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Current State of Knowledge and Research on Woodland Caribou in Canada

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Current State of Knowledge and Research on Woodland Caribou in Canada

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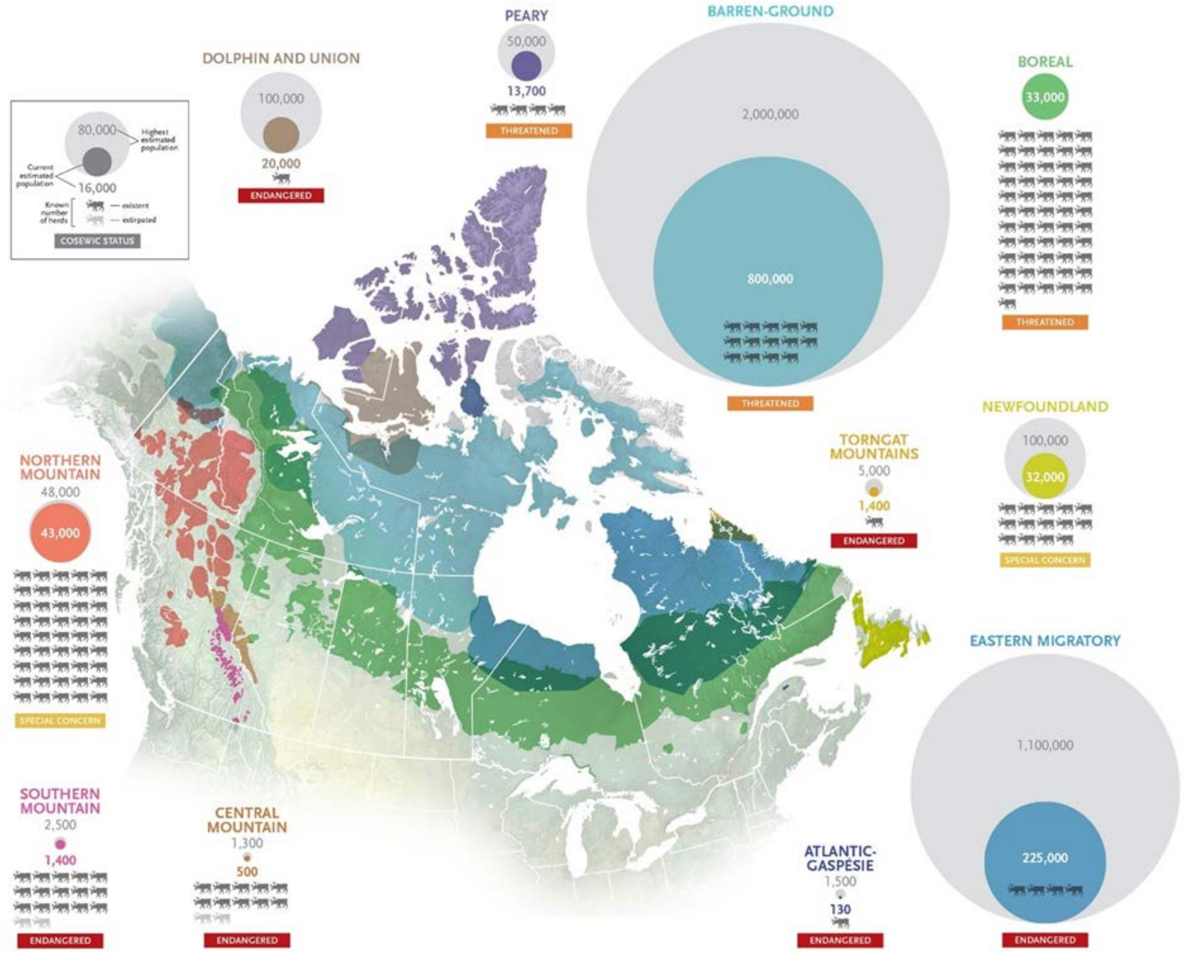
Errata:

September 2020 - Table 3.1 (page 34) and Table 5.2 (pages 55-57) were edited to correct omissions and typos in the data.

EXECUTIVE SUMMARY

- Caribou (*Rangifer tarandus*) is a species of deer that lives in the tundra, taiga, and forest habitats at high latitudes in the northern hemisphere, including areas of Russia and Scandinavia, the United States, and Canada. Caribou is the species' common name in North America, while reindeer is used in Europe and Asia.
- In 2002, woodland caribou (*Rangifer tarandus caribou*), a subspecies of caribou, was designated as threatened in Canada on Schedule 1 of the federal Species at Risk Act (SARA). Six populations have been assessed a conservation status: three are endangered; one is threatened; and two are special concern.
- Woodland caribou have experienced significant range contraction and population declines across their entire range over the last few decades. Although the ultimate reasons for declines can be multifaceted, it has become the consensus amongst researchers that unsustainable predation (primarily from wolves and bears) is the proximate mechanism behind such declines. It is believed that unsustainable predation is facilitated through habitat alteration (i.e., habitat loss, degradation, and fragmentation) from natural (e.g., wildfire, insect outbreaks) and anthropogenic (e.g., resources extraction activities such as forestry, oil and gas, mining, and tourism/leisure) causes.
- Other factors known to affect woodland caribou include climate change and extremes in weather, forage availability, hunting and poaching, parasites, disease, and insects. Woodland caribou can be affected by a combination of these factors simultaneously, making it difficult to separately assess their relative effects.
- Despite the significant amount of research recently undertaken on woodland caribou in Canada (320 peer-reviewed published articles between 2009 and 2019), substantial remaining information and knowledge gaps complicate and may inhibit effective management and recovery of the species. Woodland caribou research has focused on four specific regions: (1) central Rocky Mountains; (2) oil sands region of eastern Alberta; (3) northcentral region of Ontario; and (4) the Côte-Nord of Québec. As a result, large portions of the woodland caribou range remain understudied.
- Given the demonstrated importance of energetic and nutritional influences on the performance of individuals and populations for barren-ground caribou and other ungulate species, a considerable need exists to increase understanding of these influences on a variety of population parameters, including survival, recruitment, longevity, and persistence. Despite growing recognition of the practical importance of bioenergetics and nutrition, there remains a notable lack of studies that have rigorously evaluated this issue for woodland caribou in Canada.



Caribou population size (grey sphere: highest estimated; coloured spheres: current estimate) by subspecies range, known number of subpopulations (existent and extirpated), and most recent Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status. (map credit: Chris Brackley, Canadian Geographic)

SOMMAIRE

- Le caribou (*Rangifer tarandus*) est une espèce de la famille des chevreuils qui vit dans la toundra, la taïga et dans des habitats forestiers à des latitudes élevées de l'hémisphère nord, notamment dans certaines régions de la Russie et de la Scandinavie, des États-Unis et du Canada. Caribou est le nom commun utilisé en Amérique du Nord pour cette espèce, alors que renne est le nom commun utilisé en Europe et en Asie.

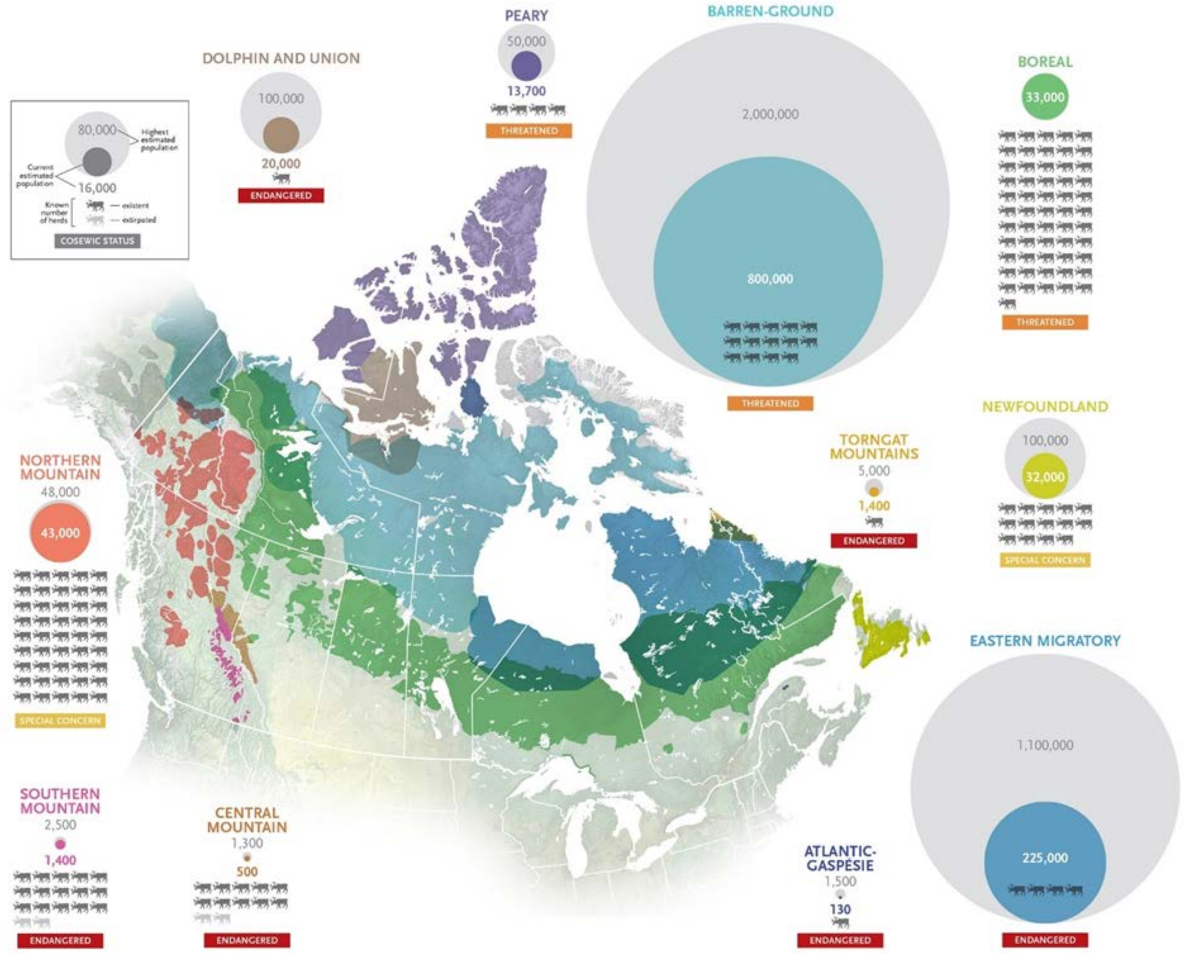
- En 2002, le caribou forestier (*Rangifer tarandus caribou*), une sous-espèce du caribou, a été inscrit dans la catégorie des espèces menacées à l'annexe 1 de la *Loi sur les espèces en péril* (LEP) du Canada. Six sous-populations de caribous forestiers ont reçu un statut de conservation: trois ont un statut d'espèce en voie de disparition, une a un statut d'espèce menacée et deux ont un statut d'espèce préoccupante.

- Au cours des dernières décennies, les populations de caribou forestier ont connu un déclin important et subi un rétrécissement significatif de leur aire de répartition, et ce, dans l'ensemble de leur aire de répartition. Bien que les causes fondamentales puissent être multiples, il y a un consensus parmi les chercheurs qu'un niveau de prédation insoutenable (principalement par les loups et les ours) est la cause la plus immédiate de ce déclin. On croit que ce niveau de prédation insoutenable est rendue plus facile par l'altération de l'habitat (c.-à-d. perte, dégradation et morcellement de l'habitat) causée par des phénomènes naturels (p. ex. feux de forêt, épidémie d'insectes) et des activités anthropiques (activités d'extraction des ressources telles que la foresterie, l'extraction des hydrocarbures, les activités minières ainsi que le tourisme/les loisirs).

- D'autres facteurs connus pour avoir un effet sur le caribou forestier sont, entre autres, les changements climatiques et les phénomènes météorologiques extrêmes, la disponibilité du fourrage, la chasse et le braconnage, les parasites, les maladies et les insectes. Le caribou forestier peut être affecté par une combinaison de ces facteurs intervenant simultanément de sorte qu'il est difficile d'évaluer séparément leur effet relatif.

- En dépit de l'énorme quantité de travaux de recherche entrepris récemment au Canada sur le caribou forestier (320 articles révisés par des pairs qui ont été publiés entre 2009 et 2019), le manque de connaissances et de renseignements dans d'autres domaines complexifie et peut ralentir les efforts de rétablissement et de bonne gestion de l'espèce. La recherche sur le caribou forestier a eu lieu seulement dans quatre régions spécifiques: (1) la zone centrale des Rocheuses; (2) la région des sables bitumineux de l'est de l'Alberta; (3) la région du centre nord de l'Ontario; et (4) la Côte-Nord au Québec. De grandes sections de l'aire de répartition du caribou forestier n'ont donc pas fait l'objet d'études.

- Compte tenu qu'il a été démontré que les facteurs bioénergétiques et alimentaires ont une grande influence sur la performance des individus et des populations de caribou de la toundra et d'autres espèces d'ongulés, il est essentiel de mieux comprendre l'influence de ces facteurs sur une variété de paramètres de population, notamment la survie, le recrutement, la longévité et la persistance. Malgré que l'on reconnaisse de plus en plus l'importance pratique de la bioénergie et de l'alimentation, il existe un manque considérable d'études rigoureuse sur l'influence de ces facteurs sur le caribou forestier au Canada.



Taille des populations de caribous (cercles gris: estimations les plus élevées; cercles colorés: estimations actuelles) par aire de répartition des sous-espèces, nombre connu de sous-populations (existantes et disparues) et le statut le plus récent attribué par le Comité sur la situation des espèces en péril au Canada (COSEPAC). (carte: courtoisie de Chris Brackley, Canadian Geographic)

CURRENT STATE OF KNOWLEDGE AND RESEARCH ON WOODLAND CARIBOU IN CANADA

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JUNE 2020

ABSTRACT

Caribou (*Rangifer tarandus*) is a species of deer that lives in the tundra, taiga, and forest habitats at high latitudes in the northern hemisphere, including areas of Russia and Scandinavia, the United States, and Canada. Caribou is the species' common name in North America, while reindeer is used in Europe and Asia. Woodland caribou (*Rangifer tarandus caribou*), a subspecies of caribou, has been listed under the Canadian Species at Risk Act (SARA) as threatened. Six populations of woodland caribou are recognized in Canada, where three have a conservation status of endangered (Southern Mountain, Central Mountain, and Atlantic-Gaspésie), one threatened (boreal), and two special concern (Northern Mountain and Newfoundland). Many of the populations across the species range are experiencing range retraction and population declines, believed to be predominately driven by unsustainable predation that is facilitated through habitat alteration (i.e., habitat loss, degradation, and fragmentation). Additional threats contributing to the decline or that may serve to impede recovery of woodland caribou have been identified: range encroachment by other ungulates species (i.e., moose and deer); disease and parasites; forage and nutritional limitations; and climate change. These individually and cumulatively have been documented in contributing to the decline of the species. Current population estimates and trends for a significant portion of woodland caribou subpopulations remain unknown because of absence or infrequency of monitoring, making it especially challenging to attribute cause and effect of declines. Although the magnitude of scientific research undertaken to date to better understand this species is substantial, it remains incomplete in several key research areas. While significant efforts have been made to understand the species' basic ecology and predator-prey dynamics, topics associated with genetics, nutrition, parasites, and diseases remain understudied across the species range, inhibiting effective management and recovery efforts for the species. Here, NCASI synthesizes current scientific literature to describe the state-of-knowledge of woodland caribou and conduct a gap analysis for the most recent decade (2009 to 2019) of research to assist the future direction of research and to identify knowledge and information gaps on woodland caribou.

KEYWORDS

boreal, caribou, climate change, disturbance, forest-dwelling, forest management, mountain caribou, predation, *Rangifer tarandus caribou*, research, woodland caribou.

RELATED NCASI PUBLICATIONS

Technical Bulletin No. 939 (September 2007). *State of knowledge and analysis of current caribou research on woodland caribou in Canada*.

Technical Bulletin No. 934 (June 2007). *A review of ungulate nutrition and the role of top-down and bottom-up forces in woodland caribou population dynamics*.

Technical Bulletin No. 893 (December 2004). *Ecological interactions among caribou, moose and wolves: literature review*.

Special Report No. 11-02 (July 2011). *An inventory of caribou research programs in Canada*.

Special Report No. 10-02 (October 2010). *Compendium of long-term wildlife monitoring programs in Canada*.

ÉTAT ACTUEL DES CONNAISSANCES ET DE LA RECHERCHE SUR LE CARIBOU FORESTIER AU CANADA

BULLETIN TECHNIQUE N^{O} 1066
JUIN 2020

RÉSUMÉ

Le caribou (*Rangifer tarandus*) est une espèce de la famille des chevreuils qui vit dans la toundra, la taïga et dans des habitats forestiers à des latitudes élevées de l'hémisphère nord, notamment dans certaines régions de la Russie et de la Scandinavie, des États-Unis et du Canada. Caribou est le nom commun utilisé en Amérique du Nord pour cette espèce, alors que renne est le nom commun utilisé en Europe et en Asie. Le caribou forestier (*Rangifer tarandus caribou*), une sous-espèce du caribou, est inscrit dans la catégorie des espèces menacées aux termes de la Loi sur les espèces en péril (LEP) du Canada. Six sous-populations de caribous forestiers sont reconnues au Canada: trois ont un statut d'espèce en voie de disparition (montagnes du Sud, montagnes du Centre, et Atlantique-Gaspésie), une a un statut d'espèce menacée (boréale) et deux ont un statut d'espèce préoccupante (montagnes du Nord et Terre-Neuve). Dans l'ensemble de l'aire de répartition du caribou forestier, il y a un déclin dans la plupart de ces populations et un rétrécissement de leur aire de répartition qui seraient largement causés, croit-on, par un niveau de prédation insoutenable rendue plus facile par une altération de l'habitat (perte, dégradation et morcellement de l'habitat). On a aussi identifié et documenté d'autres facteurs qui peuvent contribuer à empêcher le rétablissement du caribou forestier ou qui contribuent, individuellement ou cumulativement, au déclin de l'espèce, notamment l'empiètement de leur aire de répartition par d'autres espèces d'ongulés (c.-à-d. l'orignal et le chevreuil), les maladies et les parasites, la nourriture et les limites nutritionnelles ainsi que les changements climatiques. Les tendances et les estimations sur la taille des populations actuelles d'une grande partie des hardes de caribous forestiers ne sont pas connues en raison d'une absence de suivi ou d'un suivi peu fréquent, ce qui rend particulièrement difficile la détermination des causes et effets des déclins. Bien que la recherche scientifique entrepris jusqu'à ce jour pour mieux comprendre cette espèce soit considérable, elle demeure incomplète dans plusieurs domaines clés. Même si les efforts de recherche sur l'écologie de base de l'espèce et sur la dynamique proie-prédateur ont été considérables, les domaines de la génétique, de l'alimentation, des parasites et des maladies demeurent encore peu étudiés dans l'ensemble de l'aire de répartition de l'espèce, ce qui ralentit les efforts de rétablissement et de bonne gestion de l'espèce. Dans le présent rapport, NCASI résume où en est la littérature scientifique actuelle pour décrire l'état des connaissances sur le caribou forestier et effectue une analyse d'écart couvrant la décennie de recherche la plus récente (2009-2019) afin d'aider à orienter la recherche dans le futur et à identifier les connaissances et les renseignements manquants sur le caribou forestier.

MOTS-CLÉS

aménagement forestier, boréal, caribou, caribou de montagne, caribou forestier, changements climatiques, espèce sylvicole, perturbation, prédation, *Rangifer tarandus caribou*, recherche

AUTRES PUBLICATIONS DU NCASI

Bulletin technique nº 939 (septembre 2007). *État des connaissances et analyse de la recherche actuelle sur le caribou des bois du Canada* (seuls le Résumé et la Note du Président sont en français)

Bulletin technique nº 934 (juin 2007). *Revue des effets du régime alimentaire saisonnier sur les dynamiques de populations de caribous des bois* (seuls le Résumé et la Note du Président sont en français)

Bulletin technique nº 893 (décembre 2004). *Les interactions écologiques entre le caribou, l'orignal et le loup : une revue de la littérature* (seuls le Résumé et la Note du Président sont en français)

Rapport spécial nº 11-02 (juillet 2011). *Un inventaire des programmes de recherche sur le caribou au Canada* (seuls le Résumé et le Mot du Président sont en français)

Rapport spécial nº 10-02 (octobre 2010). *Recueil des programmes de suivis à long terme des espèces fauniques au Canada* (seuls le Résumé et le Mot du Président sont en français)

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CURRENT STATE OF KNOWLEDGE AND RESEARCH ON WOODLAND CARIBOU IN CANADA

1.0 INTRODUCTION

Caribou (*Rangifer tarandus* Linnaeus, 1758) is a species of deer that lives in the tundra, taiga, and forest habitats at high latitudes in the northern hemisphere, including regions of Russia, Scandinavia, the United States, and Canada, as one of the most widespread distributions of any ungulate species in the world (COSEWIC 2011). The species' common name is caribou in North America and reindeer in Europe and Asia. Its global population declined from 4,800,000 to 2,890,410 (-40%) over the past 30 years (Gunn 2016). Caribou exhibit delayed sexual maturity and reproduction, are uniparous, and often have low calf survival; thus, caribou are limited in their ability to recover from rapid population declines. In 2015, the global conservation status of caribou, according to the International Union for Conservation of Nature and Natural Resources (IUCN) changed from "Least Concern" (a status the species had maintained since 1996) to "Vulnerable A2." Further, NatureServe listed the species as G5 ("Secure" – "Common; widespread and abundant") when last reviewed in 2016 (Table 1.1). The table includes federal Species at Risk Act (SARA) and Committee on the Status of Endangered Wildlife in Canada (COSEWIC) conservation status information.

