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Investigating the Multi-Faceted Factors Impacting Caribou Conservation Challenges, in Canada

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ABSTRACT

The declining caribou populations in Quebec face an array of factors that contribute to their conservation crisis. These include climatic and human-induced causes. The expansion of activities like logging and mining has led to the fragmentation of their habitats posing significant challenges to their survival. Habitat disturbances, combined with the effects of climate change, have resulted in changes to food availability and migration patterns while also making them more vulnerable to predators, wolves. Additionally anthropogenic infrastructure development and recreational activities such as hunting further compound the difficulties these species encounter in maintaining populations.

The caribou conservation issue is further complicated by emerging health risks associated with diseases and parasites. These health concerns may have emerged due to interference or changing climate conditions. The presence of these diseases along with increased predation pressure has led to a rise in mortality rates among caribou populations.

Apart from environmental challenges, policy barriers also contribute to exacerbating the situation. Canada's diverse provinces and territories face challenges in implementing conservation policies due to the lack of uniformity and conflicts between interests and conservation goals. To address this issue, it is crucial to adopt a collaborative strategy that ensures the long-term survival of caribou within the wilderness.

Keywords: Caribou populations, Habitat fragmentation, Climate change impacts, Anthropogenic infra structures, Conservation policies

1. INTRODUCTION

Canada's vast landscapes in Quebec are home to a variety of ecosystems that support numerous species. Among them, caribou (*Rangifer tarandus*) holds significance as symbols of the region. Narratives, folklore, and local traditions often highlight the ecological importance of these majestic creatures (Bergerud, 1974; Joly et al., 2012). Caribou also play a role in maintaining the integrity of Quebec's wilderness. However, there is growing concern about the declining conditions and decreasing numbers of both forest-dwelling and migratory caribou populations, in Quebec (Schaefer, 2003).

According to the assessment conducted by the Committee on the Status of Endangered Wildlife, in Canada (COSEWIC), it has been found that several caribou populations, those in Quebec are at risk of becoming endangered. This critical situation can be attributed to factors with human activities being the reason (Wilkinson, 2010). The decline in caribou populations poses a threat to both the biodiversity of the province and the well-being of groups from a socio-cultural perspective. The caribou holds value for these communities as it represents their identity and is an important resource (Kendrick & Manseau, 2008).

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The increased concern regarding the vulnerability of these species has led conservationists, researchers, and policymakers to focus on understanding the factors contributing to this situation. The condition of caribou serves as an indicator of concerns in Quebec, such as habitat fragmentation disturbances caused by human activities and the looming impact of climate change (Vors & Boyce 2009). This concise statement aims to explore these issues with the goal of shedding light on various aspects related to caribou conservation, in this region.

2. MATERIALS AND METHODS

The primary aim of this literature study is to evaluate the factors contributing to the decrease in the caribou population in Quebec. The technique and search approach were established by drawing upon the scholarly contributions of Otekurin et al. (2023) and Saturno et al. (2023), since both authors have garnered significant recognition and citation within the field of study under consideration. A snowball search was conducted using the main ideas outlined in the study by Brown and Vellend (2014), which is a commonly used technique in systematic reviews. The presence of caribou in Quebec, the factors contributing to the decline in caribou populations, the many threats and hazards faced by caribou, the current state of caribou populations, and the status of their habitats in Canada are the key topics under consideration. The researchers used three internet databases renowned for their extensive coverage of environmental studies (Cowhitt & Cutts, 2020): Google Scholar, ResearchGate, and Academia. Criteria, particularly in the field of environmental studies, were formulated by drawing upon established methodologies in conducting comprehensive literature reviews. The aforementioned requirements have been succinctly outlined and shown in Table 1.

Table 1: Selection criteria

Criteria	Justification
Articles centered on the factors affecting caribou conservation in Canada were prioritized. Articles discussing different topics or species were excluded.	This criterion was chosen to ensure alignment with the literature review's objective and to exclusively utilize the most pertinent information.
Year of publication (1971 – 2023)	These time constraints were chosen based on the peak publication periods related to the study topic, enabling a comprehensive exploration across different eras.
Language of publication (French and English)	This selection was made because over 80% of documents on threats to caribou conservation in Canada are in French or English, the two official languages of Canada and in which the authors are proficient.
Articles published in impact journals whose indexes are scientifically recognized (Web of science, Scopus, Science Citation Index, Google Scholar)	Journals with high impact factors, indexed in reputable scientific databases, typically have expert review committees that ensure the quality of their articles. Furthermore, the chosen databases are highly regarded in the fields of environment, fauna, and flora.

The approach used in the selection process was developed in accordance with the established criteria for conducting systematic literature reviews. The adaptation of the recommendations was derived from the proposals put out by Debiaise and Locko (2017) as

well as Lovett et al. (2021). After eliminating duplicate entries from the original set of 312 publications, a selective sorting process was conducted, resulting in a final selection of 94 articles that were considered relevant for the evaluation. Data extraction was initiated after the final selection of the articles, according to the standards defined by Purvis (2010). Subsequently, a thematic analysis was undertaken to ascertain prevalent themes and patterns within the chosen articles, using a methodology often used in qualitative research (Lovett et al., 2021).

Figure 1 presents a flowchart that visually depicts the process of selecting and including studies based on predetermined search parameters.

