development allow virtual “free-entry” access and development of areas considered critical caribou habitat and homelands to many northern Indigenous peoples (5).

The relationship between subsistence harvesting and caribou population dynamics: Insights from Inuvialuit and Gwich’in harvest data

The harvesting of barren-ground caribou and other traditional foods is a cornerstone of northern Indigenous cultures, economies, and health; where communities face limited availability of affordable market foods, such harvest is critical to food security (20). The literature on Indigenous subsistence is diverse and has roots in the field of anthropology as well as sociology and economics (21, 22). It is loosely defined as a mode of production that meets basic needs through the flow of valued resources. It is distinct from commercial modes of production in that it does not entail the accumulation of those resources. There are numerous terms that have been used to describe subsistence activities such as “shadow,” “non-structured,” and “unorganized”; however, these terms have not captured the many complex ways in which people organize at the local level to meet their needs and have instead stigmatized those participating in subsistence activities as “non-progressive, backward, and resistant to change” (21).

During the decline of caribou in the 1950s, biologists such as Banfield (23) wrote often about Indigenous subsistence harvesting as a major problem for caribou; however, harvest levels were unknown during this period and any theories on harvesting as a driver of population declines were not empirically defined; rather, they were created and sustained through anecdote, conjecture, and cultural bias (14). These biases against subsistence were indicative of the colonial mindset of the time. Hobbesian assumptions about Indigenous peoples as “primitive”—without the knowledge and capacity to manage the re-

sources upon which they depend for own survival—are clearly visible in archival record of this period (13). Much has changed in northern Canada since the 1950s; more is known about natural cycles in caribou populations. There is also greater recognition of Indigenous rights to harvest (for example, as defined in both the Inuvialuit and Gwich’in land claim agreements). However, among the growing urban public, whose notions of food are shaped by what is available in grocery stores, there is little acceptance of Indigenous hunting as a contemporary cultural practice that puts food on the table. Environmental groups including animal rights advocates are also quick to dismiss “hunting” on moral grounds. Even ecotourists, prone to celebrate the “ecological Indian,” are opposed to hunting on the basis that hunting practices are no longer traditional (that is, people are no longer using bows and arrows and stone tools) (24, 25). Those operating under these biased, if not racist, assumptions, that Indigenous people should remain frozen in time (circa, 1899), have felt justified in raising fears of an inevitable “tragedy of the commons”—it is assumed that caribou will be “overhunted” to the point of extirpation unless regulated by the government.

The concept of the tragedy of the commons was made famous by Hardin in the 1960s; he sought to explain the free-rider problem or tendency for individuals to act in their own self-interest in the short term regardless of the implications for others or themselves over the long term (26). Although recent texts are more sensitive to questions of Indigenous peoples (27), scholars of conservation biology have tended to categorize subsistence harvesters in terms that are no different than other kinds of predators who hunt indiscriminately and without forethought to their fellow harvesters or those in the future (16). The tragedy of the tragedy of the commons is the inevitable loss or extirpation of a valued species with accompanying ecological and socioeconomic consequence. Although some tragedies during historic periods have been theorized and modeled, evidence of what archaeologists describe as the “overkill hypothesis” is limited (28). Most extirpations or biodiversity losses over the last two centuries are attributed to European colonization and the advance of large-scale development and land use

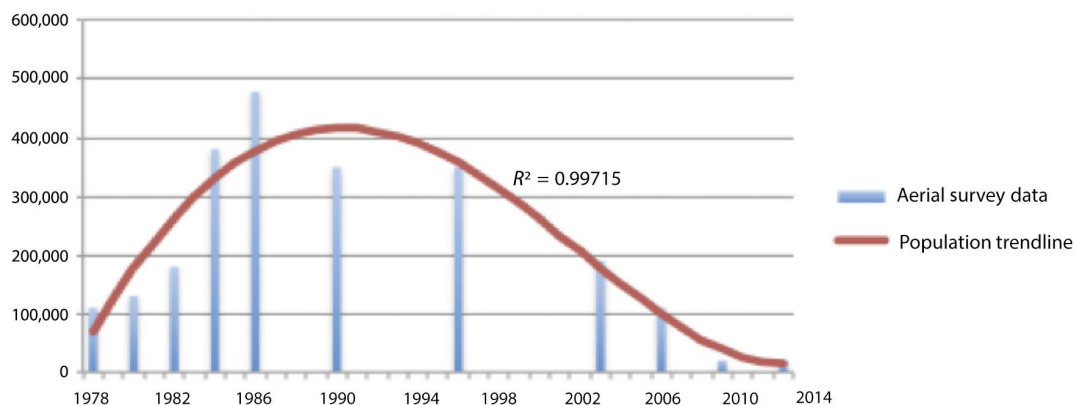


Fig. 3. Bathurst caribou population data and trends (111).

change (for example, commercial fishing and deforestation) (29, 30). There are relatively few documented cases in North America and elsewhere where extirpations of species are attributable to Indigenous harvesting. Why?

Some anthropologists have claimed that the answer is accidental conservation (24)—because Indigenous people lacked technology of a sophisticated nature, there was no real threat to the resource sustainability. However, this accidental conservation theory has been little substantiated; more evidence suggests that communities have been successful in resource conservation owing to complex practices and institutions that have developed through social learning over many generations (31). Over 30 years of research on the commons, including that of Nobel Laureate Elinor Ostrom, reveals that Hardin's theory does not really apply to communities with long histories of resource use and secure property arrangements. What Hardin did not recognize was that even in the absence of formal government regulation or private property arrangements, many communities with long histories of collective resource use, including hunting cultures of northern Canada, have sophisticated rule systems that prevent unsustainable use; these rules enable communities to resolve the issue of individual self-interest at the cost of collective interest by creating systems of management that ensure joint outcomes (32). Owing to the flexibility and adaptiveness to ecological variability, many of these rule systems are far more effective at conservation than those led by central governments and private interests (10, 33).