Table 1.1. Conservation Status by Caribou Populations[a]

Caribou Population	Agency/Committee/ Government	Conservation Status[b]
Peary	NatureServe	T1: Critically Imperiled
	COSEWIC	Threatened (2015)
	SARA Schedule 1	Endangered (2011)
	Provincial/Territorial	Northwest Territories: Threatened; Nunavut: Endangered
Dolphin and Union	NatureServe	TNR: No Status Rank
	COSEWIC	Endangered (2017)
	SARA Schedule 1	Special Concern (2011)
	Provincial/Territorial	Northwest Territories: Threatened; Nunavut: Endangered
Barren-Ground	NatureServe	T4: Apparently Secure
	COSEWIC	Threatened (2016)
	SARA Schedule 1	Not Listed
	Provincial/Territorial	Yukon: Threatened; Northwest Territories: Special Concern; Nunavut: Threatened; Saskatchewan: Not Listed; Manitoba: Not Listed
Eastern Migratory	NatureServe	TNR: No Status Rank
	COSEWIC	Endangered (2017)
	SARA Schedule 1	Not Listed
	Provincial/Territorial	Manitoba: Not Listed; Ontario: Special Concern; Québec: Not Listed; Labrador: Not Listed
Newfoundland	NatureServe	TNR: No Status Rank
	COSEWIC	Special Concern (2014)
	SARA Schedule 1	Not Listed
	Provincial/Territorial	Newfoundland: Threatened

(Continued on next page. See notes at end of table.)

Table 1.1. Continued

Caribou Population	Agency/Committee/ Government	Conservation Status[b]
Boreal	NatureServe	TNR: No Status Rank
	COSEWIC	Threatened (2014)
	SARA Schedule 1	Threatened (2003)
	Provincial/Territorial	Yukon: Threatened; Northwest Territories: Threatened; British Columbia: Red Listed (S1: Imperiled); Alberta: At Risk; Saskatchewan: S2S3: (Imperiled-Special Concern); Manitoba: Threatened; Québec: Vulnérable (S2S3: Special Concern-Threatened); Labrador: Threatened
Northern Mountain[c]	NatureServe	T4: Apparently Secure
	COSEWIC	Special Concern (2014)
	SARA Schedule 1	Special Concern (2014)
	Provincial/Territorial	Yukon: Special Concern; Northwest Territories: Not Listed; British Columbia: Blue Listed (Special Concern -S2S3: Imperiled-Special Concern)
Central Mountain[c]	NatureServe	T2: Imperiled
	COSEWIC	Endangered (2014)
	SARA Schedule 1	Under SARA, Central mountain populations are included in the Southern Mountain Population) which is listed as Threatened.
	Provincial/Territorial	British Columbia: Red Listed (S1S2: Critically Imperiled-Imperiled); Alberta: At-Risk
Southern Mountain[c]	NatureServe	T1: Critically Imperiled
	COSEWIC	Endangered (2014)
	SARA Schedule 1	Threatened (2003)
	Provincial/Territorial	British Columbia: Red Listed (S1: Critically Imperiled)
Torngat Mountains	NatureServe	TNR: No Status Rank
	COSEWIC	Endangered (2016)
	SARA Schedule 1	Not Listed
	Provincial/Territorial	Québec: Not Listed; Labrador: Not Listed
Atlantic-Gaspésie	NatureServe	T1: Critically Imperiled
	COSEWIC	Endangered (2014)
	SARA Schedule 1	Endangered (2003)
	Provincial/Territorial	Québec: Menacées (S1: Critically Imperiled)
Dawson	Extinct (COSEWIC 2002)	

[a] as set by NatureServe (rounded), COSEWIC, and federal and provincial/territorial governments
[b] IUCN reports on global status of a species (Vulnerable A2a, 2015), not at a subspecies level
[c] Central and Southern Mountain populations were initially considered to be the same designatable unit (DU)
Note: NatureServe reports global conservation status of caribou at species level as G5 (Secure)

North America is home to an estimated two million caribou (1.3 million in Canada; 660,000 in the US, Alaska), of which roughly two-thirds are made up of the barren-ground subspecies (which includes three subspecies: *R. tarandus groenlandicus*, *R. tarandus pearyi*, and *R. tarandus granti*) that live in the far north in open tundra habitats. South of the tundra, caribou are progressively less abundant. Woodland caribou occupy an area that stretches from Northeastern Yukon in the west to Labrador in the east and extends as far south as Lake Superior. Most experts recognize woodland caribou as a subspecies (*R. tarandus caribou* Gmelin, 1788); however, IUCN has yet to assess it separately from caribou overall. Woodland caribou were assigned a conservation status of G5T4 (“Global Secure” – “Subspecies Secure” – “Common, widespread, and abundant in the nation or state/province”) by NatureServe in 2016. In Canada, woodland caribou have been listed under Schedule 1 of SARA, where concerns about its conservation status and population trends are focused on six forest-dwelling populations that cumulatively contain approximately 110,000 individuals of the roughly 1.3 million caribou estimated by COSEWIC (2014a, 2014b) to be in Canada. COSEWIC has reviewed scientific information on these six populations and assessed their conservation status; three populations are listed as “endangered” (Southern Mountain, Central Mountain, Atlantic-Gaspésie), one is listed as “threatened” (Boreal), and two are listed as “special concern” (Northern Mountain, Newfoundland) (Table 1.1).

Woodland caribou are a high-profile, charismatic subspecies in Canada (Festa-Bianchet et al. 2011), and is a fundamental species for the cultural, spiritual, and dietary life of aboriginal people of northern Canada (Hummell and Ray 2008). Because of the high degree of uncertainty in estimating woodland caribou populations (Rettie 2017), the causes of declines can be challenging to attribute universally across the species range. Casual factors are complex, they can interact, and their relative contribution is known to vary significantly by both region and population (e.g., Merkle et al. 2017). There is, however, a growing consensus among researchers that unsustainable predation (primarily from wolves and bears) is the proximate mechanism causing declines, and that predation has been enhanced through habitat alteration (habitat loss, degradation, and fragmentation) from natural (e.g., wildfire, insect outbreaks) and anthropogenic (e.g., resources extraction activities such as forestry, oil and gas, mining) causes (Seip 1992; McLoughlin et al. 2003; Vors et al. 2007; Festa-Bianchet et al. 2011; Environment Canada 2012b). Other contributing factors have been identified, including increasing abundance of alternate prey species (i.e., moose [*Alces alces*] and deer [*Odocoileus* spp.]), parasites and diseases, and hunting and poaching, all of which can further exacerbate the decline of woodland caribou. Overall, these threats are closely intertwined and can have cumulative impacts that may not be detectable or evident if assessed individually (Johnson, Ehlers, and Seip 2015; Mumma et al. 2018).

Despite the considerable amount of research that has been undertaken on woodland caribou in Canada, significant information and knowledge gaps that inhibit our ability to effectively manage and recover the species remain. By identifying and addressing gaps, future research directions can be better aligned to improve the ability to manage and recover woodland caribou in Canada. NCASI (2007) reviewed woodland caribou research in Canada and identified approximately 50 woodland caribou-related projects in Canada, along with their principal investigators, students, and objectives. NCASI (2011) released a follow-up report that reviewed and updated the 2007 database. Significant changes have occurred on the Canadian research landscape since 2011, including more research, federal government assessments, and national and provincial recovery strategies for woodland caribou (Environment Canada 2011, 2012a, 2012b, 2014; ECCC 2017). The objective of this report is three-fold: (1) outline the current state of knowledge that exists for woodland caribou; (2) review the most recent decade (2009 to 2019) of woodland caribou research occurring across Canada; and (3) identify research information and knowledge gaps that can assist recovery and management of the species in the future.

2.0 BIOLOGY AND ECOLOGY

2.1 Taxonomy

All caribou or reindeer are mammals that belong to the order Artiodactyla (even-toed ungulates), in the medium-sized deer family (Cervidae). Caribou fall within the subfamily (Capreolinae), comprising deer, moose, and their relatives. Caribou belong to the genus, *Rangifer*, and the same species (can interbreed and produce viable, fertile offspring), *tarandus* (Lönnberg 1909; Figure 2.1). Caribou are distributed throughout the northern regions of North American and Eurasia, where they inhabit a wide range of biomes and ecosystems. Globally, only one species is recognized (Gunn 2016); however, scientists have created different classification and taxonomy schemes throughout the species range, which in some cases are inconsistent or based on outdated taxonomy (Klütsch, Manseau, and Wilson 2012; Gunn 2016; Yannic et al. 2018).

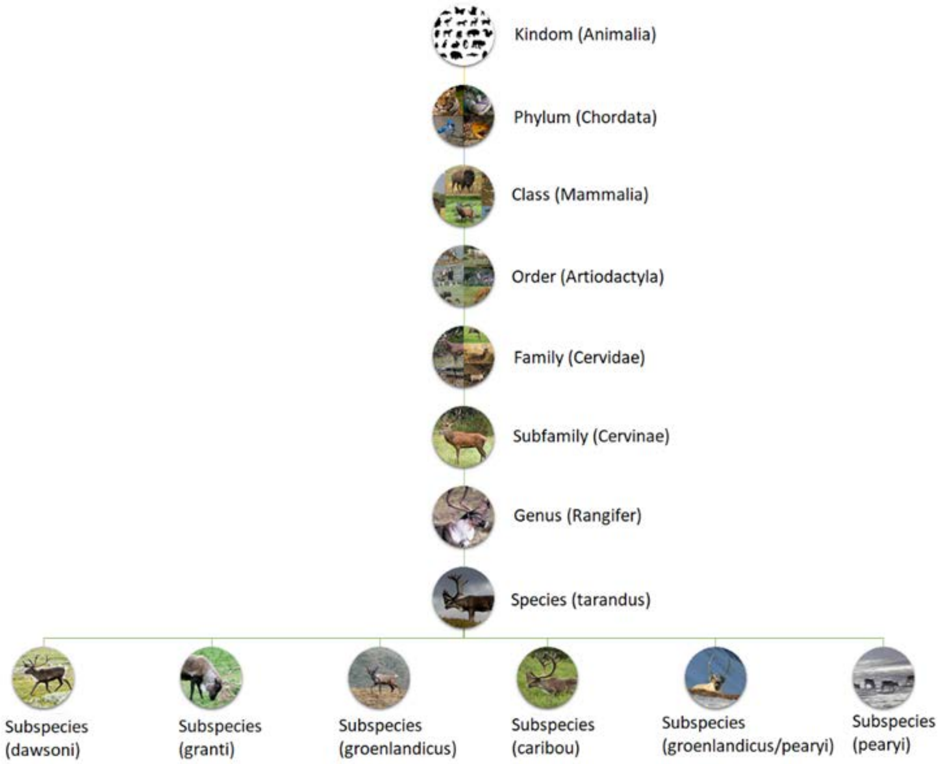

Figure 2.1. Cladogram of Scientific Classifications of Caribou

2.1.1 *Subspecies*

Prior to the last formal classification criteria for determining subspecies of caribou (Banfield 1961), 55 species and subspecies of caribou and reindeer were described (COSEWIC 2011). Banfield's classification criteria differentiate caribou at the subspecies level through differences in skeletal and skull measurements, pelage (fur), and antler and hoof shape. As a result, four native subspecies of caribou are recognized in North America: (1) *R. tarandus caribou* Gmelin: woodland caribou, Canada and southeast Alaska; (2) *R. tarandus granti* Allen, 1902: Grant's caribou, Alaska; (3) *R. tarandus groenlandicus* Linnaeus, 1767: Greenland or American tundra (barren-ground) caribou Borowski, 1780, Greenland, Canada; and (4) *R. tarandus pearyi* Allen, 1902: Peary caribou, Ellesmere, Melville, and other islands of the Canadian Arctic Archipelago (Banfield 1961; Geist 1998; Cronin, MacNeil, and Patton 2005; Harding 2009; COSEWIC 2011). An additional subspecies, *R. tarandus dawsoni* Seton, 1900 (extinct in 1908), may have occurred in the Haida Gwaii Islands (formerly known as the Queen Charlotte Islands, British Columbia), but is based on very few specimens and may not have been genetically distinct (Byun, Koop, and Reimchen 2002). After nearly four decades of use, Banfield's classification method has been increasingly criticized as being inconsistent and outdated (Miller et al. 2007; Hummel and Ray 2008). The original metrics used to classify caribou (skeletal and skull measurements) vary considerably with nutrition (Meldgaard 1986) and movement patterns (Couturier et al. 2010), contributing factors that can vary significantly across the species and subspecies range. To help address these classification concerns, a rise in alternative identification methods and classification schemes has occurred. For example, Grubb (2005) lists 14 subspecies of caribou. A consensus among scientists calls for a complete revision of Banfield's classification schema (Geist 2007; Couturier, Côté, Otto, et al. 2009; Gunn 2009), as recent advances in the collective understanding of caribou ecology, distribution, and genetics have triggered the classification of caribou by ecotype.

2.1.2 *Ecotypes*

The geographic variability of climate and environment that exists across the caribou species range has contributed to differences in morphology, physiology, behaviour, and genetics, where the species has shown the ability to adapt locally to environmental conditions (Morrison 2012). Bergerud (1988) proposed classifying caribou based on their life-history strategies and ecological conditions, and this has since been more formally recognized and accepted (COSEWIC 2011). Differentiation of caribou by ecotype was first observed by Simkin (1965), who found that differences in migration and movement behaviours existed. At least since Darby et al. (1989), two ecotypes have been identified: (1) a “sedentary” ecotype (also referred to as “forest-dwelling” or “boreal”); and (2) a “migratory” ecotype (also referred to as “forest-tundra”) (Pond et al. 2016). A third ecotype, the “montane” or “mountain” ecotype, was later recognized in western North America (Hummel and Ray 2008). In a more recent review, Festa-Bianchet et al. (2011) identified four ecotypes: two migratory (tundra and mountain) and two sedentary (boreal and mountain).

The distinction between sedentary and migratory ecotypes is primarily based on the behaviour strategy (i.e., spacing) used by females at parturition with respect to predation (Bergerud 1988; Bergerud, Luttich, and Camps 2008). The sedentary ecotype disperse or “space-out” from other parturient females, which reduces predation risk; while the migratory ecotype aggregate during calving and some populations travel long distances, thus ‘spacing away’ from predators (Bergerud and Page 1987) (Section 5.4.4, Caribou Response to Predation). Migratory-tundra (i.e., barren-ground) caribou herds can be large (Bergerud 2000) and undertake long seasonal migrations (upwards of ~2500 km) between winter ranges in the boreal forest and summer areas in the tundra (Dalziel et al. 2015). Sedentary caribou inhabit the boreal forest year-round and maintain small group sizes, rarely exceeding 50 individuals (Edmonds 1991). Woodland caribou only undertake short seasonal migrations (Section 3, Distribution). The migratory ecotype also tend to be smaller in size (150 kg males, 90 kg females) compared to their sedentary counterparts (185 kg males, 130 kg females) (Hall 1981; Bergerud 2000). The mountain ecotype, only recently described as a separate ecotype, undertake altitudinal migrations (upwards of 100 km), which allows them to find enhanced nutrition and avoid predators (Hummel and Ray 2008; Festa-Bianchet et al. 2011). The arctic ecotype includes the Peary, Dolphin, and Union caribou populations. They usually occur in small groups (typically less than ten individuals) during the post-calving period and are very well adapted to extreme cold and dry environments of the Arctic (Flagstad and Røed 2003; Festa-Bianchet et al. 2011). Their seasonal migrations are short, and they occupy relatively small homes ranges (Côté et al. 2002). Similar to Banfield’s early classification methods, ecotype classifications can lead to disagreement among caribou biologists (COSEWIC 2011, p. 13). Terminology and ecotypes corresponding to those used in COSEWIC’s 2011 report are used herein.

2.1.3 *Designatable Units*

Beginning in 2000, COSEWIC conducted assessments of caribou at the subspecies level (initially identified as “National Significant Populations”). Banfield’s subspecies classification was used as the basis for this effort, where caribou subspecies were delineated with the “best available information” based on (1) phylogenetics; (2) genetic diversity and structure; (3) morphology; (4) movements, behaviour, and life-history strategies; and (5) distribution. These initial evaluations led to the introduction of five additional subunits of woodland caribou (Atlantic-Gaspésie, Boreal, Newfoundland, Northern Mountain, and Southern Mountain) (COSEWIC 2002). In 2004, COSEWIC further refined its caribou subspecies units through the release of seven woodland caribou population assessments included in two reports: one investigating the five populations of woodland caribou, and the other the remaining arctic caribou populations (Peary, Dolphin, and Union). These assessments were used to inform and create the formal report, *Designatable Units for Caribou (*Rangifer tarandus*) in Canada* (COSEWIC 2011), wherein 12 designatable units (DU) were recognized. It continues to be referenced as the standard (Figure 2.2). The forest-dwelling (i.e., woodland) population of caribou presents the most variability across its range; so much so, that it has resulted in identification of six DUs: Northern Mountain (DU7); Central Mountain (DU8); Southern Mountain (DU9); Boreal (DU6); Atlantic-Gaspésie (DU11); and the insular Newfoundland (DU5).

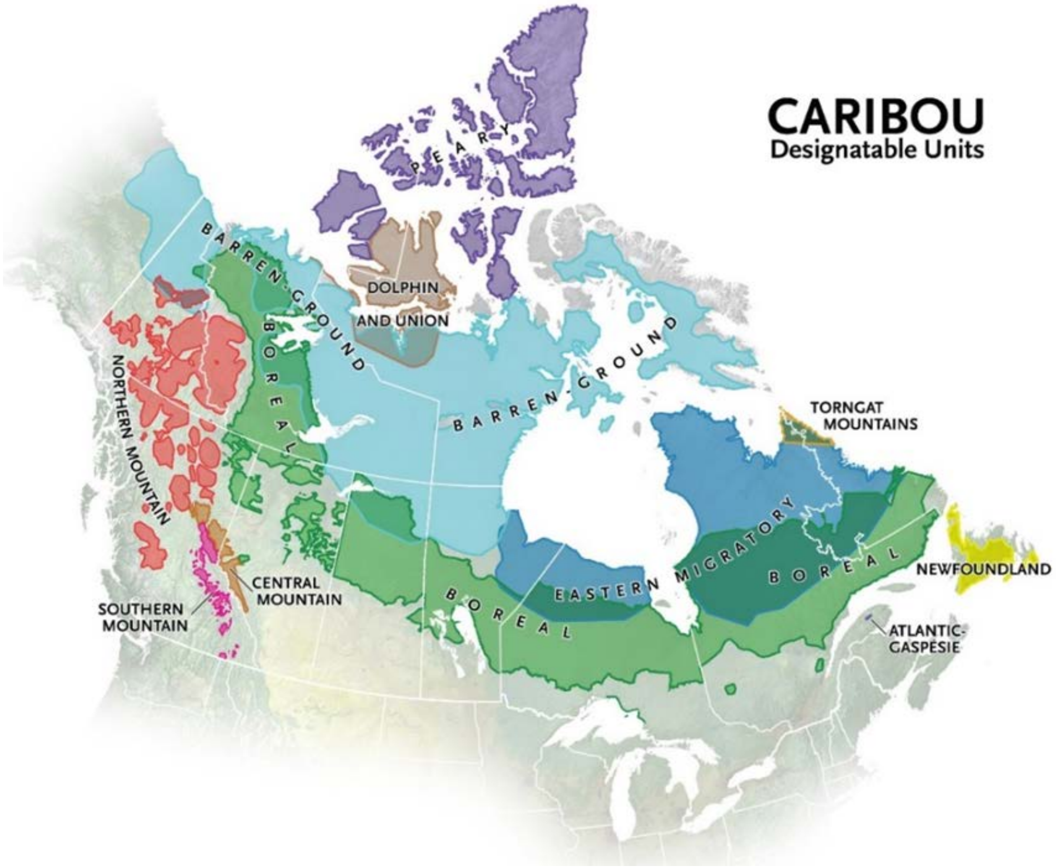

Figure 2.2. COSEWIC's Caribou Designatable Units: twelve DUs are recognized [map credit: Canadian Geographic]

2.2 Genetics

Glacial and interglacial cycles during the Pleistocene (2.58 million to 11,700 years before present) have greatly influenced the history of many species' distributions and genetic diversity in the northern latitudes of North America (Hewitt 2000), and caribou are no exception (Klütsch, Manseau, and Wilson 2012; Weckworth et al. 2012; Yannic et al. 2014; Polfus et al. 2017) (Figure 2.3). During periods of glaciation, some cold-adapted species were able to expand their ranges (e.g., connecting eastern Siberia and Alaska), which facilitated travel and increased the exchange of genetic diversity (Flagstad and Røed 2003; Weksler, Lanier, and Olson 2010; Lorenzen et al. 2011). Other species (caribou included) experienced genetic isolation or interspecific divergence among populations with the spreading of the North American Laurentide and Cordilleran ice sheets (Weksler, Lanier, and Olson 2010; Klütsch, Manseau, and Wilson 2012; Polfus et al. 2017). During periods of glacial retreat, previously isolated populations became reunified; subsequently, populations contracted as favourable conditions were redistributed across the landscape into a new mosaic (Polfus et al. 2017). Historically, caribou have shown considerable adaptability to a range of landscape features. As noted, caribou can persist in both high- and low-latitude/altitude habitats, which has been beneficial during oscillations of expanding and retracting glaciation periods. This ability to adapt has contributed to considerable intraspecific genetic diversity and complexity (Weckworth et al. 2012; Yannic et al. 2014; Klütsch et al. 2016; Polfus et al. 2017).

At the species level, caribou populations are divided into two major phylogeographic lineages: Euro-Beringia and North American (Weckworth et al. 2012; Yannic et al. 2014). The Euro-Beringia lineage covers northwestern North America, Fennoscandia, Greenland, Eurasia, and the artic archipelagos of Russia and Canada, while the North American lineage covers the northeastern portion of North America (Figures 2.3 and 2.4).