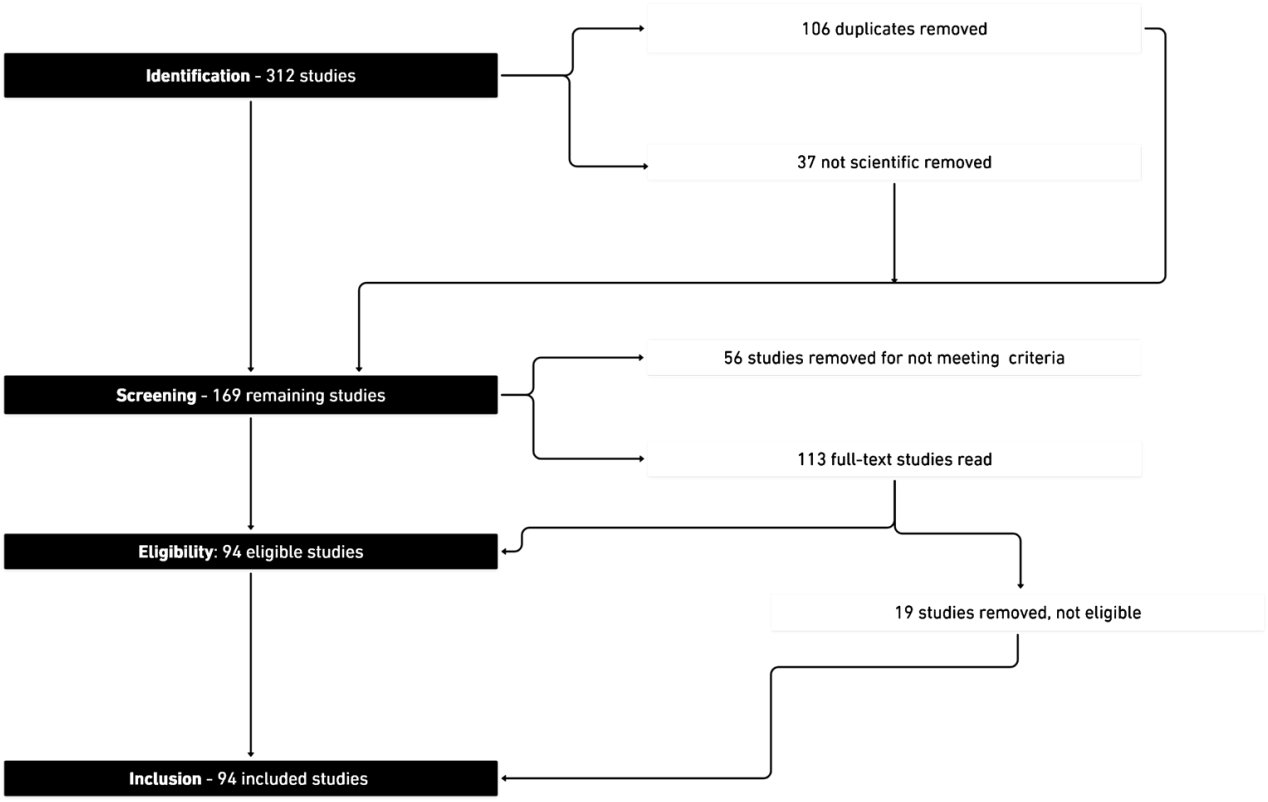

Figure 1: Flowchart illustrating the selection and inclusion process of studies based on search criteria

3. RESULTS AND DISCUSSION

Caribou, a Widely Recognized Symbol of Cultural Significance in Canada

Image 1: Majestic Caribou amidst Autumn Foliage (Source: Etsy, 2021)

The caribou, a symbolically significant animal with substantial cultural and ecological significance in Canada, exemplifies the deep connection that exists between Indigenous people and the surrounding environment. The historical connection between Indigenous people and caribou may be traced back for several generations since these groups have historically relied on caribou for sustenance, attire, and ceremonial practices (Nicholson, 2020).

The Caribou has substantial religious, cultural, and social importance for several Indigenous communities in Canada (Solmundson et al., 2023). Caribou are not just considered as a source of nutrition but are also regarded as symbolic of resilience, flexibility, and a healthy coexistence with the natural ecosystem. Chou and Huang (2021) argue that the species under study showcases its adaptability and persistence via its migratory patterns and ability to flourish in demanding northern habitats. The representation of caribou in Indigenous artistic expressions, narratives, and ceremonial practices often serves as a symbolic representation of the fundamental idea of oneness and interdependence between human beings and the natural world (Nicholson, 2020; Green et al., 2022). Furthermore, caribou play a crucial role in maintaining the ecological balance within their different habitats.

Prey animals, such as wolves and brown bears, see them as noteworthy targets. In addition, the grazing patterns of these animals have a pivotal role in shaping the composition of plants, their production, and the cycling of nutrients. The declining caribou populations in Canada have raised concerns due to their potential impact on both the species and the delicate balance of ecosystems and cultural practices (Solmundson et al., 2023).

The species under consideration is considered a keystone species owing to its grazing activity, which has a substantial influence on the flora and overall landscape. Consequently, this process gives rise to the establishment of ecosystems that provide suitable environments for a diverse range of animal species, including avian creatures, insects, and diminutive mammals. The caribou has a significance that extends beyond its cultural and spiritual importance. The caribou populations in Canada have seen significant declines in both their geographic range and total population sizes over the last century, leading to concerns about their conservation status (Chagnon et al., 2022). The decline in caribou numbers is mostly

attributed to human activities, including the deterioration of their habitat, changes in climatic patterns, and hunting practices. The decreases described above not only provide a considerable threat to the long-term sustainability of caribou populations but also have important ecological implications.

Solmundson et al. (2023) and Chagnon et al. (2022) have asserted that caribou have a significant ecological significance in the northern environment, and any decline in their number might possibly initiate a cascade of repercussions for other species and the overall ecological equilibrium of the system. The preservation of caribou has great relevance in the context of sustaining cultural traditions, promoting a balanced cohabitation between people and the natural environment, and protecting the integrity of northern ecosystems (Carlsson et al., 2019).

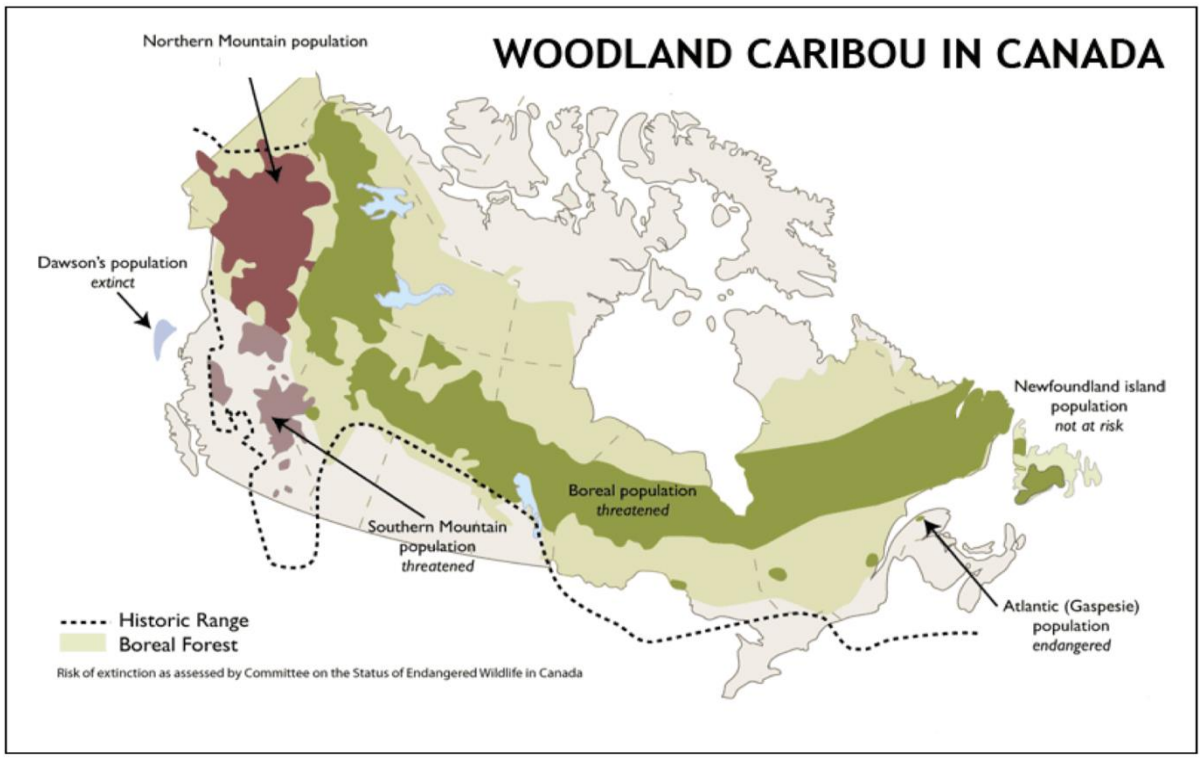

Image 2: Distribution and Conservation Status of Woodland Caribou Populations in Canada (Source: COSEWIC, 2003)