A critical element of the success of these community-based arrangements is their foundation in traditional knowledge (34), the cumulative body of knowledge, practice, and belief that has developed over many generations about peoples' relationship to their environment and to each other (35). Over the last 30 years, a large body of traditional knowledge has been documented in northern Canada about caribou ecology. Recognition of the value of this knowledge became the basis for the co-management of caribou in the Northwest Territories as early as 1982 in the case of the Beverly herd and in 1985 in the case of the Porcupine herd (36). Although there is a draft caribou range management plan being developed, there is no similar co-management board or process in place for the Bathurst herd.

There are myriad successes that are attributed to co-management processes in the Canadian north; there are also strong critiques of wildlife co-management as being a system of governance that is more focused on the management of Indigenous peoples than natural resources (37). However, these co-management arrangements do not represent the whole of "caribou management"; individual harvesters

and communities, who have been harvesting caribou for generations, have their own practices and rules for "taking care of caribou."

Practices and rules for taking care of caribou

In addition to evidence from the harvest data, a variety of adaptive practices and institutions (social norms and informal rules) for dealing with variability in the availability of barren-ground caribou were identified from a literature review (Table 1). Many of these practices and institutions are the result of systematic observation and interpretation of changes in caribou and related ecological conditions. Ecological variability, which has always been characteristic of barren-ground caribou, necessitated the development of systematic methods of observation and communication (38, 39). These practices are still in place today; an Inuvialuit elder or Denesöliné harvester will look for caribou in the same places using the same indicators and employing the same methods year after year after year. Because resources become less abundant, there is an increase in the scope and spatial scale of either direct observation or sharing of observations with other communities. Over time and when communicated and interpreted by others, this knowledge provides the cues by which harvesters and/or communities adapt. For example, when caribou are no longer found in areas where they were known to be abundant (for example, major water crossings), it triggers changes in the scope of observation and a decrease in harvest. This adaptation is more than a mechanistic response; people make changes to their harvesting activities based on concern for caribou and for future generations. As previously explained by the late Denesöliné elder Maurice Lockhart, "people who didn't care so much would not notice the changes" (40).

The literature on food security suggests that the costs of declining harvest are offset in the short term by a variety of factors such as social networking (that is, knowledge sharing and food sharing). The flexibility of food and knowledge sharing networks is well evidenced in research about northern economies; because some families and communities experience shortages, others are able to address the need through the sharing of alternative resources (for example, fish, muskoxen, and moose). Over the long term, there are also a variety of other kinds of innovations in a process that enable people to deal with decreased availability of resources harvested from the land (that is, traditional or country food).

A current and potential tragedy of open access mineral resource development in the Bathurst and Porcupine caribou ranges

For many northern Indigenous peoples, the real tragedy for caribou and peoples stems from weaknesses in governance, specifically the absence

Mechanism and case study example	Adaptive outcome
Adaptive caribou harvesting—decreased harvesting during periods of decline (and corresponding increase in harvest of other species and/or substitution for market foods) (11, 62, 64, 110, 113–115)	Decreased hunting pressure on declining resources; diversification of traditional diets and/or increased dependence on market foods of lesser nutritional value
Increase in depth of observation by individual harvesters, communities (39, 54, 92, 93, 114, 116–119)	Increase in the scope of traditional knowledge available on which to make harvest decisions
Increase in organization and communication at larger scales (36, 120, 121)	More complex institutional arrangements; opportunities for cross-scale decision-making
Increased in enforcement of informal property rights (for example, traditional hunting territory) and rules for caribou harvest (122, 123)	Self-organized enforcement of rules to protect caribou
Strengthening and/or expansion of food sharing networks within and outside the caribou range (63, 124, 125)	Increase in knowledge generation and transmission (including with younger generations) within and between communities
Cultural rediscovery, social learning, and innovation to address food shortages (108, 126)	Increase in the breadth of potential solutions to food shortages
Cultural and spiritual learning (35, 127)	New spiritual learning; changes in the sociocultural and spiritual relationship of people and caribou

of power to limit mineral exploration and development in sensitive caribou habitat (41, 42). We characterize the “open for business” approach to encouraging exploration and development as an open access problem. Open access problems are those characterized by a lack of accepted and enforced rules mediating natural resource access and use. In Canada, the mining regulations in place for the Northwest Territories and Yukon essentially allow open access to many areas considered important barren-ground caribou habitat. There are few opportunities to limit initial phases of exploration in that much of the territories are defined as Crown or public land by the federal government. All such Crown land, with few exceptions, is open for staking under existing mining regulations [for example, Northwest Territories Mining (43) under the Territorial Lands Act (44)]. There are also very few barriers to entry to staking—virtually anyone with limited qualifications can stake a claim (45). Although consideration of environmental impacts is required at later stages of assessment, the cumulative effects of development during earlier stages represent a significant adverse effect. Early and advanced exploration phases, which include constructed infrastructure (camps), air and road traffic, as well as human activity, can all take place without free, informed, and previous consent of Indigenous communities. Advanced exploration projects can continue on for many years; once active, there are very few mechanisms to stop their full development. Even during full environmental assessment, there are few examples where approval has not been granted even when communities have raised concerns about significant adverse effects or opposed the project entirely (46). What follows is the presentation and discussion of data on subsistence harvest patterns and those associated with mineral resource development; we explore how each may be related to changes in caribou populations with particular focus on the Bathurst caribou herd.

RESULTS
Inuvialuit and Gwich'in subsistence harvest patterns

The regulation of subsistence caribou harvesting has become a critical focus of the Porcupine Caribou Management Board over the last 10 years.

To date, millions of dollars have been spent on harvest management planning for the Porcupine herd and Bathurst herd (2007–2016). On the one hand, Indigenous leaders and communities have participated in these processes in good faith with the aim of doing their part to take care of the caribou (47, 48). However, at their core, these harvest management planning processes appear to be based on explicit or implicit assumptions that Indigenous harvesting poses a major risk to caribou sustainability and that harvesters will not change their harvesting practices when faced with declining caribou numbers, without the assistance of central governments.