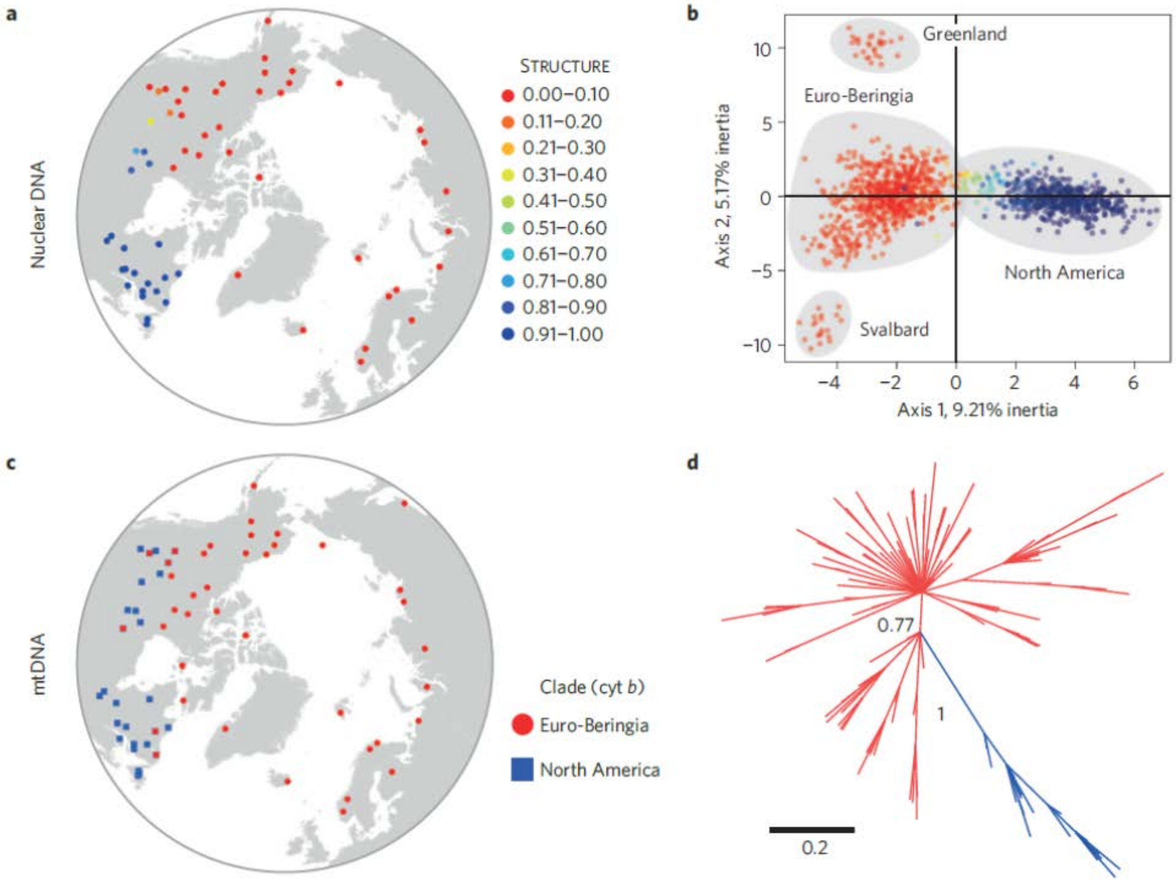

Figure 2.3. Population Genetic Structure of Caribou:
(a) proportion of population membership for each herd to North American clade, considering two genetic clusters (K=2; blue for North American clade and red for Euro-Beringian clade); (b) plot of first two coordinates from principal component analysis on microsatellite loci; (c) geographic distribution and (d) unrooted Bayesian phylogenetic tree of mtDNA haplotype lineages represented in red for Euro-Beringia and blue for North America [from Yannic et al. 2014]

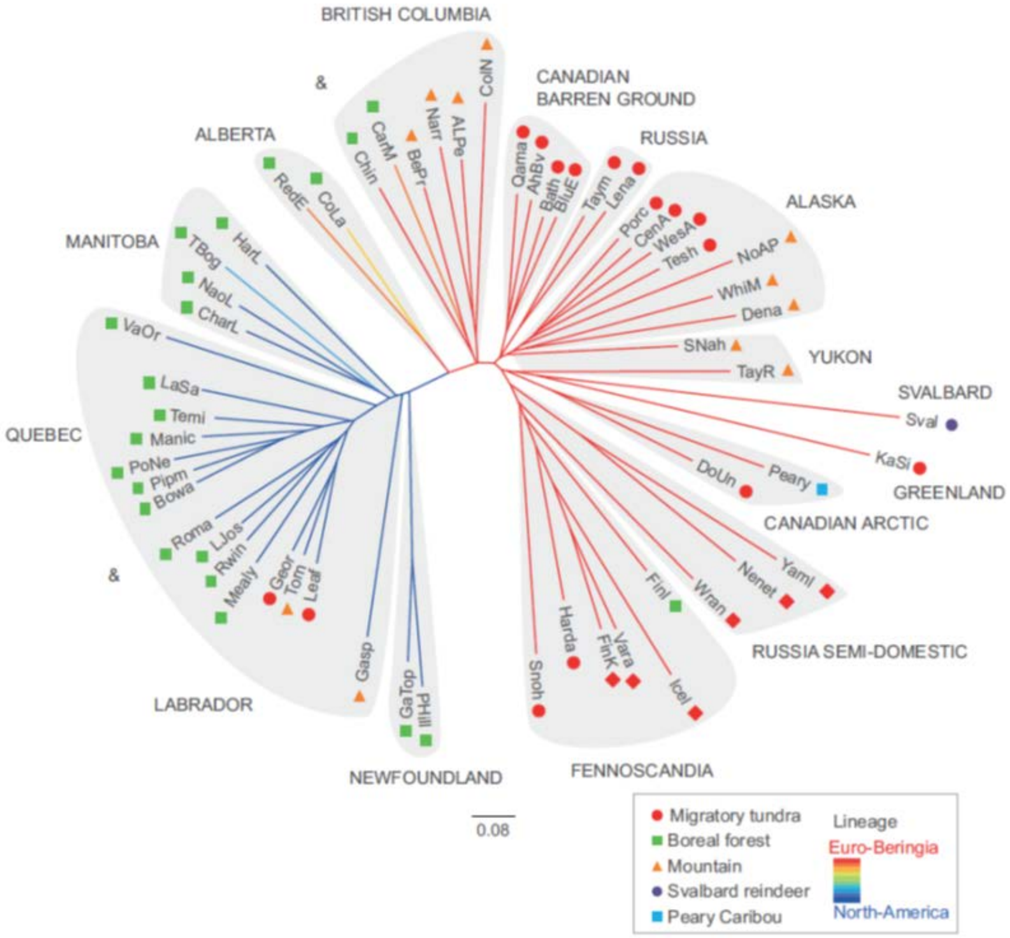

Figure 2.4. Neighbor-Joining Tree Based on Cavalli-Sforza Chord Distance (among 57 populations of caribou and reindeer herds and ecotypes) across Species' Holarctic Distribution: chord distance computed with *Populations 1.2.31* [www.bioinformatics.org/ ~ tryphon/populations] based on 16 microsatellites; length of branches is proportional to genetic distance between herds, colours correspond to Bayesian membership of each population to North American (blue) and Euro-Beringian (red) lineages obtained with Structure for K=2; red diamonds correspond to introduced or semi-domestic migratory caribou-reindeer [from Yannic et al. 2018]

Recent advances in the methodological approaches of genetic analysis have helped refine the spatial scale of genetic assessments, while also improving the ability to detect possible subdivisions within these two lineages (Yannic et al. 2016, 2018; Polfus et al. 2017) regardless of the high dispersal potential of caribou (Boulet et al. 2007; Weckworth et al. 2012). For example, Yannick et al. (2018) used a large-scale study (1297 individuals across 57 sites) to find that caribou showed significant genetic differentiation across local and regional scales, emphasizing a weak relationship with the currently defined ecotypes (Flagstad and Røed 2003). Further, Yannic et al. (2018) concluded that the boreal caribou populations in Finland and North America belong to distinct evolutionary lineages, while the Eastern Migratory (DU4), Boreal (DU5), and Mountain (DU7 to DU9) populations are ecologically different but still belong to the same North American lineage (Boulet et al. 2007; Yannic et al. 2016). Interestingly, it has been suggested that these genetic findings have been driven primarily by two environmental constraints: temperature and vegetation (Yannic et al. 2018).

2.3 Ecology

2.3.1 *Habitat Selection*

Accurately identifying how and why woodland caribou select and use habitats within and across their species and subspecies ranges remains an area of research that is essential to effectively manage and conserve the species (McLoughlin et al. 2019). Habitat selection can be significantly influenced by a series of contributing factors occurring over multiple temporal and spatial scales (Johnson 1980; Briand et al. 2009). Acquiring adequate amounts of food while minimizing risks of predation (i.e., food-predation tradeoff) are both considered principle mechanisms driving caribou population dynamics (Bastille-Rousseau et al. 2015).

Habitat selection within the landscape is a behavioural process where animals select areas that contain items or characteristics that may enhance their fitness by optimizing access to resources and reducing exposure to disease, competition, and predation (Orians and Wittenberger 1991; Morris 2003). A hierarchical process, habitat selection involves both innate and learned behavioural decisions made by an animal, resulting in disproportionate use of habitat relative to its availability (Johnson 1980; Briand et al. 2009; Mayor et al. 2009; Bastille-Rousseau et al. 2015). The fitness costs associated with habitat selection change both spatially and temporally, corresponding to different limiting factors occurring at various scales (Rettie and Messier 2000; Mayor et al. 2009; DeCesare et al. 2012). Rettie and Messier (2000) emphasized that animals select for factors that limit fitness at the coarsest scales and then select for less critical factors at the finer scale. On the contrary, McGreer et al. (2015) argued that local-scale selection patterns better predict how coarse-scale selection patterns are chosen (referred to as the “scaling-up” hypothesis) (Figure 2.5).

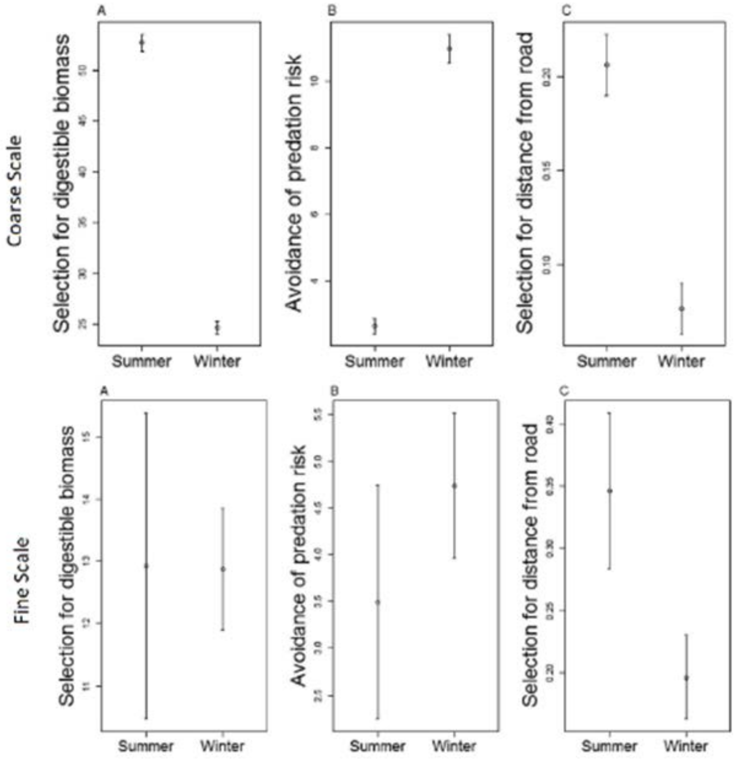

Figure 2.5. Coarse-Scale (top) and Fine-Scale (bottom) Selection Coefficients for (A) Digestible Biomass, (B) Avoidance of Predation Risk, and (C) Selection Distance from Nearest Road: bars represent 95% confidence interval around selection coefficients [from McGreer et al. 2015]

In the far north of Ontario, Avgar et al. (2015) reported that caribou selected among habitats on three biotic landscape attributes: forage availability, predators, and alternative prey. Regardless of which is the primary or secondary driver, caribou balance potential tradeoffs between acquiring sufficient forage (and associated nutrition) (Lima and Dill 1990; Johnson, Parker, and Heard 2001; Avgar et al. 2015; Denryter et al. 2017) and predation (Rettie and Messier 2000; Owen-Smith, Fryxell, and Merrill 2010; Viejou et al. 2018). For example, caribou vigilance may be lower while feeding, potentially reducing awareness of predators and increasing predation risk. In contrast, a caribou that is excessively focused on predator avoidance may sacrifice health, body condition, and reproduction, and increase susceptibility to predation, pests, or disease (Sections 5.4 and 5.5.2). While both bottom-up and top-down drivers are important in determining habitat selection and use, their relative importance is probably driven by a series of additional environmental conditions occurring at several temporal and spatial scales (Mayor et al. 2009).

Resource selection function (RSF) models currently serve as a primary tool for evaluating habitat use. They allow researchers to describe landscapes using probabilistic functions, permitting spatially-explicit examination of resource ability (e.g., Hornseth and Rempel 2016). Although these have been developed for caribou in many jurisdictions (Alberta, McLoughlin, Dunford, and Boutin 2005; British Columbia, DeCesare et al. 2012; Manitoba, Gustine et al. 2006; Quebec, Leblond, Dussault, and Ouellet 2013a, 2013b; Ontario, Hornseth and Rempel 2016), few studies have examined patterns of selection across different environmental conditions at varying scales (Johnson, Parker, and Heard 2001; Hebblewhite and Merrill 2009; Van Beest et al. 2010).

Furthermore, habitat use studies have been criticized because inferences about causality are typically weak and potentially contrived (Garshelis 2000; Morrison 2001, 2012), and because results often may simply reflect the availability of resources and how these resources are defined. Morrison (2001) noted that “[we] seem to be stuck in a revolving framework of endless site- and time-specific studies, and … our understanding of the causes of distribution, abundance, and performance are not advancing.” Garshelis (2000) noted that habitat evaluations are fraught with problems and emphasized doubt regarding the veracity of two fundamental assumptions of habitat selection studies: “that researchers can discern habitat selection or preference from observation of habitat use and that such selection, perceived or real, relates to fitness and hence to population growth rate.” Later, Morrison (2012) noted that “our studies of wildlife and habitat are largely decoupled from any meaningful relationship to the distribution of the study species.” He further indicated that habitat evaluation paradigms involve “convenience” sampling in area, design, and covariate selection, drawing samples from the usual list of parameters mainly because they are easily acquired from geographic information system (GIS) sources, and management recommendations are inappropriately extrapolated to other, unspecified areas and are usually vague and seldom verified for efficacy. With continuing refinement and increasing deployment of global positioning system (GPS) telemetry collars on caribou throughout Canada, the concerns and cautions of Morrison (2001, 2012) and Garshalis (2000) are increasingly relevant to development of conservation plans for habitat on behalf of caribou.

2.3.2 *Site Fidelity*

Ungulates exhibit high cognitive ability (Wolf et al. 2009; Merkle, Fortin, and Morales 2014; Avgar et al. 2015) and strong site fidelity or philopatry (the tendency to return to a previously occupied location) over both the short (e.g., calving or nursing sites) and long terms (e.g., home range) (Rettie and Messier 2000). Research on woodland caribou has found that they display strong evidence of site fidelity toward their home ranges (Faille et al. 2010; Lafontaine et al. 2017).

Site fidelity can enhance acquiring resources, improve performance, and reduce risk of predation (e.g., Schaefer, Bergman, and Luttich 2000; Wittmer, McLellan, and Hovey 2006; Faille et al. 2010) based on previous success or past experiences at a given site (Van Moorter et al. 2009; Avgar et al.

2013; Fagan et al. 2013; Merkle, Fortin, and Morales 2014). Animals tend to use a smaller home range if the quality of available habitat is high (Kie 1999; Donovan, Brown, and Mallory 2017). Fidelity behaviour is also believed to be driven by predation threat, where knowledge of escape routes and visibility across their home range provides an advantage to caribou. A recent study by Bastille-Rousseau et al. (2018) found that caribou had the ability to detect predator movement at ~2 km. These findings reinforce the notion that caribou can perceive their environment and make cognitive decisions about their surroundings to inform habitat selection (i.e., a cognitive map).

The strength of fidelity is also season specific. Caribou typically exhibit low fidelity in the winter, evidently due to higher interannual variability in food availability and predation pressures (Lafontaine et al. 2017). Their ability to select habitat may also be hindered to some degree when preferred sites (i.e., calving sites) are disturbed (Lafontaine et al. 2019). In response to habitat alteration, caribou modify their use of the landscape, where a smaller home range can occur and result in an increased concentration of individuals, reduced food availability and reproductive success, and easier predator detection (Seip 1991; Dyer et al. 2001; McCarthy et al. 2011; Pinard et al. 2012). The fidelity response to disturbance is not ubiquitous. Donovan, Brown, and Mallory (2017) found that caribou fidelity was not impacted by forest harvesting and suggested that the extent of a disturbance needs to exceed a certain behavioural response threshold. Other aspects of a disturbance may also elicit a behavioural response (e.g., road network, Section 5.3.1).

2.3.3 *Mountain Ecotype*

Mountain caribou are distinct from the boreal population of woodland caribou in that they occupy forests in the higher elevations of the Rocky Mountains of western Canada and the Gaspesié Peninsula of Québec (Courtois et al. 2003; Newsome, Brown, and Nemec 2016). They often select for higher elevation habitats in the late spring, summer, and fall, and may migrate to lower elevation conifer forests during the winter and earlier spring (COSEWIC 2014a). These seasonal migrations generally occur in response to snow conditions that can affect their ability to forage, and the extent of the migration is dependent on region-specific factors (i.e., topography) (Seip and McLellan 2008). During the winter, caribou generally select for windswept alpine ridges with abundant subalpine fir-dominated stands and low-elevation mature pine forests with abundant terrestrial lichen, and low-elevation cedar-hemlock forests in southern portions of the range (Kuzyk, Dehn, and Farnell 1999; COSEWIC 2014a). In the mountains, snow depth and hardness often determine habitat use, as deep or hard snow can limit access to terrestrial lichen (Cichowski 1993; Johnson, Parker, and Heard 2001). Caribou feed almost exclusively on arboreal lichen when snow is deep, which occurs for much of the year, particularly in the southern mountain subpopulations [Note: for simplicity sake subpopulations and ranges are used interchangeably in this document] (Rominger, Robbins, and Evans 1996; Terry, McLellan, and Watts 2000; Newsome, Brown, and Nemec 2016). In the northern and central DUs, snow depth is shallower and allows caribou to feed on terrestrial lichen for much of the year. Thus they may stay at higher elevations throughout the year (COSEWIC 2014a).

In non-winter seasons, caribou often descend into lower elevations to access better foraging habitat. However, they may return to higher elevations during calving periods, probably to minimize calf predation (Bergerud and Page 1987; Leclerc, Dussault, and St-Laurent 2012). In general, steeper slopes in higher elevations make it more difficult for wolves to reach caribou calves, which reduces their risk of predation (Barten, Bowyer, and Jenkins 2001; Gustine et al. 2006; Nobert et al. 2016). That said, steep slopes can also increase the likelihood of injuries to calves (Bergerud, Butler, and Miller 1984). If available, mountain caribou may select flat or gentler slopes during the calving period, evidently to improve sightability of predators (Nobert et al. 2016). Furthermore, while caribou avoid wolves by migrating upslope, they may increase exposure to other predators that use these higher altitudes (e.g., wolverines and grizzly bears) (Gustine et al. 2006; Fisher et al. 2013; Apps et al. 2016; Nobert et al. 2016), a concept known as predator facilitation (Charnov, Orians, and Hyatt 1976) (Section 5.4, Predation).

2.3.4 *Boreal Ecotype*

Habitat selection by caribou in boreal forests has been studied extensively across Canada. For example, Hornseth and Rempel (2016) investigated seasonal resource selection across four boreal caribou subpopulations in Ontario and found that when the landscape composition differed significantly due to environmental or disturbance gradients (Figure 2.6), model predictions were better from one subpopulation to another compared to using a single global model that considered all subpopulations together. These findings are consistent with other studies (Moreau et al. 2012; Johnson, Ehlers, and Seip 2015) that emphasize the importance of understanding finer-scale features when attempting to identify differences at the landscape scale. Using a single global model or fixed habitat requirements at the coarser scale can incorrectly overlook plasticity in the response(s) of caribou to habitat heterogeneity that exists at the finer scale. Thus, incorporating subpopulation-based assessments is likely to improve interpretation of results at the landscape scale (Hornseth and Rempel 2016), where many factors (e.g., disturbance) can be scale dependent (DeCesare et al. 2014).