An In-Depth Analysis of Habitat Loss and Caribou Decline in Quebec

The significant decline, in caribou populations in Quebec has become a pressing concern attracting attention from researchers, politicians, and environmental advocates alike. This decline is primarily attributed to the loss of their habitat, which has been further exacerbated by activities such as mining and deforestation (Johnson et al., 2001; Schaefer, 2003). Caribou are now considered a threatened species. It is widely recognized that the preservation of their habitat within Canada's boreal forest is crucial for their survival. Manseau (2009) states that these mammals, scientifically known as *Rangifer tarandus* and belonging to the deer family thrive when they can inhabit vast undisturbed areas within the boreal forest.

Whitman et al. (2017) confirm the role played by woodland caribou in conserving and managing their habitat within Canada's boreal forest. These caribou populations have historically relied on the boreal forest in North America as their habitat, for survival (Gonzales et al., 2015).

Over time caribou have experienced a reduction, in their range due to human activities such as logging and mining. These activities have caused damage and fragmentation to their

habitats leading to a concentration of caribou in regions. The changes in terrain structure caused by logging have led to habitat fragmentation and alterations in the distribution of stand age.

Not only are other wildlife species negatively affected by forest harvesting activities, but the development of ecosystems that benefit caribou predators is a concern when it comes to the impact of deforestation on woodland caribou. Research by Donovan et al. (2017) suggests that forest harvesting can create habitats that provide prey for caribou predators increasing predator populations. However, it's important to note that these forest harvests also divide caribou habitats making them more susceptible to predation, by animals.

The changes made to the boreal forest landscape have disrupted the availability of food, for animals. Disrupted the balance between predators and prey. These factors have contributed to a decline in caribou numbers. Caribou rely on forests as they provide elements of their habitat including abundant food sources and shelter from potential predators (Whitman et al., 2017; Rudolph et al., 2019). Conservation efforts prioritize the preservation of forests.

The significant decrease in the caribou population has consequences leading to the classification of forest-dwelling caribou as a threatened species under Canada's Species at Risk Act. The focus of discussions revolves around the decline in the woodland caribou population within western Canada's boreal forest. This decline can largely be attributed to the combination of energy development and habitat degradation resulting in access to caribou habitats. Consequently, there has been a reduction, in caribou populations. Furthermore, these modifications have had an impact, on the interactions occurring within the food chain leading to a shift in power dynamics that favors ungulate species like moose and white-tailed deer (Eacker et al., 2019).

Even though Quebec's forestry sector creates employment opportunities and contributes significantly to growth it is associated with negative effects on the biological components of the natural environment. Researchers such as Senko (2021) and Kamangadazi et al. (2016) have highlighted how deforestation and unsustainable logging practices have adversely affected this industry resulting in habitat destruction, loss of biodiversity, and soil erosion. The discourse surrounding wood harvesting in Quebec persists due to a lack of awareness regarding both harvesting methods and their long-term impact on forest health. Scholars advocate for a paradigm shift toward an approach to understanding the forestry industry that considers its economic, social, and ecological dimensions.

Li et al. (2022) emphasize the importance of broadening our perspective beyond maximizing benefits, from forestry operations by also evaluating the ecological economic advantages associated with forests. They argue that it's crucial because the previous focus has been too narrow. To ensure the long-term viability of Quebec's forestry sector a comprehensive strategy must be implemented. Undoubtedly the forestry industry has contributed to growth and the well-being of its people, but it has also had adverse impacts, on the surrounding environment (Chagnon et al., 2022).

The current scenario presents implications, including habitat deterioration, loss of biodiversity, and soil erosion. It is imperative to embrace practices that effectively minimize impacts associated with this industry to secure enduring economic benefits derived from forestry activities in Quebec. The adoption of practices is essential for realizing these benefits.

To safeguard the long-term health and vitality of forest ecosystems sustainable forestry methods necessitate an assessment of their effects. This entails implementing policies to mitigate deforestation support reforestation and afforestation initiatives and adopt logging practices, like harvesting instead of clear-cutting (James et al., 2004). These steps play a role, in combating deforestation.

As per research by Almalki et al. (2019) mining activities regardless of their size have effects. These consequences include changes to landforms and the destruction of ecosystems.

While these activities are necessary for growth and development (Schaefer, 2003; James et al., 2004; Rettie and Messier 1998) there is a chance that they can negatively impact the ecosystem.

Mining operations often involve removing vegetation, which exposes the soil and can lead to alterations in the surrounding landscape. Mining activities are well known for causing devastation and disruptions to habitats. This can have consequences for ecosystems and biodiversity in the area surrounding mining sites (Dyer et al., 2001; Vors et al., 2007). Additionally, mining activities contribute to habitat destruction. According to Strielkowski et al. (2021), the removal of vegetation through mining can result in habitat loss, for plant and animal species. This in turn can lead to a decrease, in food sources and shelter potentially resulting in population declines or even the extinction of species. Moreover, mining operations have the capacity to contaminate both the soil and nearby streams with lasting consequences on the ecosystems surrounding these operations.

These impacts can affect both water quality and the well-being of animals that depend on these water sources (Bortnikova et al., 2019). Additionally, mining activities do not only alter the landscape and habitats. They also significantly contribute to atmospheric contamination. During mining processes, various chemicals and particles are released into the air. These include dust, gases, and particulate matter (Camara et al., 2021).

In essence, the decline in caribou populations in Quebec highlights the challenges involved in finding a balance between development and preserving natural ecosystems. It is crucial for the province to devise a strategy that recognizes the value of its natural heritage and embraces sustainable practices, for long-term benefits. After that, the province will have the ability to progress.

Climate Change and Its Profound Impact on Quebec's Caribou

The term "climate change" refers to a phenomenon that carries implications. It encompasses increases, in temperatures and shifts in precipitation patterns. These changes have far-reaching consequences for ecosystems worldwide. In Quebec, Canada the effects of climate change are becoming more apparent especially when it comes to the plants and animals in the region. One notable example is the caribou population, the endangered Atlantic Gaspésie caribou, which has been significantly impacted by the widespread effects of climate change (Whitman et al., 2017).