Two of the three largest data sets related to Indigenous harvesting in the Northwest Territories (Inuvialuit Harvest Study and Gwich'in Harvest Study) were reviewed, and harvest data were summarized for this same time period (Fig. 4) (49, 50). The harvest data are publicly available from the regional co-management boards, and methods of data collection and analysis are well documented (51, 52). All active hunters were identified as participants; response rates were 90.1% in the case of the Gwich'in and 87% for the Inuvialuit. The harvest of barren-ground caribou was documented for 1988–1997 in the Inuvialuit Settlement Region (ISR) and for 1995–2000 in the Gwich'in Settlement Region (51, 52).

Although there was variability over the two periods of study, the overall decline in harvest represented in the Inuvialuit and Gwich'in harvest data are shown (Fig. 4); from peak harvest to lowest harvest, the change in both the Inuvialuit and Gwich'in harvest combined (average) was –44.6% (Fig. 4). The correlation between harvest and caribou population decline was strongly positive and statistically significant for both the Inuvialuit harvest data (0.61) and the Gwich'in harvest data (0.81).

We also examined the relationship between the Inuvialuit harvest data and caribou population levels for the same four herds (Fig. 5); the trend between harvest and population was positive ($y = 5^{-5x} - 13.875$) and statistically significant ($P = 0.0271$). The graph in Fig. 5 suggests that when the population of the four caribou herds exceeds 320,000 animals, every subsequent 10,000 increase in the population results in the harvest of an additional 0.5 caribou per capita (Fig. 5).

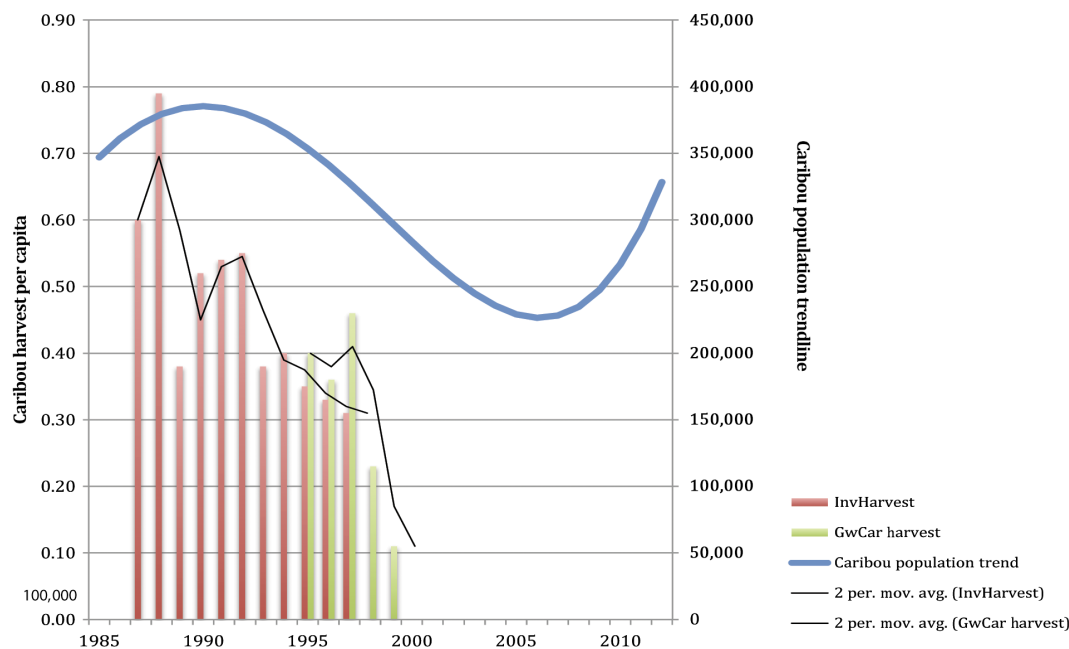


Fig. 4. Gwich'in and Inuvialuit harvest data and trends.

Where the population of Inuvialuit beneficiaries in Aklavik, Tuktoyaktuk, Inuvik, and Paulatuk is reported to be roughly 1385 persons during the years of the study, the total increase in harvest per year is 332 animals (0.001% of the total herd at that time). There were insufficient observations (years of data) in the case of the Gwich'in Harvest Study to analyze the relationship between harvest and caribou population dynamics in this region.

The data offered (Figs. 4 and 5) controvert assertions about subsistence as a driver of population dynamics have little empirical foundation. We also examined other variables including climatic variables (for example, average temperature and precipitation levels), cost of living, and employment. Although there was no significant relationship between harvest levels and these climate and cost of living variables, harvest levels and employment trends in the study communities appeared to be somewhat related. Specifically, there was a negative correlation between employment and available harvest data in the five Inuvialuit (−0.31) and Gwich'in communities (−0.48), suggesting that economic conditions may also affect harvest trends (that is, as employment went up, harvest levels decreased), but not to the same degree as population trends (see explanation in the paragraph above).

How do these trends compare to similar work elsewhere? Are there other data that might help us understand this trend? Researchers in Alaska also documented a decline in harvest levels during 1964–2008 (roughly 72%) (53). Similarly, Old Crow evidenced a 38% decline in caribou meat consumption between 1992 and 2008. In the Bathurst range between 2000 and 2014, average consumption of caribou meat by Łutsël K'e Dene First Nation dropped by 30% and then further dropped by close to 90% between 2014 and 2017 (54). These declines in harvest are also consistent with data from many diet and nutrition studies; in many parts of northern Canada, traditional food consumption is falling steadily, resulting in a substitution of other traditional and market foods, with a consequent increase in nutrient deficiencies (for example, vitamin D and iron) and lifestyle illnesses (for example, cardiovascular disease) (55). Given that there are similar trends else-

where, we might hypothesize that the data trends from the Inuvialuit and Gwich'in data are not anomalies but are good examples of northern Indigenous subsistence harvesting patterns during periods of population decline.

Although lifestyle change may be a partial explanation for declining harvests (that is, given the change in employment), the stronger correlation and relationship is between harvest and resource availability. That is, harvesters do not hunt at all costs but are sensitive to the scarcity of the resource.