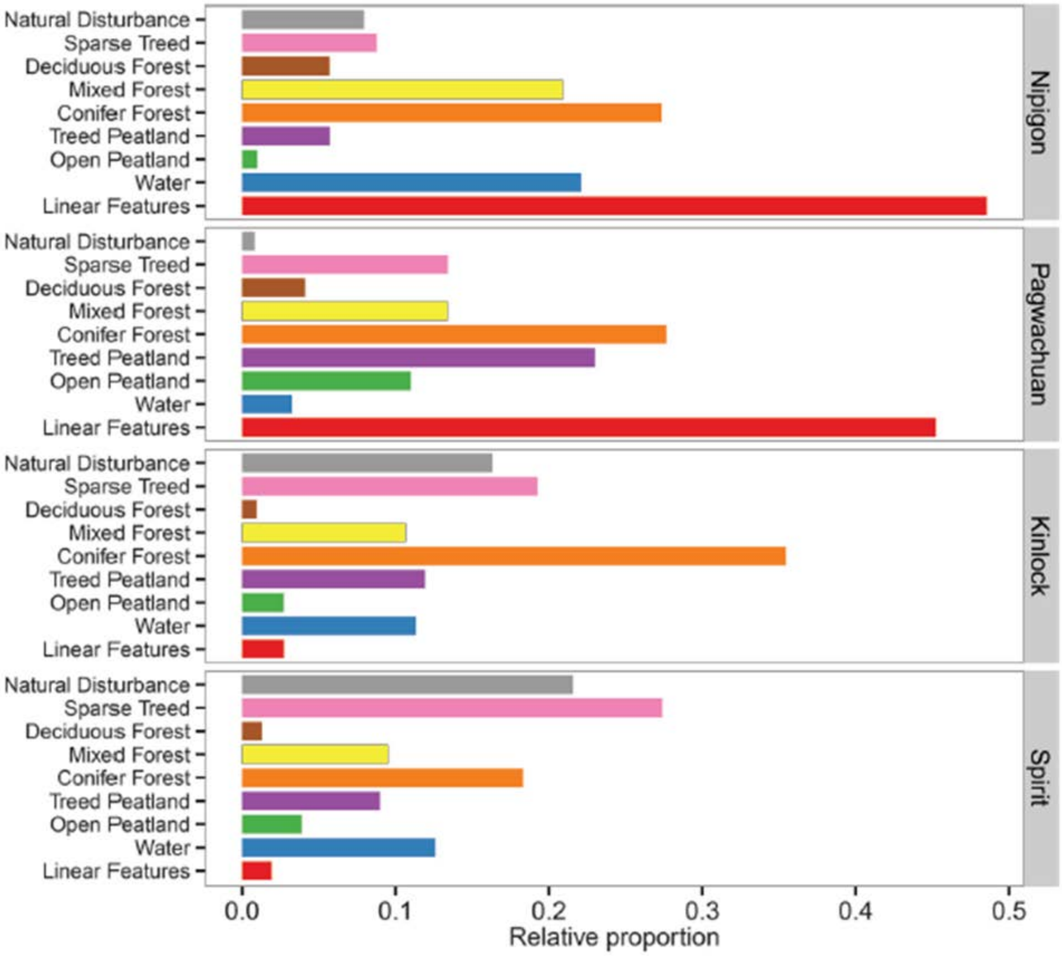

Figure 2.6. Relative Proportion of Environmental Variables across Four Subpopulations of Woodland Caribou in Northern Ontario: canopy types expressed in relative proportions; linear features expressed as km x ha x 10^{-1} [from Hornseth and Rempel 2016]

Much of the research designed to evaluate the implications of habitat use has focused on movement patterns and habitat selection (Rettie and Messier 2000; Gustine and Parker 2008; Hins et al. 2009), with relatively little focused on the relationship between habitat composition and vital rates (Wittmer et al. 2007; Sorensen et al. 2008; Leblond, Dussault, and Ouellet 2013b). Further, most habitat selection studies on woodland caribou have focused on coarse spatial scales (Briand et al. 2009). Thus, inferences are largely restricted to understanding where caribou go, not why they go there, and the implications to fitness of where they go (Garshelis 2000; Morrison 2012).

To date, the general consensus for boreal caribou has been that they require large continuous patches of old-growth conifer stands that allow them to ‘space out’ or segregate over the landscape to minimize their interaction with alternative prey while reducing their risk to predation (Seip and Cichowski 1996; McLoughlin, Dunford, and Boutin 2005; Courtois et al. 2007; Fortin et al. 2008; Bowman et al. 2010). Woodland caribou have therefore been associated with old-growth conifer forests and open lichen woodland as prime habitat. The theory is that these vegetation types provide more lichen, improve predator detection and escape, and provide little forage for alternative prey (Vanderwel, Mills, and Malcolm 2009). Considering that the geographic extent of the boreal population of caribou is vast, habitat selection can vary considerably with season and reproductive status (McGreer et al. 2015; Hornseth and Rempel 2016; Leblond et al. 2016; Viejou et al. 2018).

2.3.5 *Seasonality*

Identifying how and why caribou vary habitat use among seasons remains challenging, where caribou movement varies considerably throughout the year (Figure 2.7). Further, the ability to interpret habitat use and selection can be greatly skewed by the study area, scale of interpretation (e.g., animal, site, range, landscape), environmental covariates considered, methodology (e.g., how frequent or infrequent GPS positions are recording), and analysis of results (Garshelis 2000; Mayor et al. 2009; Morrison 2012; McGreer et al. 2015).

During the winter months, good foraging sites are limited. Caribou select areas that support lichen and generally have shallower, softer snow (i.e., mature coniferous stands with closed canopies and upland areas) that facilitate digging for terrestrial lichen (Schaefer and Pruitt 1991; Stuart-Smith et al. 1997; Rettie and Messier 2000; Dunford et al. 2006; Moreau et al. 2012). Habitat conditions that favour development and persistence of lichen were outlined by Payette and Delwaide (2018). Caribou select semi-open and open bogs during the fall and early winter but shift to mature coniferous uplands with jack pine as winter progresses (Darby and Pruitt 1984). James et al. (2004) reported that caribou in northeastern Alberta were most commonly found in black spruce/tamarack bogs and fens (peatlands), while moose and wolves were most abundant in the aspen-white spruce upland forests. Evidently, as a result, caribou incurred lower predation rates (Stuart-Smith et al. 1997). Caribou select for peatlands for much of the year (Cumming, Beange, and Lavoie 1996; James et al. 2004; McLoughlin et al. 2010) because the dense and spongy understories are not easily traversed by wolves, allowing caribou to minimize their encounter rates while also segregating from moose that prefer well-drained uplands with greater deciduous shrub browse (Crête 1989).

Caribou selection for old-growth forests is not unilateral. For example, in the Côte-Nord region of Québec, Latombe, Fortin, and Parrott (2014) found that caribou tended to avoid closed-canopy mature conifer stands in the winter and summer, regardless of the whereabouts of wolves (selecting open conifer with lichen habitats), in favour of open canopy conifer with lichen–findings supported by Courbin et al. (2009). Further, Bastille-Rousseau et al. (2018) also found that caribou selected for open areas, including open coniferous and wetland habitats, consistent with avoidance of predators and biting insects (Section 5.5.2), and habitats that generally have improved foraging opportunities (Rettie, Sheard, and Messier 1997; Bastille-Rousseau et al. 2015). In Ontario, Ferguson and Elkie (2005) found that caribou selected for lake areas in the winter, as they provided lower snow accumulation and easier predator detectability; however, Hornseth and Rempel (2016), who studied caribou in similar areas, found that they only selected for lakes during ice-free seasons. Islands and shorelines may provide relatively safe areas for caribou to calve and nurse (Bergerud 1985; Carr et al. 2011).

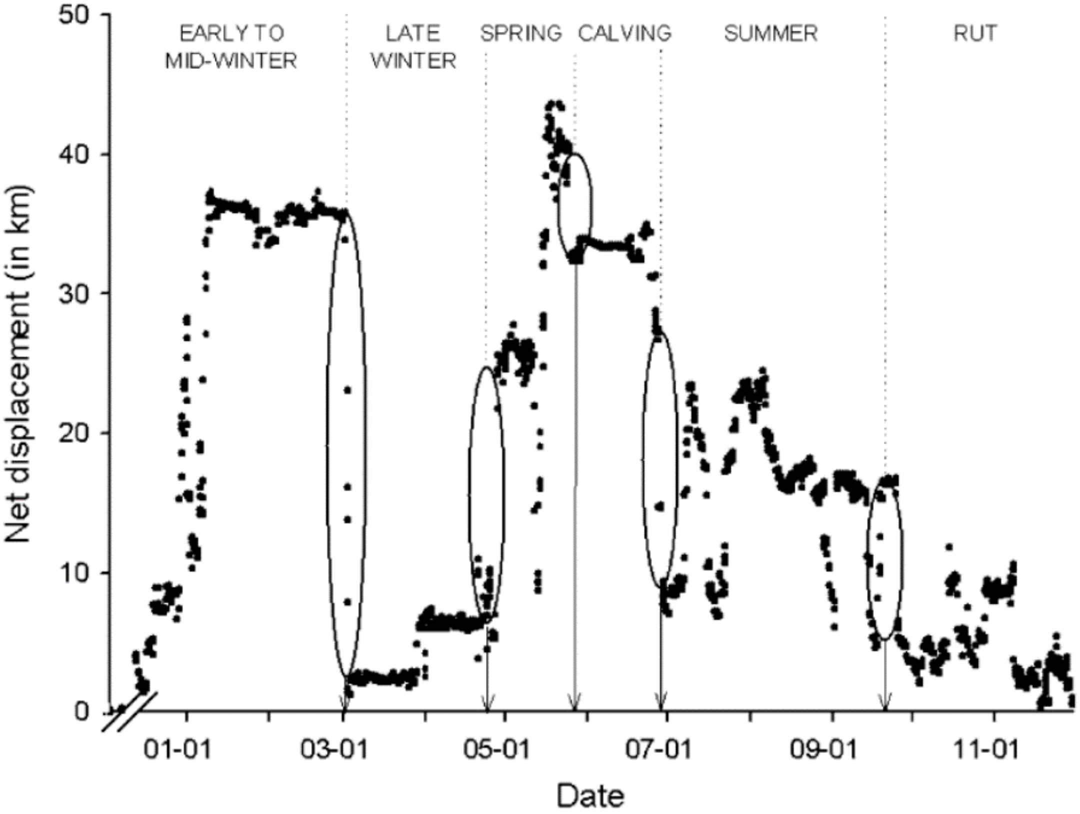

Figure 2.7. Net Displacement by a Female Caribou from Capture Site: plateaus between circled zones indicate low displacement, sudden transitions indicate important displacement (five circles); transitions reflect caribou movements to specific sites such as calving or feeding sites, and transitions were used to delineate six annual periods; here, there was no evident transition between summer and rut, and mean date of all other individuals were used to set transition date [from Courbin et al. 2009]

2.3.6 *Calving and Post-Calving*

Limited insight exists regarding habitat selection just before and after birthing (Rettie and Messier 2000; Viejou et al. 2018), but habitat use studies are increasing for this critical time (e.g., Carr et al. 2011; Pinard et al. 2012; Bastille-Rousseau et al. 2015; Viejou et al. 2018). Mothers presumably segregate from other caribou to minimize the risk of predation on their young (Brown et al. 1986; Schaefer, Bergman, and Luttich 2000). This may create a mismatch between optimizing nutrition at a time when nutritional requirements are increasing dramatically (McEwan and Whitehead 1972; Chan-McLeod, White, and Holleman 1994; Parker, Barboza, and Gillingham 2009), vs. optimizing predator avoidance when they and their newborn calves are especially vulnerable to predation. In order to accomplish a balance between acquiring food and avoiding predation, female caribou select for the following habitats during calving and post-calving periods: lakeshores and islands (Bergerud 1985; Cumming and Beange 1987; Moreau et al. 2012); old-growth coniferous forests (Lantin et al. 2003; Carr, Rodgers, and Walshe 2007; Courbin et al. 2009; Leblond et al. 2011); and open lichen woodlands and peatlands (Stuart-Smith et al. 1997; McLoughlin, Dunford, and Boutin 2005; Carr et al. 2011; Leblond et al. 2011). Females also choose higher elevations, when available, presumably to maintain their spacing out strategy (Section 5.4.4) from predators and alternative prey (Carr, Rodgers, and Walshe 2007; Lafontaine et al. 2017). In the Charlevoix subpopulation, Pinard et al. (2012) found that caribou primarily selected for calving areas to avoid predation rather than to avoid food limitation at both scales studied (home range and forest stand). Females often avoid disturbed areas, potentially to reduce predator encounters (James and Stuart-Smith 2000; Whittington et al. 2011), but conclusions vary. In western Ontario, Ferguson and Elkie (2004b) found that caribou selected for disturbed areas more in the spring than in the late winter and strongly selected for waterways during the calving period (Figure 2.8). Ungulate avoidance of human disturbances such as roads and other infrastructures has been reported (Section 5.3), especially during the calving period (Vistnes and Nellemann 2001; Vistnes et al. 2008). While there appears to be a consensus regarding caribou selecting these habitats for predator avoidance, the response seems to be driven by the cognitive ability (i.e., past experiences) of the caribou within a given subpopulation (Bastille-Rousseau et al. 2018).

Habitat selection by mothers has been linked to the abundance of forage (Bergerud and Nolan 1970; Bergerud 1972; Leblond et al. 2016; Viejou et al. 2018), which may be an essential factor for calving site selection (Johnson, Parker, and Heard 2001; Lantin et al. 2003; Carr, Rodgers, and Walshe 2007; Avgar et al. 2015). Nobert et al. (2016) found that female caribou in the Redrock-Prairie Creek and Narraway subpopulations in Alberta selected calving sites in burns at the subpopulation scale (coarser), but only caribou in the Redrock-Prairie Creek subpopulation selected for burns at the home-range (finer) scale–suggesting not only differences between subpopulations but also between the scale of assessment. Post-burned areas have been found to have higher vegetation productivity (e.g., Schaefer and Pruitt 1991) that may provide the necessary nutrition required for this high energy-demanding life stage (Parker, Barboza, and Gillingham 2009). How caribou use post-fire habitat remains poorly studied and poorly understood overall, but the use of post-burn landscapes by caribou is increasingly being questioned. For example, Kansas et al. (2016) raise a hypothetical example:

> *What if female caribou could trade-off negative aspects associated with traveling through large areas of relatively low-quality burn habitat to access isolated patches of high-quality residual habitat where forage is intact, and calf security is favourable?*

Considerable variability in anthropogenic and natural disturbance exists across the areas inhabited by woodland caribou subpopulations, and the relative impact disturbance has on forage availability also varies, particularly at the spatial scale that is required to accurately assess vegetation and its corresponding nutritional value (e.g., Denryter et al. 2017). Caribou mothers may trade what would have been higher foraging opportunities for areas that minimize predation risk when their calves are most prone to predation (Bergerud, Butler, and Miller 1984; LeBlond et al. 2016; Viejou et al. 2018). Females without calves, on the other hand, are likely to display “riskier” behaviour to access forage-rich patches with no detectable avoidance of areas potentially used by predators (Viejou et al. 2018). Females without calves may be taking advantage of the period when resource pulses overlap with the wolf (*Canis lupus*) denning period; wolf movement is significantly reduced during these times of the year (Lesmerises, Dussault, and St-Laurent 2012; Roffler and Gregovich 2018).

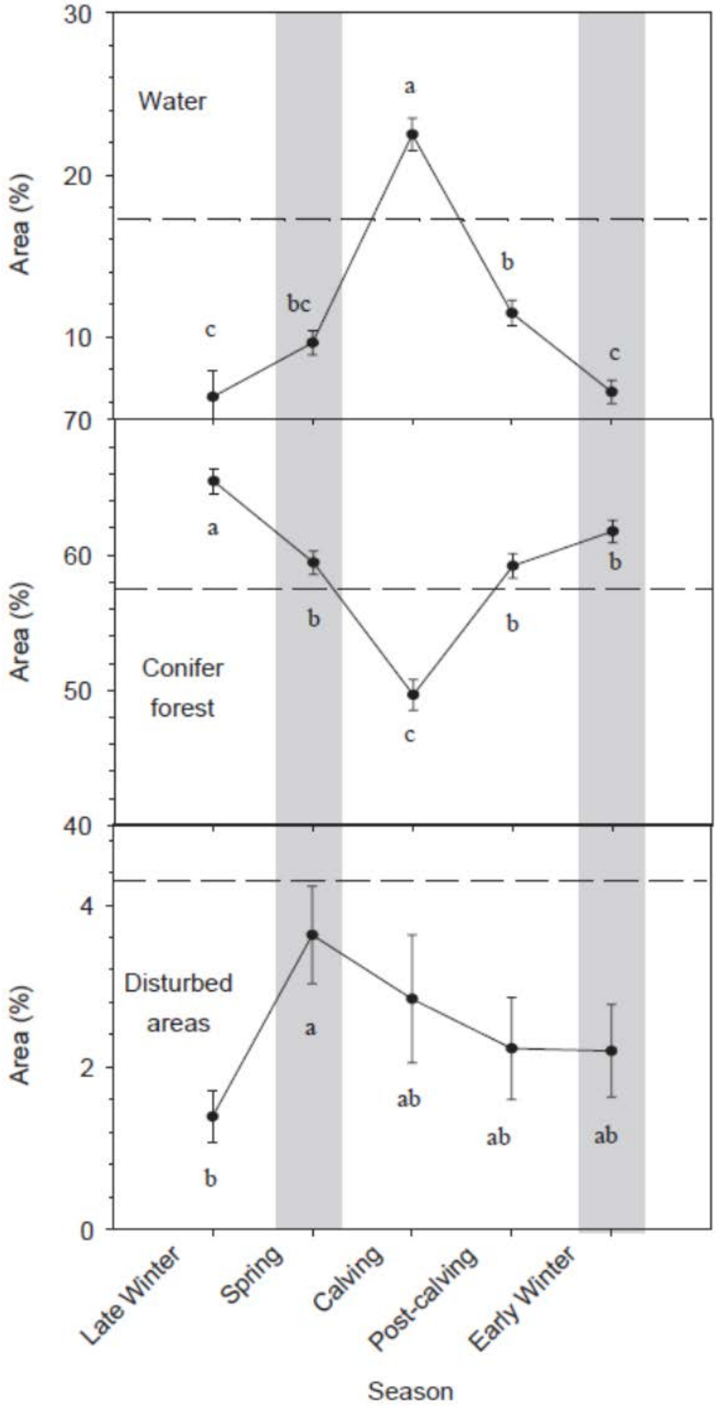

Figure 2.8. Caribou Seasonal Use of Water, Conifer Forest, and Disturbed Areas Relative to Availability (dashed line): shaded area denotes travel seasons; data presented as mean and ± standard error; means with same letter do not differ significantly from each other using Tukey's multiple comparison test [from Ferguson and Elkie 2004b]

2.4 Diet and Nutrition

In addition to the top-down influences of mortality (i.e., predation, Section 5.4), population trends are also a function of bottom-up influences on productivity and interactions between mortality and productivity (Crête and Huot 1993; Gustine et al. 2006; Hegel et al. 2010; Johnson et al. 2019). Effects of nutrition on productivity have been well documented in classical controlled studies for livestock and wild cervids for decades (Cook et al. 1996, 2004; NRC 2007). An animal's diet can have a significant multiplier effects (White 1983) on several productivity factors: the likelihood of pregnancy; timing of pregnancy; newborn vigor; juvenile growth, development, and survival; nutritional condition; age at first breeding; and endogenous reserves (White 1983; Parker et al. 1999; Cook et al. 2004, 2013; Barboza, Parker, and Hume 2009; Thompson and Barboza 2014; Denryter et al. 2017). Variability in both abundance and quality of forage resources across multiple spatial and temporal scales may lead to contrasting conclusions in terms of how caribou are using and obtaining resources on the landscape (Mahoney and Schaefer 2002; Briand et al. 2009; Mayor et al. 2009; Owen-Smith, Fryxell, and Merrill 2010).

Caribou may or may not experience marked seasonal fluctuations in body condition (fat and protein reserves) (Couturier, Côté, Huot, et al. 2009) reflecting variations in forage quantity and quality and energetic stressors imposed on the animal (e.g., predation, snow depth, insect harassment, fetal growth in the third trimester, juvenile growth, lactation) (e.g., Barboza and Parker 2008; Denryter et al. 2017). Acquisition of resources is highly seasonal, and protein and fat reserves are high before the rut and lowest during the calving and post-calving period for females and after the rut for males (Barboza et al. 2004; Gunn 2016).

Winter is the season of obvious nutritional deprivation in northern regions (Wallmo et al. 1977; Mautz 1978). This is the season during which nutritional condition of animals normally declines (Mautz 1978; Cook et al. 2013; Monteith et al. 2014) and episodes of starvation are usually observed (Houston 1982). However, the perception that nutritional limitations are of practical concern only in winter continues to be refuted by a myriad of studies worldwide for a variety of cervid species (Hjeljord and Histøl 1999; Cook et al. 2013, 2018; Hurley et al. 2014; Monteith et al. 2014; Proffitt et al. 2016; Rolandsen et al. 2017; Schrempp et al. 2019). Focusing exclusively on diet and nutrition from one season can constrain the ability to gain further insight into productivity factors that contribute to the population dynamics of woodland caribou, particularly important when many key life history stages occur in non-winter seasons (Section 2.5, Life Cycle and Reproduction) (Thomas, Edmonds, and Brown 1996; Carrière 2002).

A better understanding of caribou diets and nutrition throughout the year and across their range may be valuable in improving management of habitats and developing more robust conservation plans. This knowledge gap persists despite growing evidence of nutritional limitations operating in other cervids and other *Rangifer* subspecies that suggests considerable need for greater emphasis on nutrition research on caribou summer ranges (Dale et al. 2008; Couturier, Côté, Huot, et al. 2009). To date, however, very few studies have focused on non-winter diets or feeding habits of woodland caribou (but see Bergerud 1972; Thompson et al. 2015; Denryter et al. 2017). Unlike barren-ground caribou, where a general understanding of feeding habits and the effect(s) of nutritional resources (particularly in the spring through autumn period) on reproduction and survival have been well studied (Crête and Huot 1993; Post and Klein 1999; Cameron et al. 2005; Dale et al. 2008; Post and Forchhammer 2008; Pachkowski, Côté, and Festa-Bianchet 2013; Schaefer and Mahoney 2013), this has not yet been done at an equivalent level for woodland caribou, perhaps because it has been considered a non-issue for their conservation (Wittmer, Sinclair, and McLellan 2005; Courtois et al. 2007; Festa-Bianchet et al. 2011; Gustine et al. 2012; McLellan et al. 2012).