According to Whitman et al. (2017), one crucial aspect of ensuring the existence of caribou is their reliance on old-growth forests that provide habitat components. However due to logging and human-induced alterations, like road networks, these forested areas have been converted into mixed forests during the initial phases. As a result, caribou populations have already experienced consequences (Leblond et al., 2013; Chagnon et al., 2022).

It's important to emphasize that climate change exacerbates these challenges posing significant threats to the caribou population, in Quebec. Recent research conducted by Andrews and MacKay (2012) has demonstrated that climate change is altering the caribou's environment by causing shifts in weather patterns. These changes in turn impact the behavior, diet, and overall dynamics of the caribou population. Caribou herds in Quebec already face effects due to factors like highways and human intervention in forest management over time. However, the added pressures from climate change such as rising temperatures and altered precipitation patterns make these challenges more difficult to address.

The implications of climate change on both caribou and their habitat are significant. According to Bradley and Neufeld (2012), these shifts can potentially affect not only the availability and quality of food sources, for caribou but also their ability to navigate and find suitable habitats.

Moreover, the impact of climate change, on caribou populations is worrisome as it can potentially amplify the growth of pests and diseases. This further exacerbates the vulnerabilities

already faced by caribou due to stresses (Nobert et al., 2020). Caribou in response to changes in their habitat caused by climate change may have to travel distances in search of food and protection. As highlighted by DeMars et al. (2021) this leads to increased energy expenditure for caribou.

Quebec, known for its landscapes that include boreal forests and icy tundras is experiencing notable shifts in vegetation patterns due to climate change. According to Brown and Vellend (2014), rising temperatures are causing plant species zones to shift northward resulting in a reorganization of the region's landscape. One significant consequence of these changes is the decline, in lichen populations.

Caribou heavily rely on lichen as a source of nutrition during the harsh winter months (Vors & Boyce, 2009). However, the vegetation landscape is undergoing changes causing lichen-rich areas to be replaced by shrubs and other species commonly found in southern boreal regions. These changes, in vegetation, pose a threat to the caribous' food resources.

Schindler and Lee (2010) discovered that it's not just plant species that are migrating towards regions; a diverse range of organisms is also experiencing this phenomenon. Herbivorous species, dominant in Quebec are expanding their territory into areas traditionally occupied by caribou. This habitat shift is driven by climate change. Callaghan et al. (2011) state that such migration processes lead to resource competition and alter balance within the region.

The impact of climate change extends beyond plant life; it affects the predator-prey dynamics in nature causing shifts, in this ecological relationship. The occurrence referred to as the Northern Movement of Predators happens when herbivorous animals, like deer, expand their range into areas. This unintentionally leads to the introduction of their predators, such as wolves into unoccupied regions. As a consequence, caribou now face increased risks of being preyed upon in areas where they historically faced danger, which poses a threat to their survival as a species (Laliberte & Ripple, 2004). This shift puts caribou in an environment than they were in before.

Furthermore, the winters in Quebec have traditionally been characterized by snowfall. Are now experiencing greater variability due to climate change. Caribou possess adaptations that allow them to dig under the snow for lichen. They are encountering more challenging circumstances in their search for food (Masood et al., 2017). The variable precipitation creates layers of ice that make it difficult for caribou to access their food sources. Researchers Pettorelli et al. (2007). Post et al. (2009) have found that this difficulty can lead to malnutrition during the winter season, which is crucial, for their survival.

Given the challenges posed by climate change, it is crucial to adopt an approach, towards safeguarding our environment. While it is practice to assess the social consequences of climate change we must also recognize the ecological impacts especially when it comes to iconic species like caribou. The reaching effects of climate change are disrupting the balance that sustains ecosystems. These rapid transformations pose threats to animals such as caribou, which have evolved over thousands of years in harmony with their habitats and rely on them for survival. To tackle these challenges effectively we need an understanding of how ecosystems re-interconnected and a firm commitment, to sustainable conservation practices.

Predation and Its Impact on Caribou in an Anthropogenically Altered Landscape

The act of predation, which has been observed for thousands of years, has had a significant impact on the development of species and the dynamics of ecosystems. Predation serves as a crucial mechanism for regulating prey populations within harmonious ecosystems, fostering genetic diversity, and contributing to the general well-being and resilience of ecological communities (Estes et al., 2010). Nevertheless, the current epoch, marked by

significant human-induced modifications, is undergoing a transformation in conventional predation dynamics, with profound implications for species like the caribou in Quebec.

The Earth's landscape has been significantly impacted by the ongoing processes of urbanization and industrialization, resulting in the introduction of various "linear features" such as roads, trains, and pipelines into the environment. These artificially constructed edifices, designed with the purpose of enhancing human convenience and functionality, unwittingly confer a significant benefit to certain animal species. James et al. (2004) assert that linear characteristics have a significant impact on the facilitation of predator movement, namely in the case of wolves. Wolves, with heightened sensory capabilities and adaptability, have rapidly acquired the ability to exploit these artificially constructed pathways. Roads provide wolves with unimpeded visibility, decreased territorial travel duration, and a snow-free pathway during the challenging winter season, hence enhancing the efficiency of their hunting endeavors. In addition, linear characteristics have the potential to enhance both predator movement and human presence in formerly isolated areas, hence potentially providing indirect benefits to predators via increased scavenging possibilities (Suraci et al., 2022). This anthropogenic activity has the potential to exacerbate predation pressures on caribou and other prey species.

Habitat fragmentation is an additional consequence arising from the development of human activities in wilderness regions, as elucidated in scholarly discussions on forestry and habitat degradation. The fragmentation of habitats leads to the formation of isolated zones, which in turn disrupt the normal migratory and residency patterns of prey species like the caribou. Caribou often experience displacement to less secure habitats, hence increasing their susceptibility to predation (Bergerud, 1988). Moreover, the division of ecosystems leads to the occurrence of 'edge effects.' The conditions at the boundaries of these habitats exhibit notable variations compared to the inner regions, and these peripheral zones are susceptible to infiltration by predators, hence jeopardizing the safety of prey species (Latham et al., 2011).

Throughout history, predators have been recognized as significant contributors to the maintenance of equilibrium among caribou populations. According to Bergerud and Elliot (1986), the natural equilibrium serves to safeguard the survival of the most adaptable individuals while simultaneously curbing excessive population growth. Nevertheless, the existing paradigm, which is marked by the artificial enhancement of predator capabilities by humans, is posing a significant threat to the equilibrium. The caribou population is now confronted with the dual challenges of habitat loss and climate change, which are further compounded by an escalation in predation. This unfortunate combination has led to a reduction in the caribou population that surpasses their ability to rebound (Whittington et al., 2011).