This sensitivity is well established in other areas of wildlife and fisheries research; harvest has been used as a proxy for trends in population in relation to a variety of species. For example, harvest data for deer and moose in North America and in northern Europe have been positively correlated with population estimates from aerial surveys and mark and recapture methods (56–60).

One explanation for such harvester sensitivity is simple economics. When animals are abundant, it is assumed that the input and opportunity costs of harvest are relatively low. During periods of decline, costs increase because animals become more difficult to find, and harvesters (particularly those with limited hunting experience and/or with food resource alternatives) tend to look for less costly alternatives (that is, require less effort or input costs). But these economic explanations do not provide the whole story. In the Inuvialuit and Gwich'in regions, where adaptation to ecological variability is part of their way of life, decisions not to harvest when there are fewer caribou around are likely linked to social norms or “rules” of stewardship (for example, taking care of caribou) and other related kinds of adaptive management practices (Table 1).

Case studies on adaptation to contemporary caribou population change

Case study research between 2007 and 2012 in five Indigenous communities revealed beliefs and adaptive practices as well as systems of decision-making that enabled communities to deal with reported de-

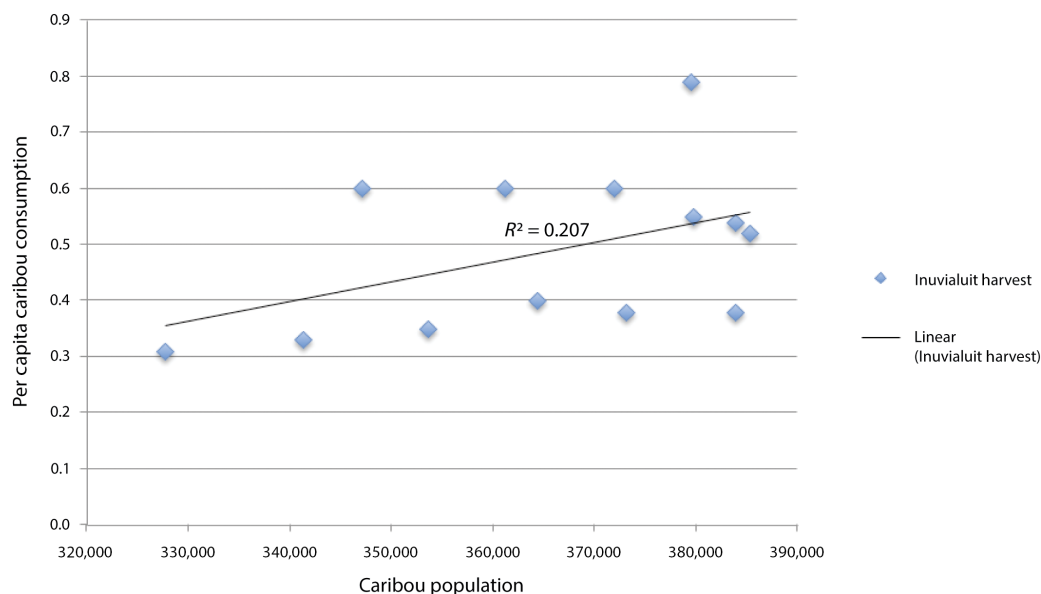


Fig. 5. Relationship between Inuvialuit harvest and caribou population change from 1987 to 1997.

clines in caribou numbers. A starting point in understanding these practices is the recognition that caribou population decline is not a fact but a sociocultural construct. Caribou counts including aerial photo surveys, although the standard method of accounting for population change, offer one kind of narrative or model, but traditional knowledge holders have different ways of knowing caribou (61). In collaboration with the Inuvialuit and Gwich'in communities of Aklavik, Fort McPherson, Paulatuk, and Old Crow, and with the Denesōliné community of Łutsël K'e Dene First Nation, longitudinal knowledge including individual observations and oral histories about previous periods of population change provided the foundation for understanding and coping with the significant decrease in caribou numbers observed and experienced. The trust of harvesters and communities in their own knowledge and respect for their elders were also critical to interpreting and managing the imposition of other kinds of knowledge considered less legitimate by community members (54, 62).

In the case of Fort McPherson, researchers identified a range of rules for caribou harvest known and in use within the community including by Gwich'in youth. These included principles such as “take only what you need,” details about when, where, and how caribou should be harvested, as well as rules about harvest sharing (62). Harvest sharing across larger sociopolitical boundaries including the Canada–United States border is another way that communities offset decreases in caribou meat in some places and in some years as well documented with the Vuntut Gwich'in of Old Crow, Yukon (63). Research in Paulatuk in the ISR was focused on the complex relationship between employment and caribou harvesting; finding ways of working together within family groups and across the community as a whole was critical to ensuring that the most vulnerable members of the community (for example, single mothers and elders) did not suffer disproportionately from the scarcity of caribou in that region. In the nearby region of Fort Good Hope, “community hunts” that target other sources of traditional food (that is, moose) were developed to offset the decreased availability of caribou meat (64).

Data from the Inuvialuit and Gwich'in harvest studies, coupled with the evidence about the effectiveness of Indigenous institutions from

both the literature review (Table 1) and case studies, provide credible evidence that there is little reason to fear that barren-ground caribou herds may be extirpated at the hands of subsistence harvesters. In the following section, we offer evidence that the greater threat to caribou population herds in the Northwest Territories, Yukon, and Alaska is increasing pressure on caribou habitat because of resource development.

A current and potential tragedy of open access mineral resource development in the Bathurst and Porcupine caribou ranges

Over 30 million hectares of land in the Northwest Territories have been disturbed as a result of mineral staking, exploration, construction, and project development. Much of this area is in the mineral-rich area known as the Slave Geological Province, located in the range of the Bathurst caribou. The period during which the mining began to boom in the 1990s (Fig. 6) mirrors the same period during which Bathurst caribou population fell dramatically (Fig. 3). Exploration activity in the Porcupine caribou range is currently limited relative to the extent of disturbance in other parts of the Yukon (Fig. 7). In 2014, the Yukon government announced plans to open up 71% of the Peel River Watershed for mining exploration as well as allow continued oil and gas exploration (Fig. 7).