Caribou are highly selective foragers (DesMeules and Heyland 1969). As ruminants and intermediate feeders, caribou require one to three days to pass food through their digestive systems (Thomas and

Kroeger 1981). Lichen (both arboreal and terrestrial forms) can make up a significant portion of their overall diet (e.g., Thompson et al. 2015; Denryter et al. 2017), particularly during winter (Figures 2.9 and 2.10). Caribou seem well adapted to living primarily on lichen, making the species exceptionally well-adapted to ecosystems of the northern latitudes (COSEWIC 2011). Caribou locate and use pulses of nutrients in space and time (Jefferies, Klein, and Shaver 1994; Iversen et al. 2014), and their diets typically shift to composites of lichen and vascular plants early in the growing season and predominantly to lichen of various species in the dormant season (Chapin et al. 1996; Wookey et al. 2009; Denryter et al. 2017).

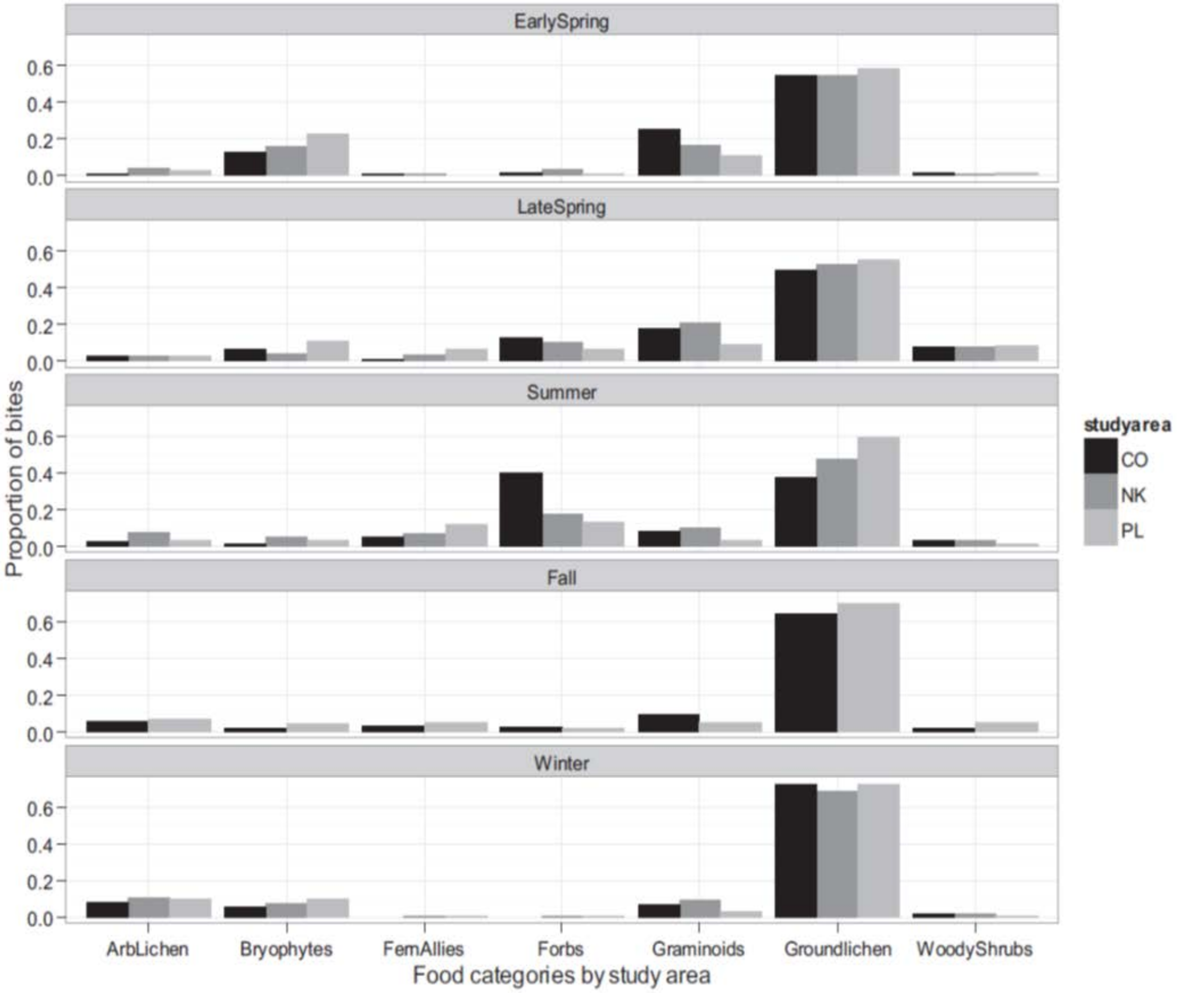

Figure 2.9. Diet Composition of Woodland Caribou by Bites Taken for Five Seasons at Three Study Sites in Ontario, 2011-2013: CO=Cochrane; NK=Nakina; PL=Pickle Lake [from Thompson et al. 2015]

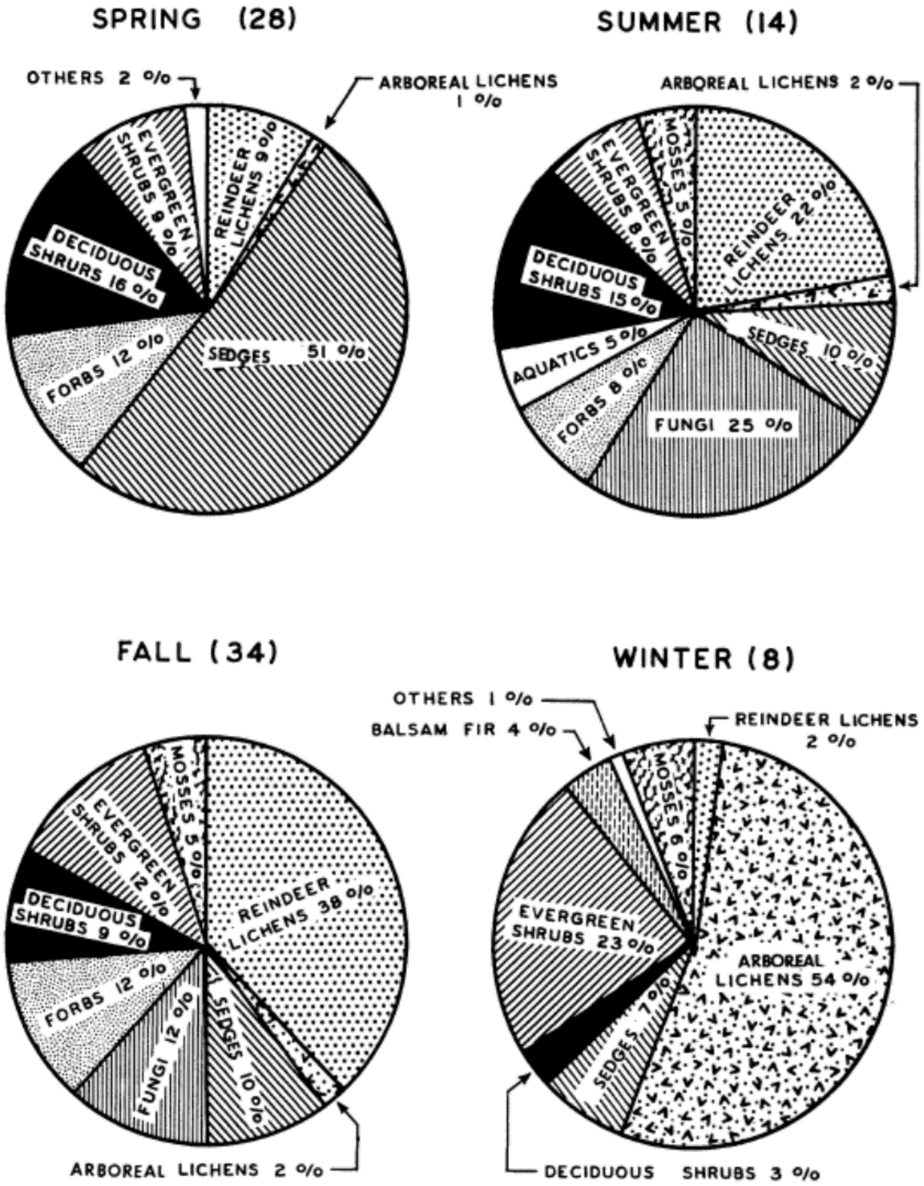

Figure 2.10. Percentage of Plant Groups Identified in Contents of Caribou Rumina in Newfoundland (n=84) [from Bergerud 1972]

2.4.1 *Winter Diet*

In winter, the abundance, diversity, and quality of forage on woodland caribou ranges is reduced, providing limited foraging options. Caribou select for semi-open and open bogs in fall and early winter months, and as winter progresses, shift to more mature conifer stands and peatlands where lichen are most readily available (Schaefer and Pruitt 1991; COSEWIC 2011). Snow conditions also influence access to forage (Stardom 1975; Boan, McLaren, and Malcolm 2013). Caribou have been documented to access preferred forage despite greater snow depths (Stardom 1975; Fancy and White 1986; Mosser et al. 2014). Early in winter, when snow conditions are more favourable, caribou forage on arboreal lichen. However, as winter progresses, caribou shift to terrestrial lichen when the snowpack is thicker and/or harder (Darby and Pruitt 1984; Schaefer and Pruitt 1991). The shift from arboreal to terrestrial lichen tends to occur when snow reaches a depth of approximately 65 cm

(Stardom 1977), but Brown and Theberge (1990) documented that caribou are capable of locating forage at nearly twice that depth (~123.0 cm), suggesting that caribou effort is dependent on forage quality and abundance and their level of famishment. Expending energy through digging and searching for forage is probably energetically inefficient, but for caribou this represents an effective approach for survival in the far north.

In winter, lichen (both arboreal and terrestrial) are the predominant forage group consumed by caribou (Bergerud 1972; Thomas, Edmonds, and Brown 1996; Fischer and Gates 2005; Thompson et al. 2015). Lichen tend to be high in digestible energy but low in protein, providing a rich energy source during the forage-limited months but one that may contribute to a negative protein balance (Bergerud 1972; Gerhart et al. 1996; Parker, Barboza, and Stephenson 2005; Mallory and Boyce 2018). Woodland caribou forage on a wide range of lichen species that include but is not limited to reindeer lichen (*Cladina* spp.), witch's hair lichen (*Alectoria* spp.), and beard lichen (*Usnea* spp.) (Figures 2.9 and 2.10). Caribou are opportunistic foragers that supplement their diet in the winter by foraging on "winter-green" vascular plants (when accessible), which may provide higher concentrations of protein than lichen, a much-needed source in the leaner months of the year (Klein 1982; Thompson et al. 2015). By increasing dietary diversity, caribou may also improve their digestion by acquiring nitrogen and minerals that help synthesis of ruminal microbes (Ørskov 1992; Storeheier et al. 2002). Although caribou have been observed ingesting moss (Demars and Boutin 2014), it is generally believed to be incidental to lichen consumption and has been suspected by others to be an indicator of deteriorating range conditions (Culling and Cichowski 2017). Further, an old-growth area that no longer supports lichen within the understory because mosses have outcompeted it may benefit from a "re-set" by disturbance that could enhance conditions that favour lichen growth again. (Section 5.5.1, Fire) (Culling and Cichowski 2017).

2.4.2 *Non-Winter Diet*

During late spring through mid-autumn, key life processes such as gestation (during late pregnancy), lactation, juvenile growth, recovery of endogenous energy after winter, and breeding impose large nutritional demands (Oftedal 1985; Cook et al. 2004; NRC 2007). Emerging literature increasingly shows that nutrition in summer inadequately supports these processes in many ecosystems and illustrates that nutrition in summer functions as a vital link between productivity of large ungulates and the habitat on which they depend (Hjeljord and Histøl 1999; Cook et al. 2013, 2018; Hurley et al. 2014). Evidence is also building that annual minima in body condition occurs in late spring and early summer in many populations (Huot 1989; Crête and Huot 1993; Gerhart et al. 1996; Chan-McLeod, White, and Russell 1999), suggesting a nutritional bottleneck in early summer. Additionally, mortality of adult female caribou peaks in summer in many populations, at least in western Canada (McLoughlin et al. 2003; Wittmer, Sinclair, and McLellan 2005), suggesting a cause-and-effect linkage between caribou survival and their nutritional condition at that time (Kelly 2020).

In non-winter months, caribou diet shifts to include more vascular plants such as graminoids (grasses, sedges, rushes), forbs, fungi, and leaves of shrubs and deciduous trees (Bergerud 1972; Rominger and Oldemeyer 1990; Thomas, Edmonds, and Brown 1996; Galloway et al. 2012; Newmaster et al. 2013; Thompson et al. 2015; Denryter et al. 2017). Caribou in northeastern British Columbia were found to select for a variety of deciduous shrubs, forbs, lichen, and mushrooms; however, the species they selected represented only 10% of available forage species (28 of 282 total species, Table 2.1). Further, these caribou showed neutral selection (i.e., species consumed in proportion to availability) for an additional 91 species during the non-winter months (Denryter et al. 2017). Denryter et al. (2020) reported that in summer caribou continued to forage even when daily forage and nutrient intake greatly exceeded requirements, suggesting an energy maximizing rather than a time minimizing foraging strategy. Ultimately, the availability of preferred, high-energy, high-protein forage depends on ecosite characteristics at fine scales (i.e., forage patch and forest stand) (Mallon 2014; Denryter et al. 2017).

Table 2.1. Forage Species for Tame Caribou Studied in Northeastern British Columbia (by forage class, scientific name, and common name)

Forage class	Scientific Name	Common Name	Selection[a]
Arboreal Lichen	*Alectoria* spp.	Witch's hair	S
	Bryoria spp.	Horsehair lichen	S
	Parmeliaceae family	Various species	N
	Usnea spp.	Old man's beard	N
Deciduous Shrubs	*Alnus crispa*	Green alder	S
	Alnus tenuifolia	Mountain alder	N
	Amelanchier alnifolia	Saskatoon serviceberry	S
	Arctostaphylos rubra	Red bearberry	N
	Betula glandulosa	Dwarf birch	S
	Betula papyrifera	Paper birch	S
	Cornus stolonifera	Red osier dogwood	N
	Lonicera dioica	Mountain honeysuckle	N
	Lonicera involucrate	Twinberry honeysuckle	N
	Oplopanax horridus	Devil's club	N
	Populus balsamifera	Cottonwood	S
	Populus tremuloides	Trembling aspen	S
	Ribes oxyacanthoides	Northern gooseberry	N
	Ribes spp.	Currant	N
	Rosa acicularis	Wild rose	S
	Rubus idaeus	Red raspberry	N
	Salix spp.	Willow	S
	Shepherdia canadensis	Soapberry	N
	Sorbus scopulina	Mountain ash	N
	Spiraea betulifolia	Birch-leaved spirea	N
	Vaccinium membranaceum	Black huckleberry	S
	Vaccinium myrtilloides	Velvet-leaved blueberry	S
	Vaccinium ovalifolium	Oval-leaved blueberry	N
	Vaccinium uliginosum	Bog blueberry	S
	Viburnum edule	Squashberry	N
Evergreen Shrubs	*Arctostaphylos uva–ursi*	Bearberry	N
	Dryas integrifolia	Mountain avens	N
(Continued on next page. See notes at end of table.)			

Table 2.1. Continued

Forage class	Scientific Name	Common Name	Selection[a]
Forbes	*Achillea millefolium*	Yarrow	N
	Anaphalus margaritaceae	Pearly everlasting	N
	Aralia nudicalis	Wild sarsparilla	N
	Arenaria spp.	Sandwort	N
	Artemisia arctica	Boreal sagebrush	N
	Aruncus dioicus	Goat's beard	N
	Aster conspicuous	Western showy aster	N
	Aster spp. including *A. ciliolatus*	Aster	S
	Astragalus alpinus	Alpine milkvetch	N
	Astragalus americanus	American milkvetch	N
	Astragalus australis	Indian milkvetch	N
	Bistorta vivipara	Alpine bistort	N
	Castilleja spp.	Indian paintbrush	N
	Clintonia uniflora	Queen's cup lily	S
	Delphinium glaucum	Mountain larkspur	N
	Epilobium angustifolium	Fireweed	N
	Epilobium watsonii, E. ciliatum	Willow herb	N
	Erigeron spp.	Daisy	N
	Galium borealis	Northern bedstraw	N
	Geum macrophyllum	Large leaf avens	N
	Hedysarum alpinum	Alpine sweetvetch	N
	Hieracium spp.	Hawkweed	N
	Lathyrus spp.	Sweet pea	S
	Lupinus arcticus	Arctic lupine	N
	Maianthemum canadense	Canada mayflower	N
	Medicago falcata	Blue alfalfa	S
	Mertensia paniculate	Tall bluebells	N
	Osmorhiza chilensis	Sweet Cicely	N
	Oxyria digyna	Mountain sorrel	N
	Oxytropis campestris	Field locoweed	N
	Oxytropis nigrescens	Blackish locoweed	N
	Petasites frigidis	Arctic sweet coltsfoot	N
	Petasites palmatus	Palmate coltsfoot	N
	Petasites sagittatus	Sweet coltsfoot	N
	Polemonium caeruleum	Jacob's ladder	N
	Polemonium pulcherrimum	Showy Jacob's ladder	N
	Potentilla spp.	Cinquefoil	N
	Prunella vulgaris	Heal-all	N
	Pyrola spp.	Wintergreen	N
	Rubus pedatus	Five-leaved bramble	N
	Rumex arcticus	Arctic dock	N
	Sanguisorba stipulate	Sitka burnet	N
	Senecio lugens	Black-tipped groundsel	N
	Senecio spp.	Groundsel	N
	Sibbaldia procumbens	Creeping sibbaldia	N
	Smilacina racemose	False Solomon's seal	N
	Smilacina stellate	Little false Solomon's seal	N
	Smilacina trifolia	Three-leaved Solomon's seal	N

(Continued on next page. See notes at end of table.)

Table 2.1. Continued

Forage class	Scientific Name	Common Name	Selection[a]
Forbes (continued)	*Solidago canadensis*	Canada goldenrod	N
	Solidago multiradiata	Alpine goldenrod	N
	Streptopus amplexifolius	Clasping twisted-stalk	S
	Tanacetum vulgare	Tansy	N
	Taraxacum spp.	Dandelion	S
	Tellima grandiflora	Saxifrage	N
	Trifolium spp.	Clover	S
	Vicia Americana	American vetch	N
Fungus	Conk (various spp.)	Conk	S
	Mushroom (various spp.)	Mushroom	S
Grasses	*Agropyron trachycaulum*	Slender wheatgrass	N
	Bromus spp.	Brome grass	N
	Elymus glaucus	Blue wild rye	N
	Elymus innovates	Hairy wild rye	S
	Festuca altaica	Altai fescue	N
	Festuca ovina	Sheep fescue	N
	Festuca spp.	Fescue grass	N
	Hierochloe alpine	Alpine sweetgrass	N
	Phleum alpinum	Alpine Timothy	N
	Phleum pretense	Timothy	N
	Poa spp. including *P. pratensis*	Meadowgrass	N
	Trisetum spicatum	Spike trisetum	N
Graminoid (non-grasses)	*Equisetum arvense, E. pratense*	Horsetail	N
	Equisetum sylvaticum	Horsetail	N
	Equisetum variegatum	Horsetail	N
	Eriophorum spp.	Wooly sunflower	N
	Juncus spp.	Bulrush	N
Terrestrial Lichen	*Alectoria ochroleuca*	Witch's hair	S
	Cetraria aculeata, C. islandica	Cetraria lichen	N
	Cladina mitis	Green reindeer lichen	S
	Cladina rangiferina	Grey reindeer lichen	S
	Cladina stellaris	Reindeer lichen	N
	Cladonia spp.	Cladonia lichen	S
	Dactylina Alpine	Arctic finger lichen	N
	Flavocetraria cucullata, F. nivalis	Flavocetraria lichen	S
	Gowardia nigricans	Gray witch's hair	N
	Nephroma arcticum	Green kidney lichen	N
	Rhizocarpon geographicum	Map lichen	N
	Umbilicaria hyperborea	Rock tripe	N

[adapted from Denryter et al. 2017]

[a] N=neutral; S=selected

2.4.3 *Scale*

On landscapes where the distribution of forage quality and quantity is heterogenous, habitat selection is a powerful tool that herbivores may use to obtain diets dominated by palatable and nutritious forage (Moen, Pastor, and Cohen 1997; Cook et al. 2018). However, because objectives for habitat selection probably reflect other "currencies" such as minimizing risk from predation and harassment from biting insects, herbivores face tradeoffs that may affect reproduction and survival. In addition, habitat selection may be hierarchical, and implications are that if animals prioritize habitat selection for one currency they may sacrifice in terms of satisfying their needs for others (Rettie and Messier 2000;

Mayor et al. 2009; McGreer et al. 2015). It increasingly seems that caribou first select habitats to minimize predation risk, then within these areas attempt to select for areas of better forage quality and quantity (Gustine and Parker 2008). Habitat selection patterns throughout the year are probably dynamic, reflecting changing needs of caribou and changing distributions of resources. The propensity to select areas to reduce predation risk may be highest around the time of birth and when calves are still relatively immobile and thus highly susceptible to a variety of predators (Section 5.4, Predation), but implications of habitat selection in the context of tradeoffs among currencies may reflect the spatial and temporal distribution of resources. In some settings, for example, habitat selection to avoid predators may not affect access to good forage. In others, the tendency to avoid insect harassment may be the predominant determinant of habitat selection if caribou can locate areas where biting insects can be avoided (Section 5.5.2). In addition, the balance between the need for food and the energy expended to acquire adequate nutritional resources may influence selection. For example, in winter caribou probably select areas of shallow, soft snow to reduce the energy required for foraging (Figure 2.11). At the fine scale, caribou may tolerate plant communities with forage of poor quality or abundance (Denryter et al. 2017).