In addition, the phenomenon of climate change is exerting an influence on the geographical range and behavioral patterns of both prey and predator species. The geographical distribution of several species, including both herbivores and their predators, undergoes a poleward shift in response to increasing temperatures (Ge et al., 2011). This phenomenon has the potential to facilitate novel interspecies interactions among formerly geographically isolated populations, hence leading to heightened levels of competition and predation threats for caribou.

Ultimately, the far-reaching consequences of human activities extend beyond their local spheres of influence. The accidental alteration of predator-prey dynamics in Quebec is being induced by the introduction of linear features, as well as habitat fragmentation and distribution changes resulting from climate change. Predatory organisms, guided by innate behaviors, exploit such advantageous circumstances; yet the ramifications for some species, such as the caribou, are notably detrimental. It is imperative that conservation strategies acknowledge these altered dynamics and use targeted interventions aimed at reinstating ecological equilibrium. This necessitates considering not just habitat restoration, but also predator control and climate adaptation tactics.

Human Disturbance and Its Implications for Caribou Populations in Quebec

Quebec, renowned for its wilderness and diverse wildlife is currently experiencing a transformation due, to extensive human activity. This evolving environment poses challenges for the caribou, a species of the region. Human disturbances ranging from activities to noise are profoundly altering the habitats and behaviors of these majestic creatures posing grave threats to their survival.

In the past Quebec's natural soundscapes were characterized by rustling leaves the melody of rivers and the calls of various wildlife (Dickie et al., 2019). However in today's era a new soundscape has emerged—one dominated by technological hums, car noises and human clamor. While this auditory evolution signifies progress and development it poses issues for local species like caribou (Vistnes & Nelleman 2007).

Similar to wildlife species caribou heavily rely on auditory cues to navigate their surroundings—finding food and detecting potential threats. The introduction of sounds disrupts these cues and causes discomfort as well as altered behavior patterns that can endanger their survival (Barber et al., 2010). Two critical stages, in a caribous life cycle are. Migration. Male caribou employ courtship rituals to attract mates during the breeding season. However increased human activity can disrupt these rituals leading to reduced mating success and potentially causing long-term declines, in population (Francis & Barber 2013).

Migration plays a role in the survival of caribou herds as it allows them to find feeding areas and avoid harsh weather conditions. Unfortunately, the current environment in Quebec is crisscrossed with highways, trains, and other man-made structures that pose obstacles to their movements. The noise and presence of these structures can cause caribou to deviate from their migration routes forcing them into suitable habitats or exposing them to increased risks from predators (Dyer et al., 2002).

Extensive scientific research has provided an understanding of how human disturbances negatively impact caribou. A seminal study by Vors et al. (2007) clearly demonstrated a correlation between disruptions. Decreased calf recruitment within caribou populations. These findings underscore the effects of activities that extend beyond immediate habitat loss and affect critical stages of caribou life. The province of Québec experiences impacts on its caribou populations due, to disturbance.

Caribou populations, in Canada have experienced fluctuations in years and experts attribute a portion of the decline to human activities (Andrews and MacKay 2012). The disturbance caused by humans affects caribou through the fragmentation of their habitats and changes in land usage, which consequently leads to increased predation rates. These changes occur due to alterations in habitat structure and the subsequent rise in populations notably moose (Dickie et al., 2019). Consequently, the presence of caribou becomes an attraction for predators like wolves that prey on them (James et al., 2004).

In Quebec province, human disturbance poses consequences for caribou populations. It significantly impacts their habitats through alterations caused by activities such as road construction or logging operations. This interference can result in the division of caribou habitats into areas or fragments known as habitat fragmentation (Antwi et al., 2023). Fragmented habitats have been proven to affect caribou populations by disrupting their natural movement patterns and limiting their access to resources. Ultimately these fragmented habitats render caribou populations more susceptible, to predation.

The rise, in caribou predation, can be attributed to the effects of activity (Rettie & Messier 1998). The presence and actions of humans within caribou habitats are connected to disruptions in their experiences (Serouya et al., 2011). One example of disruptions is the building of roads and infrastructure within caribou habitats, which leads to increased noise levels, traffic congestion and human presence. These disturbances have the potential to interfere with the behavior and stress levels of caribou causing them to avoid areas (Wray, 2018).

Avoiding areas can have consequences for caribou herds. Caribou tend to avoid disrupted habitats resulting in a concentration of their populations in remaining viable habitat areas. This concentration intensifies competition for resources among caribou potentially leading to overgrazing and degradation of the remaining habitat (Serouya et al., 2011). All these factors contribute to a decline in the quality of habitat for caribou populations.

Moreover, artificial disruptions in the caribou ecosystem can induce changes in these animals. These changes include alterations in locomotion patterns and reduced efficiency, in foraging activities (Whittington et al., 2011).

Human activities do not only directly affect the number of caribou. They also have indirect consequences, for other animals and Indigenous communities. When humans enter wildlife areas it can disrupt processes resulting in changes in how different species interact with each other. For instance, the increase in populations due to disturbance can lead to a higher risk of predation on caribou (Parrott et al., 2012). Additionally, as human activity expands into caribou habitats there may be an increase in hunting and poaching which directly contributes to higher caribou mortality rates (Whittington et al., 2011). Overall the impact of disturbance on caribou populations in Quebec is significant. Research by Dickie et al. (2019) found that such disturbances had indirect effects on caribou numbers.

These effects include increased competition for resources changes in breeding conditions, disruption of nests or eggs interference with routes, and an elevated risk of mortality due to increased hunting activity. Moreover, when humans are present along migration routes it can lead to stress, for caribou in terms of their physiological well-being and nutritional needs. These direct impacts mentioned above have the potential to decrease caribou populations and even threaten the survival of herds (Festa-Bianchet et al., 2011). Apart, from the impacts human activities also have effects, on caribou populations.

Disease and Parasites: Hidden Adversaries of Caribou Populations in Quebec

In the wilderness of Quebec, the caribou stands as a symbol of Canada's rich ecological systems. These majestic creatures, known for their antlers and robust physique play a role in maintaining the biological diversity of the local ecosystem. However, beneath their magnificence there are hidden threats that pose risks to their survival; various diseases and parasites (Gibson et al., 2020). While discussions, about conservation often focus on habitat degradation and human impact it is important to recognize the influence of hazards on caribou populations.

Like ungulates, caribou are susceptible to a wide range of diseases (Jenkins et al., 2006). These illnesses can occur spontaneously. Have been observed to become more prevalent and severe due to changes in ecological factors. Infectious diseases such as viral infections well as fungal ailments can cause significant health issues reduce vitality and impair reproduction among caribou. Pneumonia for example—a condition linked to viral infections—has been identified as a cause of mortality, among wild ungulate populations.