What do these data on disturbance mean? Much scientific research on caribou has been catalyzed by the assessment of mines, pipelines, and related infrastructure in northern Canada (19, 65). A review of this literature reveals multiple kinds of stresses both direct and indirect. Avoidance behavior of lost and disturbed caribou habitat, coupled with the added stresses of noise, dust, and habitat degradation, affects population through stress on critical physiological functions such as fecundity, rearing, and thus population recruitment (66). Habitat fragmentation caused by linear features is also problematic for barren-ground caribou movement patterns as it is for other migratory species (67). Broader and cumulative effects of habitat fragmentation caused by multiple projects and linear features are also problematic for barren-ground caribou as it is for other migratory species (67). Although the effects of single resource development projects can often be mitigated,

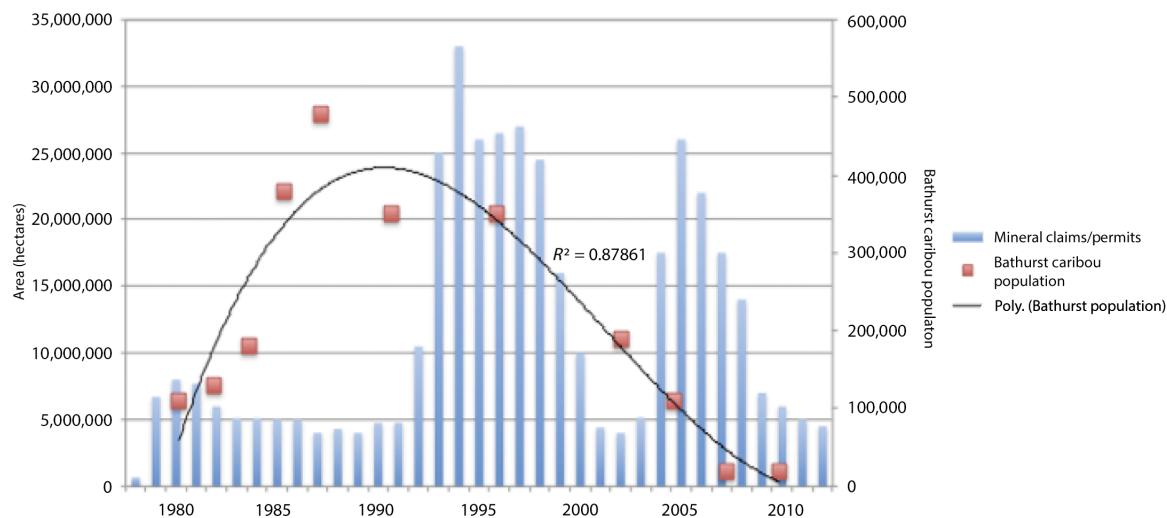


Fig. 6. Trends in mining exploration and development activity in the Northwest Territories (112).

the cumulative effects of many disturbances are a major threat to caribou sustainability, a pattern that has been observed in a variety of arctic and subarctic regions (2, 12, 68–75).

Traditional knowledge holders offer additional perspectives on the stresses of mining on caribou. With few exceptions, elders and other traditional knowledge holders in the Yukon, Northwest Territories, and Nunavut highlight that caribou habitat, caribou health, movements, and population dynamics are negatively affected by resource development including mining (76–86). Of greatest concern is the impact of noise, dust on forage, and the blockage of caribou routes by linear features (that is, roads). The lack of respect or spiritual consideration for the animals and land can also lead caribou to move away (79, 87, 88). Much of this documented knowledge is empirical, in which harvesters who have consistent hunting territories and systematic methods of rigorous observation have given detailed narrative accounts of changes in body condition and fecundity (89), habitat conditions (83, 90), distribution (54, 91, 92), and population dynamics (93–96). Together, the evidence is significant; however, it seems to have had little demonstrable effect on limiting the progress of mining development in the Bathurst and Porcupine caribou ranges.

DISCUSSION

The science-policy gap in the Porcupine caribou range

The Porcupine caribou range falls within the jurisdictions of the Yukon government, government of the Northwest Territories, and the State of Alaska. On the basis of the reports that this herd was in decline, a harvest management planning process was initiated in which the Porcupine Caribou Management Board took a lead role in determining how limits to harvest might be developed and enforced (97). Impatient with the progress of the management planning process, and seemingly spurred by anecdotes of overharvesting in local newspapers, in 2009–2010, the territorial government of the Yukon took steps to create a system of mandatory harvest surveillance and to limit various aspects of the harvest itself. Their efforts at top-down control of Indigenous subsistence were ill received by the Porcupine Caribou Management Board members and other local Indigenous governments (98). The Gwich'in and Inuvialuit governments, who saw little legitimacy in the efforts of the

Yukon government and who expressed concerns about the unnecessary cost and bureaucracy associated with the measures, initiated legal action against the Yukon government on the basis that the interim measures were an infringement on both their constitutional rights and those defined in their land claim agreements (99). Tensions over the value of interim measures escalated when the Yukon media inferred heaving criticism of the continued subsistence harvest of caribou by Gwich'in and Inuvialuit peoples, implying that it was likely to cause the Porcupine caribou to disappear completely (100). In 2012, however, when it was determined that the population had not declined at all but had actually grown to nearly 200,000 animals (well surpassing its previous peak of 178,000), Yukon newspapers were silent on the issue of subsistence. Not long after (2014), the Yukon government unilaterally made the decision to increase mining activity in the Porcupine caribou range by opening up the Peel River watershed to exploration (Fig. 7) (101). The decision was made in contradiction to the recommendations of a 7-year land use planning study led by its own Peel Planning Commission, which highlighted the importance of the region as habitat for Porcupine caribou. The study clearly identified the watershed as providing critical caribou habitat including calving (102). Recognizing mining activity as a major threat to the sustainability of the Porcupine caribou and other ecological and cultural values, Indigenous groups again took legal action against the Yukon government. The Supreme Court of Canada heard the Peel Watershed case on 22 March 2017. As of November 2017, the final decision was still pending.