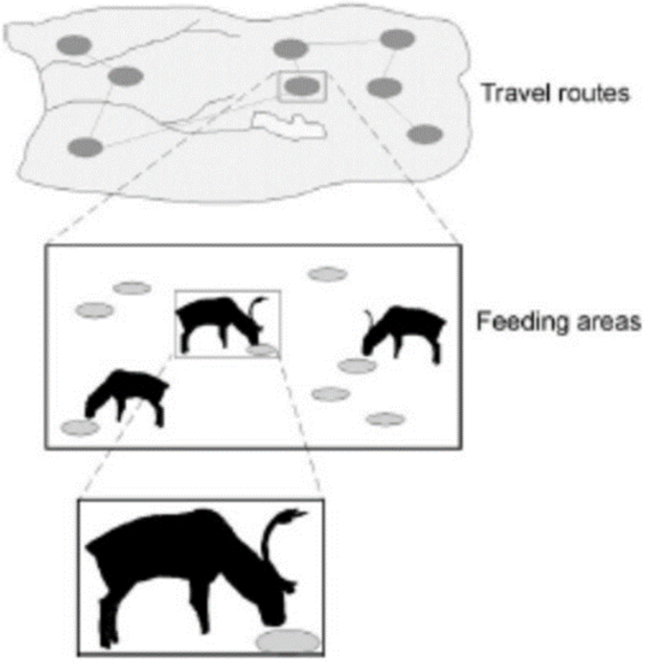

Figure 2.11. Schematic Representation of Hierarchical Levels of Habitat Selection by Caribou (finest scale at the bottom) [from Mayor et al. 2009]

2.4.4 *Measuring Diet and Nutrition*

It remains challenging to accurately measure the diet composition and corresponding nutrition of woodland caribou. Improving an understanding of the effect of diet and nutrition must measure subtle habitat, seasonal, and individual differences that may exist and use methods that accurately measure these responses (Newmaster et al. 2013). A variety of approaches provide insight into caribou diet and forage selection, each with potential benefits and drawbacks (Table 2.2). Examinations of stomach contents and scat are the most common methods used to evaluate the diet composition of terrestrial animals (Litvaitis 2000; Mumma et al. 2016). This post-ingestion technique (i.e., fecal pellet analysis) and subsequent DNA barcoding is popular (Newmaster et al. 2013; Gustine et al. 2014; Jung, Stotyn, and Czetwertynski 2015; Schaefer et al. 2016; Erickson et al. 2017) because of the ease of sample collection and its low cost. However, the species composition of what remains after ingestion is not necessarily the same as what was eaten. For example, microhistological examination of feces overestimates species that are slow to digest (i.e., low-quality forage) and underestimates rapidly-digested forages, and thus has a tendency to infer high value to plant species that are of relatively low value or quality (Coissac, Riaz, and Puillandre 2012; Mumma et al. 2016). In addition, post-ingestion techniques have been criticized for having low accuracy and taxonomic resolution (Carrière 2002; Coissac, Riaz, and Puillandre 2012).

Table 2.2. Methods for Measuring Caribou Diet Composition: Benefits, Drawbacks, and Citations

Approach to Measuring Nutrition or Diet	Possible Benefits of Approach	Potential Drawbacks of Approach	Examples of Studies (non-exhaustive)
Post-hoc investigation of feeding craters	Inexpensive Inferences can be made about plant selection and fecal analysis with peripheral plots	Reveal little about consumption	Thomas, Edmonds, and Brown 1996 Johnson, Parker, and Heard 2000
Rumen content analysis	Direct measurement	Difficulties with representation Inability to consider digestion rates	Bergerud 1972
DNA sampling (hair, tissue, hoof)	Passive collection	Indirect measurement Expensive analysis	Drucker et al. 2010 Merkle et al. 2017
DNA barcoding (fecal)	Passive collection	Ingested, no insight into initial quality or nutritional value Limited insight Expensive	Newmaster et al. 2013 Jung, Stotyn, and Czetweryynski 2015 Schaefer et al. 2016
Video collars	Cost-effective Passive collection, can collect large scale	Limited measurement Laboratory assessment can be difficult to interpret	Newmaster et al. 2013 Thompson et al. 2015
Tame animals	Direct measurement No visual obstructions	Costly Labor and time intensive Management and protocol Infrastructure	Parker and Barboza 2013 Thompson and Barboza 2014 Denryter at al. 2017

Another option for assessing caribou diet composition is using GPS collars equipped with video cameras. This allows a dietary assessment across the landscape (Newmaster et al. 2013; Thompson et al. 2015), but challenges can arise with image quality, point of view, and duration of observations, which cumulatively may influence accuracy and precision.

A third technique for assessing diet composition for caribou is use of tame animals. The benefit of using such an approach is greater proximity to foraging animals (within a metre or less), which may provide greater accuracy and precision of observations (Trudell and White 1981; Rominger and Oldemeyer 1990; Denryter et al. 2017). Importantly, comparative studies have indicated that dietary composition estimates using tame ungulates, including caribou, show indistinguishable differences in diet selection and forage dynamics between tame and wild animals (Bergerud and Nolan 1970; Bergerud 1972; Spalinger et al. 1997). Use of tame animals has been proposed as a plausible habitat assessment tool (Rominger, Robbins, and Evans 1996). Drawbacks of using this approach include the requirement for significant experience in managing cervids, the high cost of maintaining the animals, and the necessary infrastructure to house the animals while trials are being conducted.

2.4.5 *Other Contributing Factors*

The wide distribution of woodland caribou emphasizes the species' ability to endure habitats and habitat qualities ranging from poor to highly productive forests, dry to wet environments, and low-lying to high alpine tundra (COSEWIC 2014a, 2014b; Bernes et al. 2015). Caribou have behavioural and physiological plasticity to respond to changes in food availability and their environment; thus, several additional factors can influence their foraging habits. Caribou may alter their use of space, increase vigilance, and change foraging patterns when predators are nearby (McLoughlin, Dunford, and Boutin 2005; McLellan et al. 2012; Barber et al. 2018). Nutritionally stressed animals probably undertake riskier behaviour to attain food resources, a hypothesis known as "predation-sensitive foraging" (Sinclair and Arcese 1995). Female caribou in Newfoundland displayed this riskier behaviour, risking predation to acquire higher quality summer forage (Hébert and Weladji 2013; Bastille-Rousseau et al. 2015; Schaefer et al. 2016). Caribou also may select for forage independent of any external factors (i.e., predation or competitors for resources) (Mallon et al. 2016), as has been commonly found in other ungulate species (Van Dyke and Darragh 2007; Van Beest et al. 2010; Cook et al. 2018). Predation risk can contribute to inefficient or inadequate foraging, which creates an interaction of top-down and bottom-up processes that can be confounded and difficult to disentangle (McLellan et al. 2012; Boutin and Merrill 2016).

Disturbances (natural or anthropogenic in origin) alter habitat used by caribou and directly (through removal or increase in vegetation consumed by caribou) or indirectly (through alteration of habitat for competitors and/or predators) impact forage availability and/or quality (Schaefer et al. 2016). A change (positive or negative) in forage availability or in abundance of competitors/predators may influence caribou nutrition and, potentially, body condition (Jefferies, Klein, and Shaver 1994; Bergerud, Luttich, and Camps 2008).

Dietary overlap with competing ungulates (e.g., moose, deer, elk, bison) may also contribute to the health status of woodland caribou (Section 5.4.5, Apparent Competition). A study conducted by Jung, Stotyn, and Czetwertynski (2015) evaluated the dietary overlap of large ungulates (caribou, muskoxen, moose, thinhorn sheep, bison, elk, horses) in the Yukon, and concluded that caribou overlapped most with moose (0.43 on a scale of 0 to 1, where 0 indicates no overlap and 1 indicates complete overlap) and bison (0.51) in summer, but had minimal overlap in winter (moose 0.12, bison 0.22).

2.5 Life Cycle and Reproduction

Caribou are relatively long-lived, with a life expectancy of approximately 12 to 16 years for females and generally a few years less for males (Thomas and Kiliaan 1998). In captivity, caribou can live 22 years (Müller et al. 2010). A generation length for woodland caribou is estimated to be 6 years (COSEWIC 2014a, 2014b), which is based on the average age of parents and reflects turnover rates of breeding individuals within a given population (IUCN 2013). Caribou also display considerable sexual dimorphism; males typically grow until the age of 5 or 6 years, while females reach their adult size at an earlier age, generally at 3 or 4 years (COSEWIC 2014a, 2014b).

Like all ungulate populations, caribou frequently experience substantial variation in juvenile survival with high adult survival (Gaillard et al. 2010). Most stable populations of woodland caribou demonstrate high adult survival (80 to 90%), while populations in decline tend to exhibit a combination of lower adult survival and low annual recruitment (<20 calves/100 cows) (COSEWIC 2014a, 2014b; Gunn 2016; McLoughlin et al. 2019). It is estimated that woodland caribou can produce 70 to 74 calves per 100 females, but generally, only 30 to 50% of calves survive to the end of their first year (Thomas and Gray 2002).

Male caribou can reach sexual maturity as early as the age of 2, but more typically at the age of 4 (COSEWIC 2014a, 2014b). Males are polygynous (i.e., multiple mates) and are thought to form harems where a single male guards several females at a time to prevent other males from approaching (L’Italien et al. 2012). During the rutting period, which begins in late September and lasts until mid to late October (Moisan 1957; Bergerud 1973; Dauphiné and McClure 1974; Stuart-Smith et al. 1997; Ferguson and Elkie 2004a; Schmelzer 2014), a clear hierarchy among males is established, where bullying behaviour and fighting occurs between males for the right to mate (Bergerud 1973). This energy-intensive and demanding activity can leave males famished and in much poorer body condition, where they have been observed to lose upwards of 25% of their protein reserves (Barboza et al. 2004).

The annual caribou life cycle begins with cows being bred during the rut (Figure 2.12). Cows typically give birth in the spring (May to June) following a long gestation period (200 to 240 days, or 6.5 to 7.8 months) (Bergerud 1975; Leader-Williams 1988). The length of gestation has been considered a physiologically-fixed or genetic parameter, where the timing of calving has been found to be related to a series of factors, including latitude, the onset of breeding, plant phenology, predation, and the mother’s body condition from the previous autumn (Banfield 1961; Thomas 1982; Leader-Williams 1988; White 1992; Cameron et al. 1993; Post et al. 2003; Gustine et al. 2006; Leclerc, Dussault, and St-Laurent 2012; Pinard et al. 2012; Gunn 2016; Nobert et al. 2016).

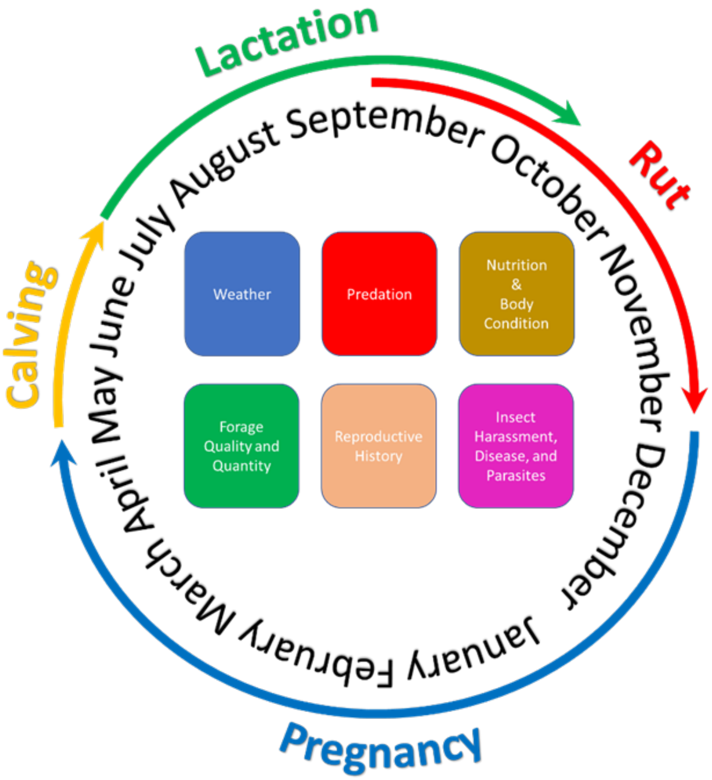

Figure 2.12. Annual Reproductive Cycle of Female Caribou and Main Contributing Factors Potentially Influencing Reproductive Success: estrus and conception occur during fall rut, followed by gestation, calving, and lactation before next rut; body condition can also be influenced by presence of diseases, parasites, age, and weather

Calves are usually able to stand within the first few minutes of birth and can generally keep pace with their mothers after a few days (Gunn 2016). Calves use a “follower” strategy according to the follower-hider dichotomy of mother-calf relationships (Lent 1974). If the calf can avoid predation within its first two months of life it is likely to become agile and robust enough to avoid predation, at least at a rate comparable to that of its adult counterparts. A follower strategy has been associated with less variation in timing of birth, which may numerically “swamp” predators and, as a result, increase calf survival (i.e., “predator saturation hypothesis”) (Lent 1974; Rutberg 1987). In addition, synchronized births in the spring allow females to maximize forage quality and availability (“plant phenology hypothesis”) to coincide with the period of energetically-costly lactation (Estes and Estes 1979; Bonar, Laforge, and Vander Wal 2017). Woodland caribou calving dates are highly synchronized (±30 days) across the species range (Environment Canada 2011). Highly synchronous and early births allow more time for females to acquire resources between birth, weaning, and the subsequent rut (Bonar, Laforge, and Vander Wal 2017). Up to 90% of females are mated within a 10 to 21 day window (Leader-Williams 1988). Calves born earlier in the spring are often heavier than those born later and are much more likely to accumulate sufficient resources and improved body condition to survive the winter (Côté and Festa-Bianchet 2001; Bonar, Laforge, and Vander Wal 2017), although how much earlier greatly influences the magnitude of the effect (Cook et al. 2004).

Calf mortality occurs through predation, abandonment, accidents, inclement weather, disease, and/or poor nutrition (leading to smaller, more vulnerable calves) within the first couple months, which can significantly hinder caribou recruitment (≤50% of the cohort can be lost) (Thomas and Gray 2002; McLoughlin et al. 2003; Jenkins and Barten 2005; Gustine et al. 2006; Bergerud, Luttich, and Camps 2008; Lewis et al. 2017). Calf survival is an essential component of population growth rate, and low recruitment has been identified as a problem across several woodland caribou ranges (e.g., Hervieux et al. 2013), where calf predation has been identified as the leading cause (Section 5.4, Predation).

Overall productivity of caribou is considered low in comparison with other cervids because they produce a single offspring annually (Bergerud 1974) and there are delays in the first year of reproduction (which is at 2 or 3 years of age) (Bergerud 1974, 1980, 2000; Thomas and Kiliaan 1998; Thomas and Gray 2002). Caribou can calve each year following maturity and can maintain a relatively high reproductive capacity until the age of 16 (Adams and Dale 1998; Larter and Allaire 2014). However, young females may require a few reproductive years before successfully raising a calf, contributing to the relatively poor calf survival rates (Dussault et al. 2012). Lack of sufficient fat and protein reserves due to rearing a previous offspring, combined with poor foraging conditions, can lead to reproductive pauses (i.e., the inability to reproduce viable offspring in consecutive years) (Cameron 1994; Gerhart et al. 1997; Thomas and Kiliaan 1998). Regardless of high pregnancy rates (>75%) across the woodland caribou range (Bergerud 1974; Seip and Cichowski 1996; Bergerud, Luttich, and Camps 2008; Nagy et al. 2011), a combination of predation, forage availability, and inclement weather contributes to variations in calf recruitment each year.

2.6 Cultural Significance of Caribou

Caribou have significant cultural value, particularly for aboriginal Canadians. Historically, caribou were the most abundant large mammal in much of its range and provided subsistence, tools, clothing, and social and economic contributions as well as holding high cultural and spiritual significance for many northern communities (Gordon 2003; Wells et al. 2011). The boreal population of caribou overlaps with over 400 First Nations, Inuit, and Métis communities across Canada. Although hunting of caribou (for both sport and food) has been prohibited in much of its range since being federally listed in 2003 (Environment Canada 2011), aboriginals retain the right to hunt caribou to some extent (Section 5.3.3, Hunting and Poaching). The hunting of caribou and sharing of the harvest in northern regions helps build and strengthen social capital within these communities, while also ensuring knowledge exchange. Caribou meat is an excellent source of protein and fat and is often preferred to other wild meats by many First Nation communities (Schuster et al. 2011). When harvested, very little of the animal is wasted (Figure 2.13). In response to caribou declines across the range, aboriginal communities are experiencing significant health and lifestyle changes. A transition away from a traditional diet, which is also associated with a connection to the land and physical activity (i.e., hunting, fishing, walking), to a more sedentary lifestyle and diet (increased consumption of refined and processed foods) has led to higher rates of chronic diseases and obesity in northern communities (Pasda 2013).

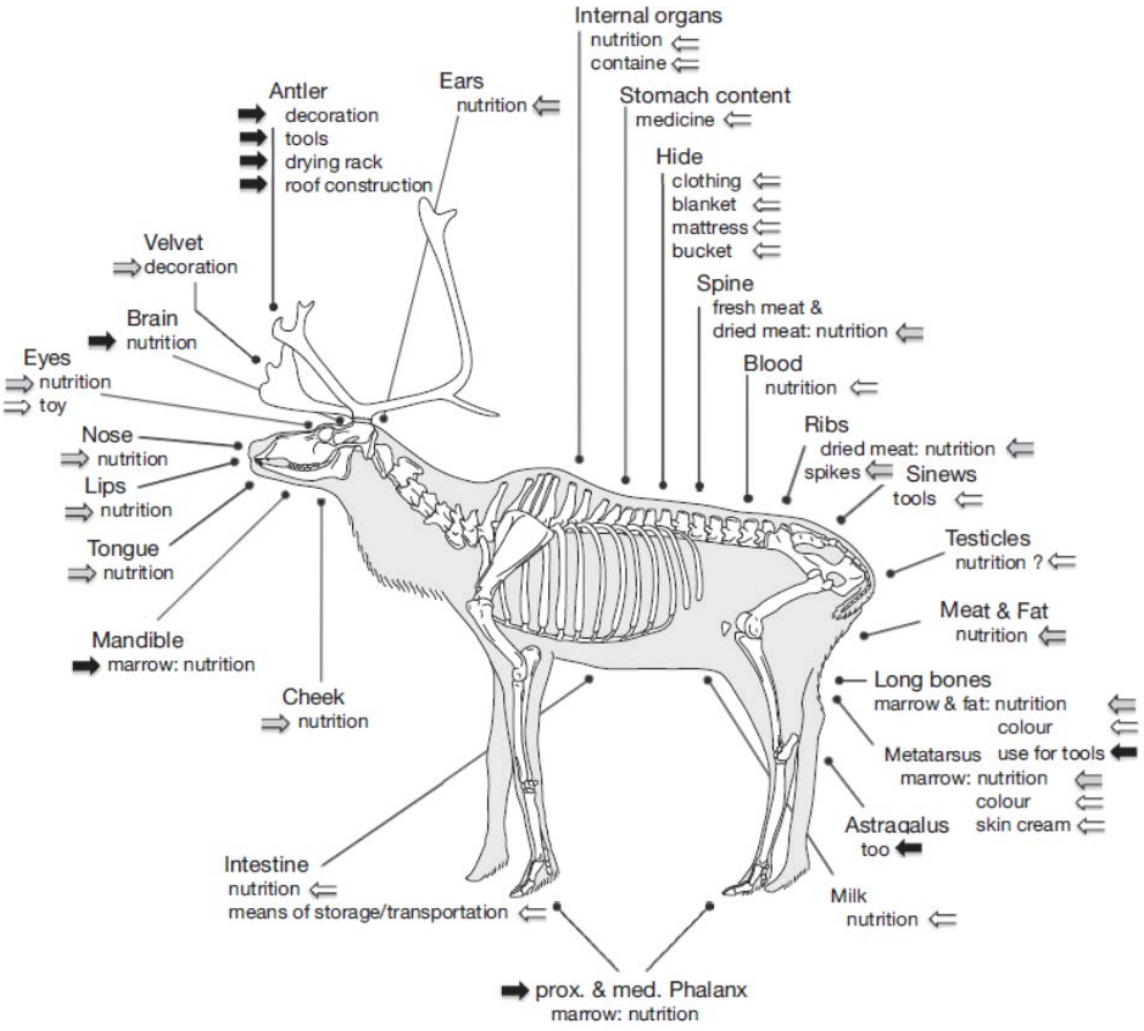

Figure 2.13. Archaeological Verifiability of Utilization:
black arrows, archaeologically verifiable; grey arrows, partially archaeologically verifiable; white arrows, archaeologically unverifiable [from Pasda 2013]

Caribou are also sought after for wildlife tourism across Canada and are considered a long-time Canadian emblem, first appearing on the reverse of the 25-cent piece (opposite King George VI on the obverse) in 1937 (Royal Canadian Mint, https://www.mint.ca/store/template/home.jsp [September 11, 2019]). The species is also represented on several coats of arms across Canada: Federal Court; Newfoundland and Labrador; and Nunavut. From an ecological and conservation perspective, caribou have been proposed as a flagship and umbrella species for the boreal forest because of its role as a prey species, its impact on the landscape (as foraging species), and its effectiveness as a charismatic species for conservation efforts (Festa-Bianchet et al. 2011; Bichet et al. 2016). Although there is still discussion on the effectiveness of using caribou as a surrogate for conservation of other species (Murray et al. 2015), there is little doubt of its value to Canadians.