Not only do these diseases cause deaths but they also weaken the immune systems of these animals making them more susceptible to additional threats (Cassirer et al., 2013). Caribou face diseases and a wide range of parasites that further hinder their well-being. These parasites include nematodes, lungworms, and ectoparasites like ticks (Kutz et al., 2015). While some parasites may not cause discomfort others can severely impact the health of caribou. For instance, lungworm infestations can impair functions. Reduce stamina making caribou more vulnerable to predators and less capable of dealing with environmental challenges (Jenkins et al., 2006).

The situation becomes more complex due to the changing global climate. The rising temperatures have led to an increase in parasite occurrences in regions like Quebec. Ticks, as

studied by Gibson et al. (2020) thrive in temperatures. Consequently, this climatic shift has been linked to a surge in infestations and subsequent disease outbreaks, among caribou herds.

The overall effects of diseases and parasites, on caribou go beyond health. When a population faces these threats, it can lead to a decrease in reproduction rates due to changes in mating behaviors or an increase in calf deaths. Additionally, those affected by illnesses or parasites become more susceptible to predators, which worsens the decline in population numbers (Brook et al., 2009; Murray et al., 2006).

In the context of conservation, illnesses, and parasites may not always be obvious. They have a significant impact on the well-being and long-term survival of certain species like caribou (Kutz et al., 2013). Given the changing landscape, it is crucial to recognize and address the hidden challenges that Quebec and other regions are currently facing. It is imperative to have a conservation strategy that considers both invisible dangers for the continued survival and well-being of the caribou population, in Quebec.

Overhunting and Its Impact on Caribou Populations

Hunting has played a role, in survival, culture, and traditions throughout recorded history (Image 3). It has undeniably shaped cultures by providing sustenance and later becoming an activity. However, like actions, there can be ecological consequences when moderation turns into excess (Lesmerises & St Laurent, 2017). The caribou serves as a symbol of the impacts of overhunting across the landscapes of Quebec and North America.

Indigenous communities have always held respect for and dependence on the caribou due to its antlers and resilient nature. The caribou represented more than food for these communities; it also provided materials for clothing and tools. Even held spiritual significance. Their hunting practices were rooted in reverence and an understanding of the environment, which helped maintain healthy caribou herds and preserve the ecological balance (Parlee et al., 2005). However, this dynamic changed with the arrival of settlers and the expansion of industries. Modern weapons, growing human populations, and commercial hunting interests shifted the focus away from sustainability, towards profit.

There has been an increase, in caribou hunting over the past few decades due to the growing popularity of recreational hunting. This rise can be attributed to incentives. Despite attempts to regulate and limit hunting through legislation overhunting still occurs. The vastness of the area and inadequate enforcement powers contribute to this problem (Wittmer et al., 2005). The situation has worsened with the advent of technologies such as snowmobiles, which have made inaccessible areas open for hunters. As a result, endangered caribou herds face pressure (Boulanger et al., 2018).

However the consequences of overhunting extend beyond the decline in caribou populations. Areas abundant in caribou support a balance where each species plays a unique role. When caribou herds are overhunted it disrupts gender roles within them. Alters the age structure of the herd. These disruptions can have far-reaching effects affecting everything from patterns to predator-prey interactions (Bergerud, 1971).

Looking ahead we face a challenge; protecting species, like caribou while also acknowledging and respecting our nation’s hunting heritage. The effective approach moving forward involves efforts that actively engage local communities, particularly indigenous groups who possess valuable knowledge of sustainable hunting practices. By combining wisdom with conservation strategies we can foster harmonious communities (Brook & McLachlan, 2008). In summary, hunting itself reflects our connection, to the world. However like any relationship, it requires respect, understanding, and balance. The story of the caribou in Quebec and North America serves as a tale about the importance of preserving nature's equilibrium. Through coordinated actions, informed policies, and a return to behaviors we can safeguard the legacy of the caribou for generations.

Excessive hunting has had consequences on Quebec's caribou population. Several factors have contributed to the decline in Canada's caribou numbers. Induced disturbances and habitat fragmentation resulting from activities such as logging and road construction are among these factors (Leblond et al., 2013). Overhunting has been a driver behind the decrease in caribou populations in Quebec since the 19th century. Multiple sources including James and the National Council for Air and Stream Improvement have identified overhunting as a cause for reducing or even extinguishing caribou populations, in Quebec.

Local residents have provided testimony indicating that the rise, in hunting, coincided with the expansion of forestry and road construction in the area. This has resulted in a decline and in some cases extinction of caribou populations within the region (Rettie et al., 1998). The decrease in caribou herds in Quebec can be mainly attributed to overhunting and other human activities like logging and habitat fragmentation (Courbin et al., 2009). These factors pose a threat to the long-term survival of caribou in the province. The impact of overhunting on the caribou population has been devastating.

The term "overhunting" refers to hunting that occurs at a rate that surpasses a species' reproductive capacity leading to population decline. There are reasons for the overhunting of caribou in Quebec. The increased logging and road construction activities have made it easier for hunters to access caribou populations thus intensifying hunting pressure (Rettie et al., 1998). Human-induced disruptions such as habitat loss and predation also contribute significantly to declining caribou populations. As a result of these aforementioned factors, including reduced habitat suitability, predators such as wolves have become more prevalent threats, to caribou survival.

The actions of humans, like cutting down trees have caused damage, to caribou habitats. Broken them into parts. This has made caribou more at risk of being hunted by wolves (St Pierre et al., 2021).

Image 3: Caribou hunts in North America (Source: Henik Lake adventure, 2023)

Competition for Food in Caribou Habitats: The Consequences of Climate Change and Habitat Alterations

Ecosystems have developed over millions of years with species finding their unique roles within the intricate web of nature. However human-induced environmental changes, in decades have disrupted these established dynamics. In Quebec, the caribou, a symbol of the region is facing increased competition for food due to these shifts.

The caribou is perfectly suited for the boreal forests and tundra landscapes of Quebec and its diet varies depending on the season. During months they feed on plants, like grasses,

sedges, and herbs. However, during winter when snow covers the ground they heavily rely on lichen as a source of nutrients (Russell et al., 1993). Climate change has brought rising temperatures and altered precipitation patterns that are transforming habitats. As a result, many species are now migrating in search of conditions. For example, the tailed deer that was traditionally found in Quebec is now expanding its range further northward. The migration of deer, which is caused by milder winters and changes, in vegetation creates a competition with caribou for food. This competition becomes more intense during the summer (Murray et al., 2006).

Apart from the impact of climate change human activities are directly altering habitats. Actions such as deforestation, urban expansion, and converting land for agricultural purposes are reshaping the landscape. These changes often benefit species that can adapt to these conditions. For instance, moose thrive in fragmented forests or areas affected by activities. As their population increases in areas traditionally inhabited by caribou, the competition for food resources escalates (Rempel et al., 1997).