The science-policy gap in the Bathurst caribou range

Unlike the Porcupine caribou range, which, until recently, had been little disturbed by resource development activity, the Bathurst range has seen significant mineral exploration and the development of five major diamond mines since the mid-1990s (Fig. 8). From the beginning of this development rush, Indigenous communities raised concerns about the impact of the mining activity on the caribou herds. In a report from the community of Łutsël K'e Dene First Nation on the impact of the first major development, the Ekati Diamond Mine, harvesters suggested that caribou frequently injured their legs trying to cross the sharp rocks used to construct mining roads, that their migration patterns were “screwed up” by the mine, and that road development has allowed non-Indigenous hunters greater access to the herds. When the second major mine,

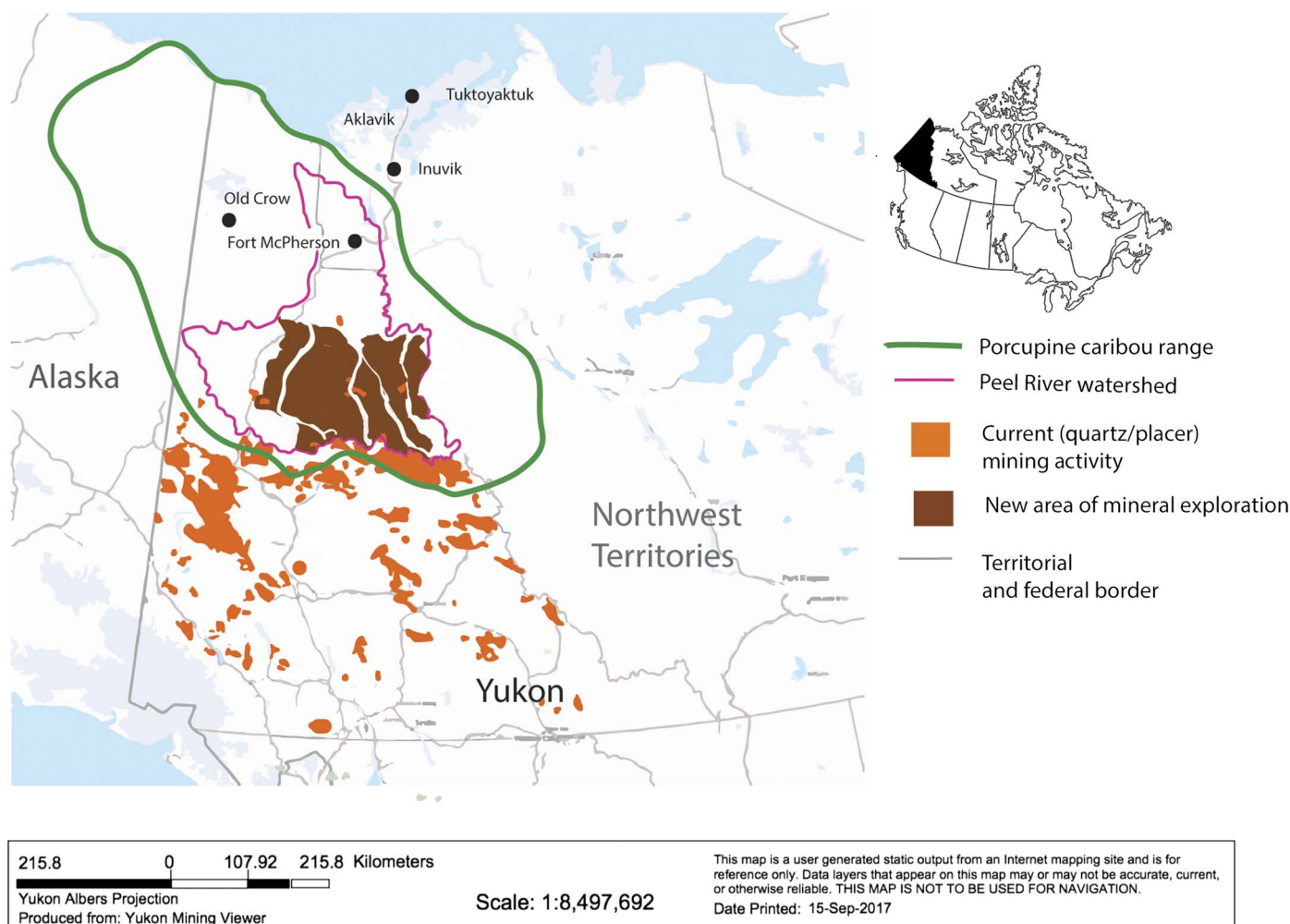


Fig. 7. Mining footprint relative to Porcupine caribou range and Peel River watershed, Yukon.

Diavik, was undergoing a federal environmental assessment in 1999, Dene communities and environmental groups worried that the failure to analyze the cumulative impacts of multiple development projects posed a grave danger to the wide-ranging Bathurst caribou herd. Commenting in 2011 on the combined impacts of the Snap Lake (2008) diamond mine and the nearby Gahcho Kué project, Łutsël K'e Dene First Nation Chief Antoine Michel suggested that "they're driving the caribou away..." (103).