3.0 DISTRIBUTION

3.1 Global Range

Caribou is one of the most widespread of any ungulate (COSEWIC 2011). It is present across the boreal, subarctic, montane, and arctic biomes. Most populations of reindeer are found in the Nordic countries (Norway, Sweden, Finland, and Russia), while caribou occupy Greenland, Alaska, and Canada. The range of woodland caribou in Canada stretches from the northeast corner of the Yukon to Labrador and extends down to Lake Superior in the south (Figure 3.1). Across Canada, the species' southern boundary has gradually receded northward since the early 20th century, and it is now extirpated from the US states of Montana, Idaho, Wisconsin, Vermont, Maine, and New Hampshire, as well as from the Canadian Maritimes, a trend that continues today (Bergerud 1974; Thomas and Gray 2002; Schaefer 2003; Festa-Bianchet et al. 2011; COSEWIC 2014a, 2014b).

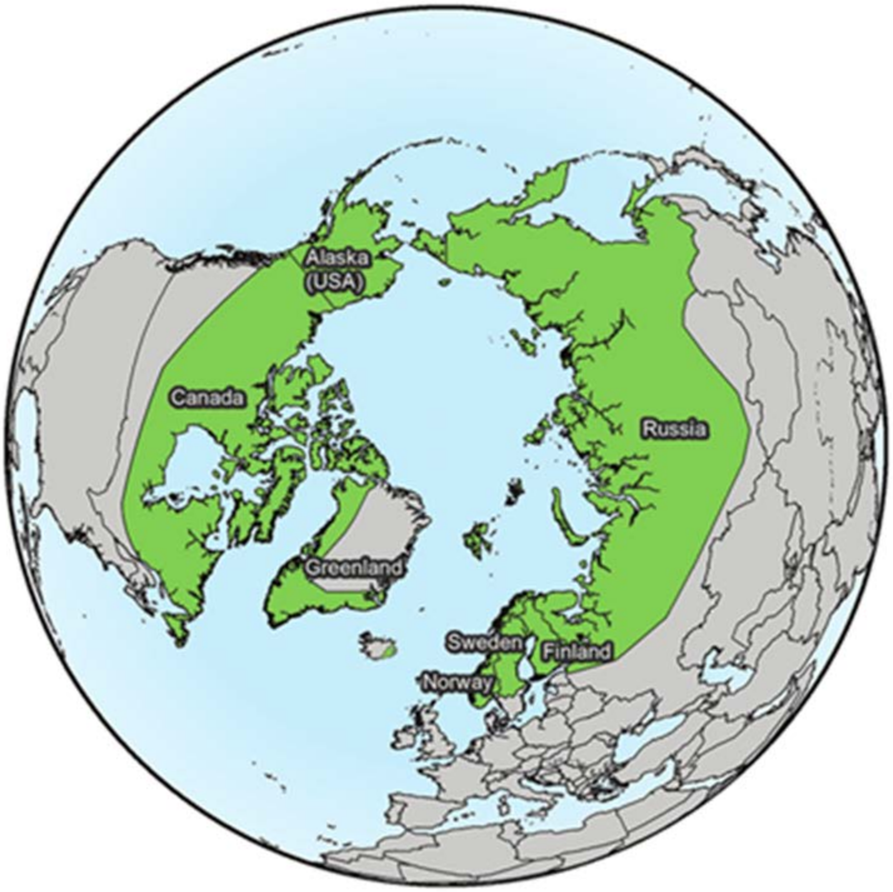

Figure 3.1. Approximate Global Distribution of Caribou and Reindeer [from Mallory and Boyce 2018]

3.2 Woodland Caribou Ranges

3.2.1 *Northern Mountain*

Caribou in the Northern Mountain population are distributed among 45 subpopulations that range from west-central British Columbia to its northern population limits in the Yukon and Northwest Territories (Figure 3.2). These subpopulations (or ranges) include nine within the central portion of British Columbia that were previously identified within the Southern Mountain population of woodland caribou. Twenty-six are located in the Yukon, where half straddle the borders with other regions (Alaska, two subpopulations; British Columbia, six subpopulations; Northwest Territories, five subpopulations). Caribou distribution within the Northern Mountain population has generally experienced a minimal reduction in the past century; however, range recession has occurred in its southern portion (COSEWIC 2014a). Caribou were originally found throughout the interior plateau regions of British Columbia (Spalding 2000). In the southernmost portions of this population during the mid to late 1980s, 52 caribou were translocated from the Itcha-Ilgachuz subpopulation to the neighboring Charlotte Aplands as a means of re-establishment (Young, Youds, and Freeman 2001).

3.2.2 *Central Mountain*

The Central Mountain population of woodland caribou includes ten subpopulations located in the east-central portions of British Columbia and west-central portions of Alberta (Figure 3.2). These caribou are found in the Rocky Mountains, and before the COSEWIC DU report (COSEWIC 2011) all subpopulations were identified within the Southern Mountain populations (COSEWIC 2002). The Central Mountain subpopulations have been under severe range reduction, and two subpopulations, Banff (2009) and Burnt Pine (2014), have been extirpated (Hebblewhite, White, and Musiani 2010; COSEWIC 2014a).

3.2.3 *Southern Mountain*

Caribou in the Southern Mountain population are found in the southeastern portion of British Columbia and comprise 15 subpopulations (Figure 3.2). Three have been extirpated: George Mountain (2003), Central Purcells (2005), and Southern Selkirks (2019), from which the last individual was translocated to the nearby Columbia North population. Several other subpopulations are on the brink of extirpation (Section 4, Population Sizes and Trends). About 40% of the historic British Columbia caribou range has been lost in the past century, most of which is represented within this population (Spalding 2000).

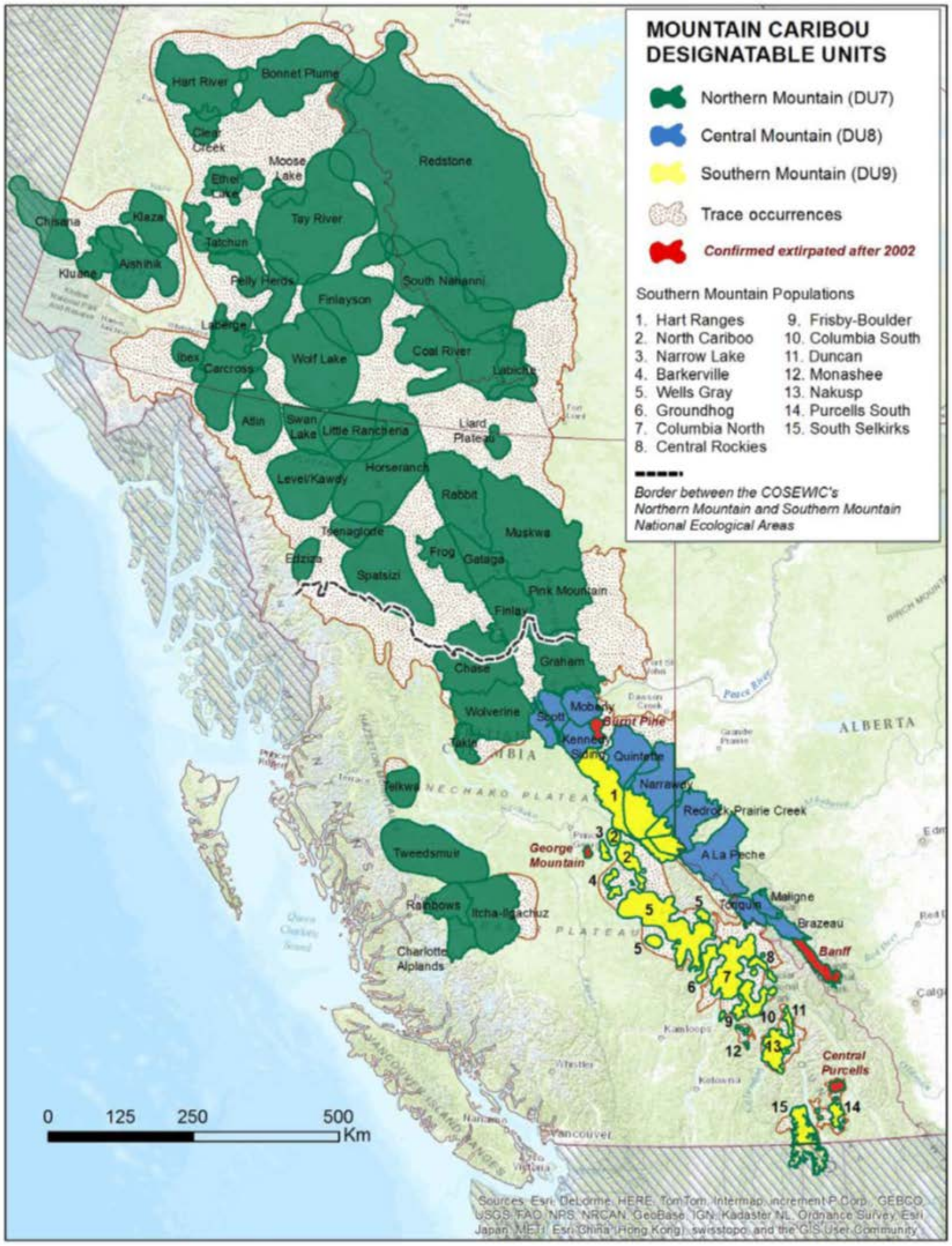

Figure 3.2. Caribou Subpopulations in Northern, Central, and Southern Mountain Populations [from COSEWIC 2014a]

3.2.4 *Boreal*

The boreal population of woodland caribou occurs in all jurisdictions in Canada except Nova Scotia, New Brunswick, Prince Edward Island, and Nunavut. This population covers a vast area that ranges from the Mackenzie Mountains in the northwest to the southern Labrador coast in the east and as far south as Lake Superior (isolated Lake Superior Coastal range, Figure 3.3) and covers three ecozones: Boreal Shield, Boreal Plains, and the Taiga Plains–equivalent to more than one-third of Canada's landmass (Wiken 1996).

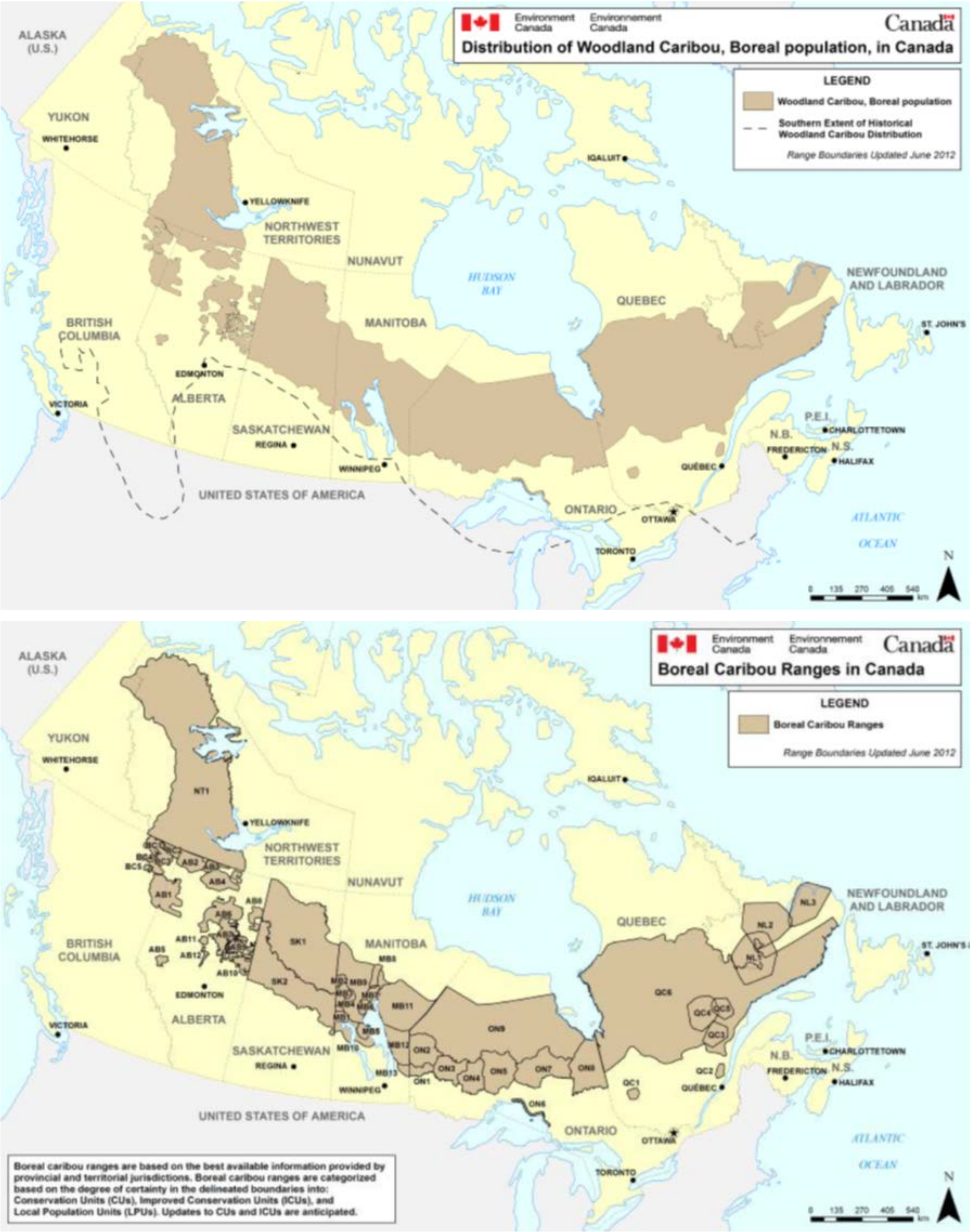

Figure 3.3. Distribution of Boreal Caribou Population in Canada (top; estimated southern extent of historical species range indicated by dashed line), and Geographic Distribution of Boreal Caribou Ranges (bottom; n=51) [from Environment Canada 2012b]

The boreal caribou population is recognized by Environment and Climate Change Canada (ECCC 2017) as having 51 ranges (Figure 3.3, Table 3.1). These ranges were determined based on the best available information provided by provincial and territorial jurisdictions, as delineated through telemetry data and biophysical analyses (Environment Canada 2011). Boreal caribou ranges vary considerably in size (Table 3.1) and can overlap with others. For example, along the northern limit of the boreal population considerable overlap exists for the Eastern Migratory (DU4) and Barren-ground (DU3) populations.

Table 3.1. Boreal Range Identifications, Names, and Total Areas[a]

Province/Territory	Range ID	Range Name	Total Range Area (ha)
Northwest Territories	NT1	Northwest Territories	44,166,546
British Columbia	BC1	Maxhamish	710,105
	BC2	Calendar	496,393
	BC3	Snake-Sahtahneh	1,198,752
	BC4	Parker	75,222
	BC5	Prophet	119,396
Alberta	AB1	Chinchaga	3,162,612
	AB2	Bistcho	1,436,555
	AB3	Yates	523,094
	AB4	Caribou Mountains	2,069,000
	AB5	Little Smoky	308,606
	AB6	Red Earth	2,473,729
	AB7	West Side Athabasca River	1,572,652
	AB8	Richardson	707,350
	AB9	East Side Athabasca River	1,315,980
	AB10	Cold Lake	672,422
	AB11	Nipisi	210,771
	AB12	Slave Lake	151,904
Saskatchewan	SK1	Boreal Shield	18,034,870
	SK2	Boreal Plain	10,592,463
Manitoba	MB1	The Bog	446,383
	MB2	Kississing	317,029
	MB3	Naosap	456,977
	MB4	Reed	357,425
	MB5	North Interlake	489,680
	MB6	William Lake	488,219
	MB7	Wabowden	628,938
	MB8	Wapisu	565,044
	MB9	Manitoba North	6,205,520
	MB10	Manitoba South	1,867,255
	MB11	Manitoba East	6,612,782
	MB12	Atikaki-Berens	2,387,665
	MB13	Owl-Flinstone	363,570
Ontario	ON1	Sydney	753,001
	ON2	Berens	2,794,835
	ON3	Churchill	2,150,490
	ON4	Brightsand	2,220,921
	ON5	Nipigon	3,885,026
	ON6	Coastal	376,598
	ON7	Pagwachuan	4,542,918
	ON8	Kesagami	4,766,463
	ON9	Far North	28,265,143
Québec	QC1	Val d'Or	346,861
	QC2	Charlevoix	312,803
	QC3	Pipmuacan	1,376,899
	QC4	Manouane	2,716,449
	QC5	Manicouagan	1,134,129
	QC6	Québec	62,156,186
Newfoundland	NL1	Lac Joseph	5,802,491
	NL2	Red Wine Mountain	5,838,594
	NL3	Mealy Mountain	3,948,463

[a] for 51 ranges recognized by Environment Canada 2012b

3.2.5 *Atlantic-Gaspésie*

The Atlantic-Gaspésie is the only woodland caribou population that remains south of the St. Lawrence River, where it is mostly confined to Gaspésie National Park and is surrounded by both the Matane and Chic-Chocs wildlife reserves on the Gaspé Peninsula of Québec (Figure 3.4). It belongs to the mountain ecotype and is genetically distinct from the boreal population (Courtois et al. 2003). Since the mid-19th century, the population went from 30,000 km^2 in area to its current size of approximately 800 km^2 (COSEWIC 2014b). Three subpopulations have often been described within this population and correspond to the different mountain summits: Mount Logan, Mount Albert, and the McGerrigle Mountain.

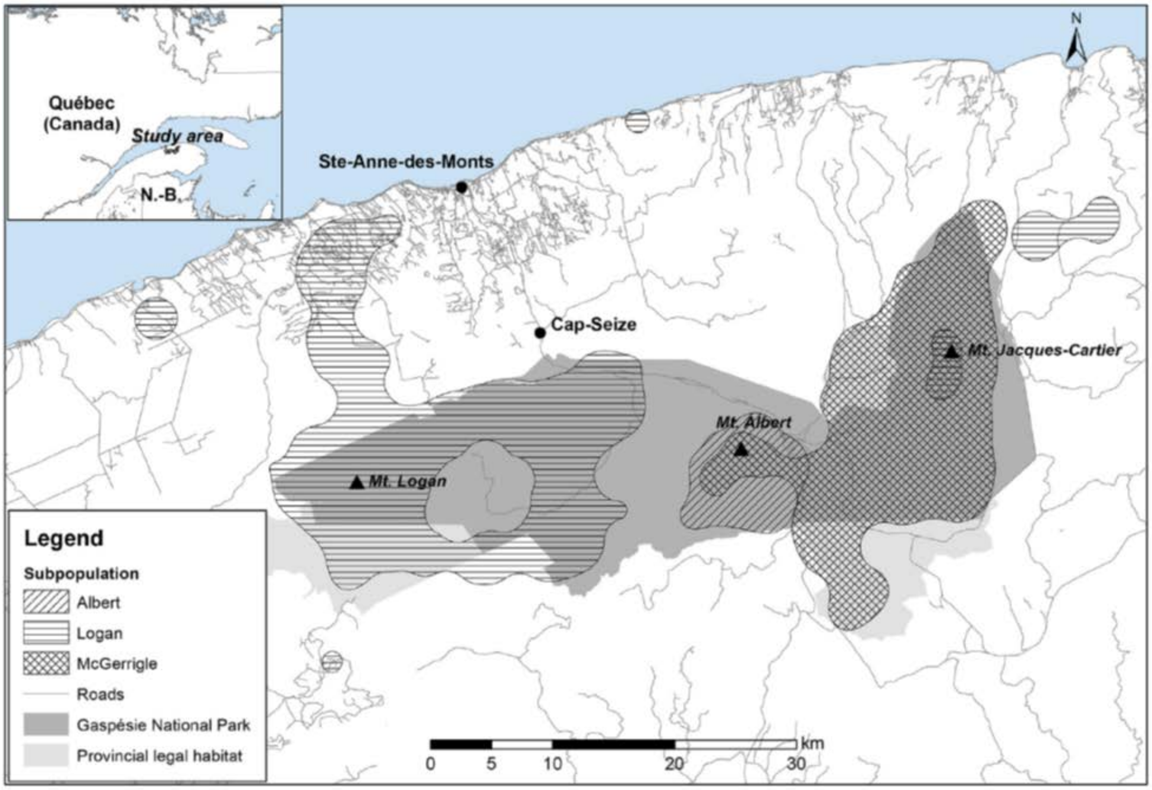

Figure 3.4. Gaspésie National Park and Distribution of Gaspésie Caribou Subpopulations of Atlantic-Gaspésie Caribou Population [from Rioux, Pelletier, and St-Laurent 2019]

3.2.6 *Newfoundland*

Woodland caribou are found throughout most of the island of Newfoundland (Figure 3.5). Several relocation efforts were undertaken during the 1960s and 1970s (Mercer et al. 1985), and led to the creation of 36 subpopulations of caribou across the island. Because of the considerable seasonal variability across Newfoundland (Weir et al. 2014) and the fluidity among ranges, these have since morphed into approximately 14 recognized subpopulations (COSEWIC 2014b; Lewis and Mahoney 2014).