The cumulative effect of increased food competition can have consequences for caribou populations. Limited access to food sources can lead to malnutrition decreased reproduction rates and higher vulnerability to diseases and predators. These factors combined contribute to declines in caribou populations disrupting the balance of the region (Post & Forchhammer 2007). In summary, the challenges faced by caribou in Quebec represent the challenges we face today. As climate change impacts and human interventions reshape landscapes within the region species, like caribou find themselves caught in a situation.

To tackle these challenges effectively it is crucial to have a grasp of the changing dynamics and to implement conservation strategies that address both the causes and the emerging effects.

Industrial Pollution and Its Detrimental Impact on Caribou Habitats in Quebec

The advancement of industrialization has brought about a time of growth, in technology and infrastructure benefiting well-being and societal advancement. However, this progress has not come without drawbacks as it has also led to challenges. One of the issues is industrial pollution, which has a range of impacts on ecosystems and the numerous species they support (Purvis, 2010). In the landscapes of Quebec, a province deeply connected to activities the indigenous caribou populations are struggling with the harmful effects of such pollution. It endangers their habitats and essential sources of food (Williamson, 2012).

Quebec’s abundant natural resources have made it a center for industries like forestry, mining, energy production, and advanced manufacturing. While these industries play a role in driving Quebec's vitality, they also generate different types of pollutants (Purvis, 2010). These include metals, chemical waste products, greenhouse gases, and particulate matter. Each type carries its consequences (Joly et al., 2012).

Caribou are creatures that inhabit Quebec’s boreal forests and expansive tundra areas. They are particularly susceptible to the changes caused by these pollutants. When water bodies become contaminated with industrial waste products they can suffer from acidification.

Not only does pollution disrupt the ecosystem but it also has a broader impact, on the food web that includes caribou. It's concerning because pollutants that settle on land can change the chemistry of the soil, which affects vegetation patterns. This is especially worrisome for caribou as lichen their primary winter food source, can be affected by these changes in soil conditions. These altered growth patterns of lichen can have an impact on the nutrition intake of caribou affecting their overall health and ability to reproduce.

Apart from the effects of pollution, there is also a threat called bioaccumulation. As heavy metals and certain chemicals enter the ecosystem, they get absorbed at the bottom of the food chain. When caribou consume plants and smaller organisms that have accumulated these

toxins, they end up having levels in their bodies. Over time this accumulation can lead to health problems and reproductive issues and make them more vulnerable to diseases and predators.

Considering both the hidden dangers posed by pollution in Quebec it is crucial to shift towards cleaner technologies as well as improve waste management practices. Additionally, it's essential to enforce environmental impact assessments, for industrial initiatives to significantly reduce ecological impacts.

In conclusion finding the balance, between progress and taking care of the environment is a crucial challenge, for present-day Quebec. The caribou, which symbolizes Quebec's beauty acts as an indicator of the health of its ecosystems. Their welfare reflects the well-being of the province's environment. Therefore, it is essential for us to collectively commit to practices that allow economic growth and environmental protection to go hand in hand.

Caribou in Quebec: A Symbol of Ecological Challenges

The caribou populations, in Quebec are facing increasing challenges caused by activity. The construction of infrastructure has allowed predators to have access to caribou habitats. Recreational and industrial activities directly disturb the caribou while diseases and parasites pose threats to their well-being. Hunting practices and pollutants from activities also put pressure on their habitats and food sources. Climate change further complicates the situation by introducing competitors for food. To ensure the survival of this species it is crucial for Quebec to find a balance between development and conservation. While each individual factor may not pose a threat to the caribou population in Quebec, when combined they create a concerning situation as supported by cited studies. Taking steps to mitigate these causes is vital for the future of caribou in Quebec and, for preserving Canada's wilderness biodiversity. Table 2 summarizes the discussed causes providing references to support the points from various sources.

Table 2: Overview of the discussed causes

Causes	Description	References
Habitat Loss	Forestry and mining lead to forest fragmentation, disrupting migratory patterns and increasing predator vulnerability.	Schaefer (2003); Buuveibaatar et al. (2012)
Climate Change	Warming shifts boreal species northward, competing with caribou. Altered snowfall affects foraging.	Schindler and Lee (2010); Post and Forchhammer (2008)
Predation	Human-made linear features like roads enhance predator mobility, increasing predation rates on caribou.	James et al. (2004); Whittington et al. (2011)
Human Disturbance	Noise and activities from industrial developments and recreation interfere with caribou behaviors.	Vors et al. (2007); Lesmerises and St-Laurent (2017)
Disease & Parasites	Increased vulnerability to diseases and parasites can impact caribou health and population numbers.	Jenkins et al. (2013); Kutz et al. (2015)
Overhunting	Unsustainable hunting practices have led to a decrease in some caribou populations.	Russell et al. (2013); Wittmer et al. (2005)
Competition for Food	Other species, migrating due to climate change or habitat changes, can compete with caribou for vital food sources.	Johnson et al. (2002); Serrouya et al. (2011)

Industrial Pollution	Contaminants released from industries can degrade habitats and food sources essential to caribou survival.	Gamberg et al. (2017); Williamson-Ethers et al. (2012)