Despite these concerns, the government of the Northwest Territories has approved more mining projects, including the "Jay Project," near Ekati. During the same period, however, the territorial government also imposed a hunting ban for Indigenous harvesters. Some communities in the region were supportive of the move, having already created their own harvest limits. At that time, it was clear in the media and elsewhere that caribou numbers had dropped from an already low count of approximately 35,000 in 2013 to just under 20,000 animals. However, the hypocrisy of imposing hunting bans while simultaneously approving new mining projects was not lost on local communities. During the public hearings on the Jay Project, representatives of Łutsël K'e Dene First Nation asked why the government was prepared to approve a new mine the company had estimated would cause a 0.3% loss to the

Bathurst herd population while, at the same time, the government of the Northwest Territories' Environment and Resources Minister stated publicly that the "herd could not withstand the harvest of even one animal" (104). The Yellowknives Dene First Nation claimed that both the Ekati Mine and the proposed Jay Project are located in a significant migratory route for the Bathurst caribou and that the new project would amplify the negative impacts of the older mine on the herd (105). On the basis of all the evidence presented at the assessment hearing, the Mackenzie Valley Review Board concluded that the Jay Project would have significant adverse site-specific impacts on the herd and contributes to the cumulative impacts of the other mines in the region. Nonetheless, the board recommended that the project go ahead with enhanced mitigation and monitoring plans (especially for road design and dust suppression), some of them based on the development of "pilot" (that is, experimental and unproven) technologies. Despite these measures, Łutsël K'e Dene First Nation was among those who recommended that the project not be approved until the Bathurst caribou population recovered (106). Legal action against the government was taken to stop the project from going ahead; however, due to lack of financial resources, the First Nation was unsuccessful in moving the case forward.

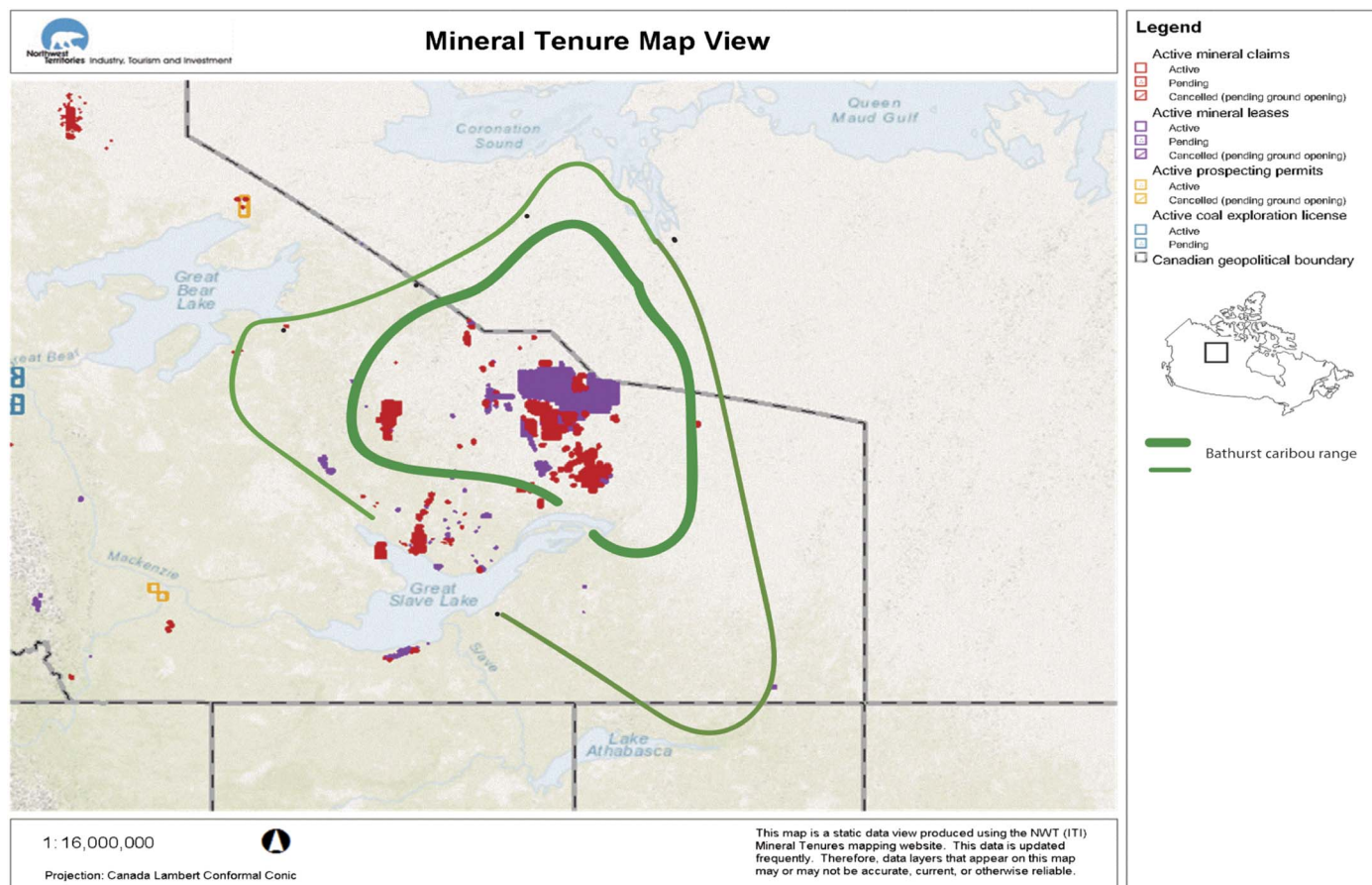


Fig. 8. Mineral resource development in the Bathurst caribou range.

CONCLUSIONS

Barren-ground caribou are among the most dynamic species in the circumpolar arctic/subarctic (107). Over the last century, top-down efforts to manage caribou have had greater socioeconomic implications than ecological. The contemporary scenario and framing of Indigenous harvesting as a threat to caribou sustainability seems a replay of previous periods of northern wildlife management history, which saw widespread efforts to control subsistence caribou harvesting. As with the contemporary scenario, historical efforts to control hunting were ideological rather than empirically grounded (14).

Although much attention, effort, and dollars have been focused on curbing subsistence harvesting, the greater problem appears to be the growing disturbance of caribou habitat by resource development, particularly in the Bathurst range where populations have plummeted over the last two decades from an estimated high of 475,000 to lower than 20,000 animals (68). It is the only herd of all the barren-ground caribou herds in Canada that has fallen so steeply and to such lows; when compared to other barren-ground herd ranges, the Bathurst caribou range has also experienced the greatest amount of disturbance from mining during this last cycle of decline.

Despite a large body of research related to the effects of development on barren-ground caribou habitat, the evidence “has neither effectively influenced policies nor galvanized public opinion sufficiently to push governments into effective action” (68). Legal actions in both the Northwest Territories and Yukon, challenging government approvals of new

mining projects, have also failed to alter the course of such development. There are some exceptions to this rule among territorial governments. Concerns about the health of the caribou in the Kivalliq region of Nunavut, most particularly from the community of Baker Lake, were among the key issues behind the Nunavut Impact Review Board’s decision not to recommend the approval of a multimillion dollar uranium mining project that was proposed within the summer range of the Beverly caribou herd.

Both the government of the Yukon and government of the Northwest Territories have heavily promoted the territories as “open” for mineral exploration and development regardless of impacts on the caribou. There are other threats for the Bathurst caribou on the horizon as new mining projects are proposed including an all-weather road and deep water port project that would significantly adversely affect caribou habitat including areas considered sensitive calving grounds. The de facto system of open access is made possible by Canada’s free-entry system of mining regulations, which are best described as a “sorry anachronism” dating back to the gold rush era (45). Even for skeptics and cautious scientists who consider the evidence about the impacts of mining on caribou habitat and population dynamics as incomplete, taking a precautionary approach to limit development, particularly in the Bathurst range, would seem a prudent course of action.

Previous research on community-based resource management in the circumpolar north and elsewhere has described numerous examples where Indigenous communities and other land-based societies with

long histories of resource use have successfully dealt with variability in natural resources in various ways (108). This case study builds on that literature by revealing details about how and to what extent communities have been able to adapt to variability in barren-ground caribou populations in the western arctic. The presentation of this work challenges conventional thinking and theories about the role of subsistence in wildlife population dynamics in northern Canada; although based in northwestern Canada, it may be relevant to other regions where subsistence is commonly associated with resource scarcity.

The combined stresses of resource development on caribou and people are also considered in this paper. By bringing forward and linking both science and traditional knowledge, we articulate the negative relationship between habitat disturbance from development and caribou population change; during the period that the Bathurst caribou herd decreased by over 95%, habitat disturbance has increased exponentially.

We suggest that this case of a science-policy gap is really a knowledge-policy mismatch between the evidence from both science and traditional knowledge on the one hand and government decision-making on the other hand. The disregard for evidence about the environmental costs of mining for caribou, particularly in the Bathurst range, may be a kind of willful blindness to science—a noted concern over the past decade in Canada and the United States (109). The indifference to traditional knowledge and other kinds of Indigenous voices regarding the resource development problem is a similarly worrying dimension of the same problem. More worrying still are the ways in which public and community concerns about caribou have been addressed by focusing on Indigenous harvesting. Unless the mismatch can be addressed, Canada may be witness to another major resource collapse similar to that of the Atlantic cod stocks, which disappeared in the early 1990s.

Although it is easy to attribute blame on an individual hunter who has been anecdotally seen in a pickup truck on the highway, there is no evidence that Indigenous harvest practices have had any influence on caribou population dynamics; what evidence does exist points to a precipitous and alarming decrease in caribou harvesting and traditional food consumption. The implicit narrative behind harvest management planning processes, that Indigenous peoples are responsible for the decline of the resource, if not their recovery, is compounding this worrying trend in health (for example, increased prevalence of chronic illness). Furthermore, there are implications for cultural discontinuity in Indigenous communities when traditional practices are considered “problems” as opposed to protective factors to health and well-being.

Finally, this case points to some worrying patterns in governance including co-management. Many Indigenous communities participated in harvest management planning processes with government in good faith and with the aim of doing their part to take care of the caribou. Territorial government efforts to side-step co-management board processes (as in the Yukon) and efforts to impose harvest restrictions while opening up new caribou habitat for mining activity may have substantially damaged the legitimacy of co-management arrangements and the many decades of trust building between government and communities. Given the significant role of co-management arrangements in northern governance, this may have long-term and broader implications for land and resource management in northern Canada. By doing so, governments may have contributed to the destabilization of traditional systems of caribou management including delegitimized traditional community rule makers (that is, elders) that have been so critical to the sustainability of northern Indigenous people and caribou for generations.

MATERIALS AND METHODS

The mixed methods research informing this article had three dimensions. (i) Literature review: A review of the scientific literature was carried out using academic databases. The review identified 57 papers focused on the question of human disturbance and its impacts on barren-ground caribou including caribou habitat, health, behavior, distribution, and/or population dynamics. These papers primarily focused on resource development disturbance roads, pipelines, mines, aircraft, dust deposition, and noise (27); hunting pressure (21); and cumulative effects (9). The papers dealing with cumulative effects included only those that featured resource development and hunting pressure. Unpublished or non-peer-reviewed material (for example, government and consulting reports) was not included. Although there are similarities and lessons to be learned from research on boreal caribou and reindeer systems, this body of work was also excluded. A second phase of literature review focused on identifying published sources of traditional knowledge related to barren-ground caribou; these sources were reviewed, and a synthesis report was created. A third literature review focused on harvest and consumption patterns of Indigenous communities with greatest focus on those dependent on the Porcupine and Bathurst caribou herds. (ii) Analysis of secondary data: The research also draws on documented and publicly available harvest data from the Inuvialuit and Gwich'in regions (51, 52, 110). Secondary data on historic and contemporary resource development activity in the Bathurst range were sourced from the government of the Northwest Territories and the public registry of the Mackenzie Valley Impact Review Board in the Northwest Territories. (iii) Community-based research: Case study research was collaboratively carried out with four communities in the Inuvialuit, Gwich'in regions of the Yukon, and Northwest Territories (Old Crow, Fort McPherson, Tuktoyaktuk, and Paulatuk), and with Łutsël K'e Dene First Nation. Multidisciplinary social science research methods were used including historical ethnographic methods, harvest surveys, in-depth interviews, and focus groups about socioeconomic effects, harvesting behaviors, and traditional rules of caribou management.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at <http://advances.sciencemag.org/cgi/content/full/4/2/e1701611/DC1>
Supplementary Text

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