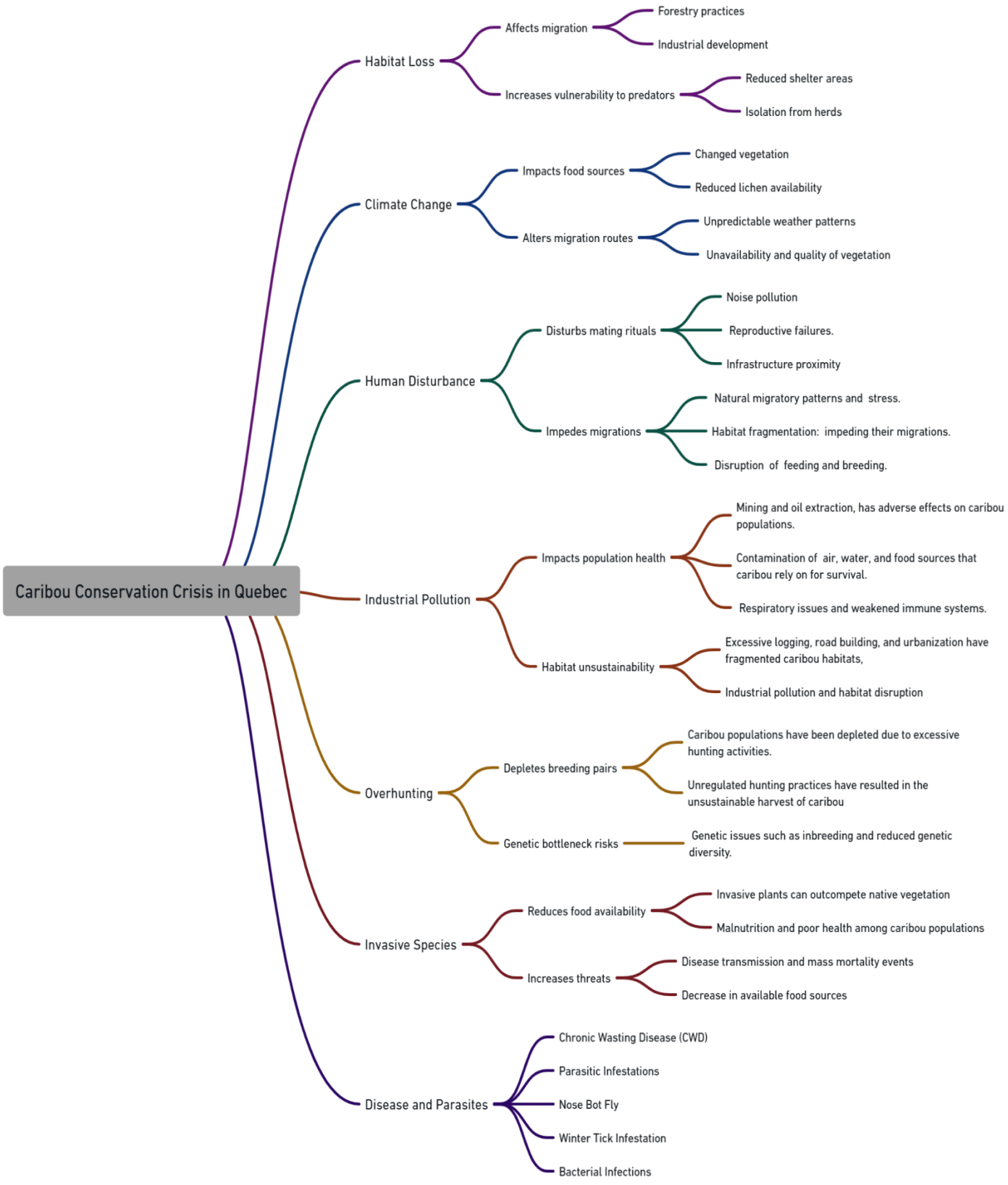

Figure 2: Overview of Causes behind Canada's Caribou Conservation Crisis in Québec

4. CONCLUSION

The loss of Quebec's caribou population is a multifaceted and concerning matter that encompasses several biological, environmental, and human variables. The expansion of these species has been impeded because of the fragmentation of their natural habitats caused by industrial activities like as logging and mining. The phenomenon of climate change has resulted in significant modifications to both the accessibility of food resources and the patterns of movement, rendering them more susceptible to the predation of wolves. The lives of these species are adversely impacted by human activities like as hunting and the development of infrastructure. The potential connection between human activities or climate change and health risks, such as emerging illnesses and parasitic infestations, has been identified. The observed phenomenon has resulted in an increase in caribou fatality rates.

Policy hurdles, such as the lack of uniformity in conservation regulations and the presence of conflicting interests between corporations and conservation objectives, provide significant challenges to the successful implementation of effective protection measures. To effectively mitigate this intricate matter and safeguard caribou populations in the Canadian wilderness, a comprehensive and well-coordinated strategy is necessary. It is essential to establish a harmonious equilibrium between the interests of caribou and humans to safeguard the existence of these emblematic creatures and preserve their crucial ecological significance.

5. LIMITATIONS OF THE STUDY

It is important to note the limitations of the research. Although attempts were made to conduct a comprehensive search, it is crucial to acknowledge that papers that were not indexed in the chosen databases or published outside of the specified criteria could have been excluded from this study. Moreover, because of the linguistic criteria that was used, it is possible that significant literary works in languages other than the chosen one may have been disregarded. The primary emphasis of this research is on caribou populations in Quebec, which may not comprehensively reflect the circumstances in other parts of Canada. The populations of caribou exhibit notable variances throughout different provinces and territories, thereby necessitating a comprehensive examination of regional disparities.

While the investigation encompasses several elements that contribute to the loss of caribou, it lacks an in-depth analysis of the causal connections between these causes and the decrease in population. Further inquiry has the potential to result in a deeper comprehension of these linkages.

Furthermore, the research explores the potential emergence of new illnesses due to human intervention. Nevertheless, this study lacks a comprehensive analysis of the various transmission routes of these illnesses and their distinct impacts on caribou populations. A comprehensive analysis of the mechanisms involved in the transmission of sickness might provide valuable insights into this specific aspect of the subject. Ultimately, although the research does recognize the existence of policy barriers, it falls short in providing a comprehensive analysis of the effectiveness of existing conservation measures or offering specific policy recommendations. Additional research is necessary to evaluate the impact of policy implementation on caribou populations.

6. POTENTIAL AREAS FOR FUTURE RESEARCH

To address these limitations, it is crucial to explore many avenues for further investigation. Longitudinal studies provide a valuable chance to systematically observe and study the dynamic changes in caribou populations and their habitats over an extended duration. Through the use of these methodologies, these research endeavors have the potential to provide more comprehensive and intricate data pertaining to patterns within the population. Consequently, this may facilitate the detection of potential signs of resurgence or continued

decline. The use of genetic studies enables the examination of the genetic diversity and adaptability of caribou populations in response to environmental changes and disruptions resulting from human activities. This facilitates the acquisition of valuable information about the long-term survival prospects of these populations.

Undertaking thorough examinations of predator-prey dynamics, particularly focusing on the impact of wolf populations on caribou, might provide essential knowledge on this basic ecological interaction. The discipline of disease ecology provides a valuable platform for conducting thorough research on the epidemiology of illnesses that affect caribou. These investigations span several aspects, including the sources of diseases, their mechanisms of transmission, and potential strategies for disease management and mitigation.

Moreover, it is feasible to conduct an analysis aimed at assessing the effectiveness of conservation policies in different provinces and territories. The objective of this research would be to identify exemplary tactics and places that might benefit from improvement. Through the active engagement of a wide range of stakeholders, including Indigenous communities, conservation groups, and industry representatives, it becomes feasible to cultivate a shared comprehension and cooperative approach towards the development of efficient conservation strategies.

To assess the implications of climate change, academic inquiries may analyze the specific impacts on caribou habitats, patterns of travel, and availability of food resources. This research can contribute to the development of targeted adaptation strategies. Furthermore, economic valuation studies have the capability to evaluate the economic benefits linked to the preservation of caribou, including several factors like as tourism, ecosystem services, and the safeguarding of traditional indigenous livelihoods. In the long term, the development of predictive models for caribou populations, considering a range of factors including climate change, predation, and habitat degradation, has the potential to inform the development of holistic conservation strategies.

DATA AVAILABILITY STATEMENT

All data used in this manuscript are available online.

ETHICS STATEMENT

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

KFD and YEM conducted data collection and analysis and wrote the initial drafts of the manuscript. KFD and YEM participated in the interpretation and discussion of the results. KFD and YEM supervised the overall review. KFD and YEM improved the final drafts of the paper. All authors participated in designing the study. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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