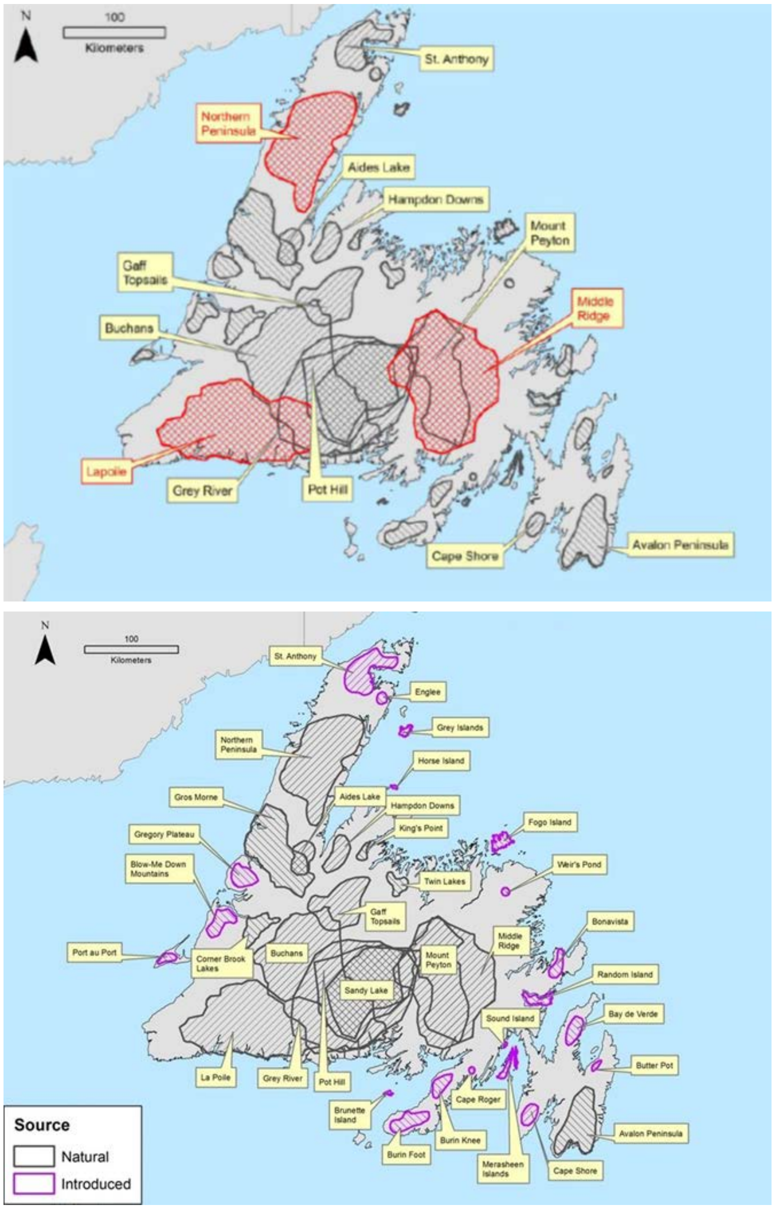

Figure 3.5. Annual Ranges of Newfoundland Woodland Caribou (top), ranges in red were focus of Newfoundland government's 2008-2013 caribou strategy [adapted by Weir et al. 2014]; and Distribution (bottom) of Natural (black) and Introduced (purple) Ranges during the 1990s [from COSEWIC 2014b]

4.0 POPULATION SIZE AND TRENDS

Gathering accurate population estimates of woodland caribou is a challenging task. Conventional wildlife inventory and assessment techniques are not considered possible for woodland caribou (OMNRF 2014a) because they occur at very low densities (6 to 20 individuals), are cryptic, and reside in dense forests, unlike their barren-ground counterparts (Thomas and Gray 2002; COSEWIC 2014b). Woodland caribou typically form mixed-sex groups, but this changes during the calving periods, where females are generally solitary (Nagy et al. 2011). Further, many of the subpopulations have been formally assessed only once or twice to date and may not represent the number of individuals within a given area.

Woodland caribou subpopulations across Canada vary considerably in population size (Tables 4.1 through 4.4), area (Table 3.1), and density. Density typically averages 2 to 3 per 100 km^2 (Environment Canada 2011). Environment and Climate Change Canada (Environment Canada 2011) suggests that for a population to be "self-sustaining," a minimum of 300 caribou would need to occupy ranges of at least 10,000 to 15,000 km^2, a conclusion that has not come without criticism (Schindler 2018).

4.1 Estimating Population Size

Accuracy of population estimates can vary depending on the method of estimation or data collection/interpretation approach (e.g., collaring, aerial surveys, fecal DNA, capture-mark-recapture), survey conditions, survey intensity (i.e., flight pattern, duration, extent), survey type (systematic or random), the surveyor's experience, and time of year. Ultimately, these factors collectively contribute to animal detection and the error associated with estimating a local population (DeCesare et al. 2012). It is not uncommon for upwards of half of all animals to be missed in aerial ungulate surveys (e.g., elk, Vander Wal, McLoughlin, and Brook 2011; moose, Peters et al. 2014; mule deer, Zabransky et al. 2016). Corrections via adjustment or standardization for sightability do exist (e.g., Samuel et al. 1987; Unsworth, Kuck, and Garton 1990) and can provide opportunities to adjust for estimates based on aerial surveys.

Because of the inability to reliably estimate population size of woodland caribou, many jurisdictions rely on a recruitment-mortality (R/M) equation to monitor a population's trend or status. R/M is often based on annual survival rates of collared adult females and aerial surveys to determine calf recruitment rates. Each year, the rate of population growth or decline can be estimated using the formula outlined by Hatter and Bergerud (1991):

$$\lambda = \text{Adult Female Survival} / (1 - \text{Female Calf Recruitment})$$
$$\lambda > 1\text{, population is increasing}$$
$$\lambda = 1\text{, population is stable}$$
$$\lambda < 1\text{, population is declining}$$

Because λ can vary significantly between years for a particular subpopulation/range, accurate population trends require long-term survey efforts to reduce the likelihood of false predictions. Survey techniques have improved over time, improving the accuracy of trend estimates; however, many subpopulations still rely on data extrapolation and expert opinion (Rettie 2017). Additional advances in survey methods and understanding of the biophysical needs of caribou has led and continues to lead to an adjustment of range boundaries, making comparisons within and across ranges from the past difficult over the long term. Finally, because of the difficulty (and in some cases absence) in estimating populations of woodland caribou, confidence in applying long-term trends can be even more troublesome. COSEWIC recommends that long-term trends be done over a three-generation time frame (~27 years) (COSEWIC 2014b).

While several methods for estimating population size exist and the value of their direct comparison may be limited, Section 4.2 synthesizes the most current reported range estimates.

4.2 Population Size and Conservation Status

4.2.1 *Northern Mountain*

The Northern Mountain population is estimated at 43,443 to 51,649 individuals (Table 4.1), which accounts for about 95% of the Western Mountain caribou found in Canada (Figure 4.1) (COSEWIC 2014a). Subpopulation estimates vary significantly among years. Generally, estimates are similar between reporting sources; however, in some instances, considerable differences are reported (see population estimates for Hart River and Tay River ranges, Table 4.1).

Table 4.1. Subpopulation Estimates and Reported Trend Information for the Northern Mountain Population of Woodland Caribou

		Estimate (Year Reported)			Reported Trend		
Region	Subpopulation (Range)	COSEWIC (2014a)	Environment Canada (2012a)	Other Sources	COSEWIC (2014a)	Environment Canada (2012a)	Other Sources
NWT/ Northern Yukon	Hart River	1,853 (2006)	2,133 (2006)	2660 (2015)[a]	Unknown	Unknown	Stable[a]
	Clear Creek	801 (2001)	900 (2001)	900 (2001)[a]	Unknown	Unknown	Unknown[a]
	Bonnet Plume	4,200 (1987)	5,000 (1982)	5000 (1982)[a]	Stable	Unknown	Unknown[a]
	Redstone	7,300-10,000 (2012)	5,000-10,000 (1997)	10,000 (2012)[a]	Stable	Unknown	Stable[a]
	South Nahanni	1,886 (2009)	2,105 (2009)	2100 (2009)[a]	Stable	Unknown	Stable[a]
	Coal River	413 (2008)	450 (1997)	450-700 (2008)[a]	Unknown	Unknown	Stable[a]
	La Biche	388 (1993)	400 (1993)	450-700 (1993)[a]	Unknown	Unknown	Unknown[a]
	Sub-total	16,841 - 19,541	15,988 - 20,988	21,560 - 22,060			
Southwest Yukon	Chinsana	587 (2010)	766 (2008)	700 (2013)[a]	Stable	Stable	Stable[a]
	Kluane	163 (2009)	180 (2009)	180 (2009)[a]	Decreasing	Decreasing	Stable[a]
	Aishihik	1,813 (2009)	2,044 (2009)	2050 (2009)[a]	Increasing	Increasing	Stable[a]
	Klaza	1,065 (2012)	650 (2000)	1180 (2012)[a]	Unknown	Increasing	Stable[a]
	Sub-total	3,628	3,640	4,110			
Central Yukon	Ethel Lake	289 (1993)	300 (1993)	300 (1993)[a]	Unknown	Stable	Stable[a]
	Moose Lake	270 (1991)	200 (1991)	300 (1991)[a]	Unknown	Unknown	Unknown[a]
	Tay River	2,907 (1991)	3,750 (1991)	3,750 (1991)[a]	Unknown	Stable	Unknown[a]
	Tatchun	415 (2000)	500 (2000)	500 (2000)[a]	Unknown	Stable	Stable[a]
	Pelly Herds	876 (2002)	500 (2002)	1,000 (2002)[a]	Unknown	Unknown	Unknown[a]
	Finlayson	2,657 (2007)	3,100 (2007)	3,100 (2007)[a]	Decreasing	Decreasing	Decreasing[a]
	Wolf Lake	1,240 (1998)	1,400 (1998)	1,500 (1998)[a]	Unknown	Stable	Unknown[a]
	Sub-total	8,654	9,750	10,450			
Southern Lakes Yukon	Laberge	176 (2003)	200 (2003)	100-300 (2003)[a]	Unknown	Unknown	Unknown[a]
	Ibex	748 (2008)	850 (2008)	850 (2008)[a]	Increasing	Increasing	Increasing[b]
	Cacross	674 (2007)	775 (2008)	860 (2015)[b]	Stable	Stable	Increasing[b]
	Atlin	514-857 (2007)	800 (2007)	800 (2007)[a]	Stable	Stable	Stable[b]
	Sub-total	2,112 - 2,455	2,625	2,610 - 2,810			
Northwest BC	Swan Lake	515-686 (2007)	400 (2005)	600 (2007)[b]	Unknown	Unknown	Unknown[b]
	Little Rancheria	672-1342 (1999)	1,000 (1999)	1,200 (2003)[b]	Unknown	Increasing	Unknown[b]
	Horseranch	680-850 (2000)	600 (1999)	600 (1999)[b]	Unknown	Unknown	Unknown[b]
	Level Kawdy	1,239 (1998)	1,500 (1999)	200 (2013)[b]	Unknown	Unknown	Decreasing[b]

(Continued on next page. See notes at end of table.)

Table 4.1. Continued

Region	Subpopulation (Range)	Estimate (Year Reported)			Reported Trend		
		COSEWIC (2014a)	Environment Canada (2012a)	Other Sources	COSEWIC (2014a)	Environment Canada (2012a)	Other Sources
Northwest BC (continued)	Edziza	140 (2006)	175 (2005)	25 (2017)[b]	Unknown	Unknown	Decreasing[b]
	Tsenaglode	85-340 (2008)	200 (1999)	650 (2017)[b]	Unknown	Unknown	Increasing[b]
	Spatsizi	2,258 (1994)	3,000 (1996)	671 (2010)[b]	Unknown	Unknown	Unknown[b]
	Sub-total	5,589-6,855	6,875	3,946[c]			
North-east BC	Laird Plateau	140 (2010)	150 (2005)	87 (2017)[b]	Decreasing	Unknown	Unknown[b]
	Rabbit	1,095 (2007)	1,300 (2007)	1,045 (2014)[b]	Unknown	Unknown	Unknown[b]
	Muskwa	828 (2007)	1,250 (2000)	172 (2017)[b]	Unknown	Unknown	Decreasing[b]
	Gataga	200 (2000)	338 (2001)	138 (2007)[b]	Unknown	Unknown	Stable[b]
	Frog	199 (2001)	150 (2000)	93 (2012)[b]	Unknown	Unknown	Unknown[b]
	Finlay	19 (2002)	26 (2002)	10-18 (2018)[b]	Decreasing	Decreasing	Unknown[b]
	Pink Mountain	1,145 (1993)	850 (2000)	323 (2017)[b]	Unknown	Unknown	Decreasing[b]
	Sub-total	3,626	4,064	1,868 - 1,876			
North-central BC	Graham	637 (2008)	708 (2009)[d]	86 (2017)[b]	Stable	Stable	Decreasing[b,e]
	Chase	404 (2008)	475 (2009)[d]	347 (2010)[b]	Unknown	Unknown	Decreasing[b]
	Wolverine	298 (2009)	341 (2010)[d]	266 (2018)[b]	Unknown	Decreasing	Stable[b,e]
	Takla	98 (2003)	122 (2004)[d]	44 (2018)[b]	Unknown	Unknown	Decreasing[b]
	Sub-total	1,437	1,646	829			
West-Central BC	Telkwa	19(2013)	19 (2013)[d]	24 (2017)[b]	Decreasing	Decreasing	Decreasing[b]
	Tweedsmuir	248 (2001)	300 (2002)[d]	146 (2017)[b]	Decreasing	Decreasing	Decreasing[b]
	Itcha-IIgachuz	1,220 (2012)	1,685 (2014)[d]	1,350 (2017)[b]	Decreasing	Decreasing	Stable[b]
	Rainbows	43 (2008)	50 (2008)[d]	32 (2016)[b]	Decreasing	Decreasing	Decreasing[b]
	Charlotte Alplands	6 (2012)	7 (2012)[d]	23 (2001)[b]	Decreasing	Decreasing	Decreasing[b]
	Sub-total	1,536	2,061	1,575			
TOTAL		43,443 - 47,752	46,649 - 51,649	46,715 - 47,415	D:9, I:2, U:27, S:7	D:9, I:4, U:24, S:8	D:11, I:3, U:16, S:15

[a] Environment Yukon 2016

[b] BC Gov 2019

[c] Spatsizi herd only partially surveyed in 2010

[d] Environment Canada 2014

[e] Serrouya et al. 2019 – active/adaptive management (e.g., translocation, maternity penning, predator and/or competitor control)

[f] D=decreasing; I=increasing; U=unknown; S=stable

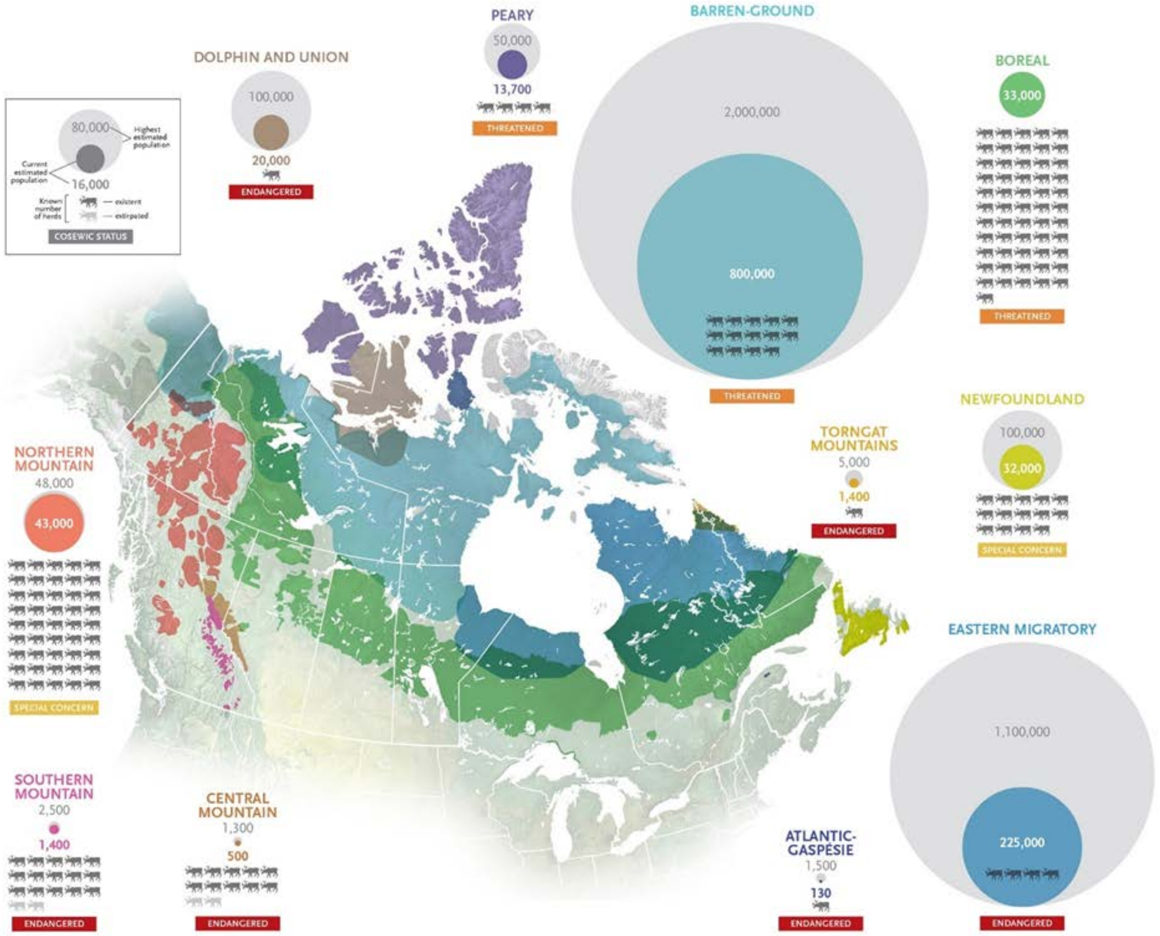

Figure 4.1. Caribou Population Size (grey sphere=highest estimated; coloured=current estimate) by Subspecies Range, Known Number of Subpopulations/Ranges (existent and extirpated), and Most Recent COSEWIC Status [map credit: Chris Brackley, Canadian Geographic]

Provincial population estimates generally reported greater numbers than those from COSEWIC (2014a) or Environment and Climate Change Canada (Environment Canada 2012a) for the higher latitude ranges compared to those from more southern latitudes (Table 4.1). Further, provincial estimates that are more current and are available for a particular range are often not used as the basis for figures reported by COSEWIC or Environment and Climate Change Canada. For example, British Columbia reported the Frog range to have 93 individuals in 2012; however, COSEWIC and Environment and Climate Change Canada reported population estimates from a decade earlier (COSEWIC 2014a, 199 individuals; Environment Canada 2012a, 150 individuals).

The Northern Mountain population is listed as “Special Concern” in Schedule 1 under SARA and was last assessed by COSEWIC in 2014 when it received the same designation (Table 1.1). At the provincial scale, the same “Special Concern” status was identified in the Yukon and British Columbia (Blue listed - S2S3: Imperiled-Special Concern), but the portion in the Northwest Territories has not been listed. The Northern Mountain population also has a NatureServe status of G5T4T5 (“Globally Secure”- “Subspecies Apparently Secure-Secure”), which was assigned in 2013.

Overall, it is difficult to assess the population trend of the Northern Mountain population because estimates tend to vary significantly across subpopulations and because inconsistencies exist between provincial and federal estimates. Eight of the 45 Northern Mountain subpopulations number <100 individuals, and five of the eight are <50 individuals according to provincial sources (Table 4.1). The largest subpopulations of Northern Mountain caribou reside in the Yukon, where ten subpopulations are estimated to have >1000 individuals each. Only three of the 23 (Little Rancheria, Rabbit, and Itcha-Ilgachuz) subpopulations in British Columbia also have >1000 individuals. Population estimates also vary as much as one-half to two-thirds between provincial and COSEWIC or Environment and Climate Change Canada sources (see Northeastern and Northcentral portions of British Columbia for nearly the past decade, Table 4.1). Although the COSEWIC (2014a) report on Northern Mountain caribou highlights that long-term trend data are limited (available for only 15 of the 45 subpopulations), surveys of subpopulations are increasing. The governments of both British Columbia and the Yukon reported that long-term population trends remain unknown for 16 of the 45 subpopulations; however, different subpopulations are identified as unknown from those reported in COSEWIC or Environment and Climate Change Canada reports (Table 4.1). For example, the provincial governments consider nearly twice the number of subpopulations to be stable than does COSEWIC (2014a), and one-third more population trends are reported (Table 4.1).

4.2.2 *Central Mountain*

Of all woodland caribou populations, the Central Mountain population is at highest risk of extirpation. Since its estimated population reported in 2002 (1293 individuals, COSEWIC 2002), the Central Mountain population has declined by two-thirds. All Central Mountain caribou subpopulations currently maintain less than 150 mature individuals, and six subpopulations have <40 individuals (Table 4.2). The most current estimate for the Central Mountain population is 474 mature individuals, which is consistent with estimates reported by both COSEWIC (469) and Environment and Climate Change Canada's Southern Mountain Recovery Strategy (483) (Table 4.2, Figure 4.1). More recent population control measures (maternal penning, predator and alternative prey control) have shown promise (Serrouya et al. 2019) and have resulted in increase or stabilization of four subpopulations (Table 4.2). Although population control efforts have been successful, two subpopulations are confirmed extirpated (Banff in 2009, Burnt Pine in 2014). An additional three (Scott, Maligne, and Brazeau) may be extirpated in the coming years (McNay et al. 2014; McFarlane et al. 2018).

The Central Mountain population is listed as "Threatened" in Schedule 1 of SARA. At the provincial scale, this population is listed "At-risk" in Alberta and is Red-listed (S1S2: Critically Imperiled-Imperiled) in British Columbia (Table 1.1). The Central Mountain population had a NatureServe Status of G5T2Q ("Globally Secure"- "Subspecies Imperiled-Questionable taxonomy that may reduce conservation priority") when it was last reviewed in 2002.

Table 4.2. Subpopulation Estimates and Reported Trend Information for the Central Mountain Population of Woodland Caribou

Subpopulation (Range)	Estimate (Year Reported)			Reported Trend		
	COSEWIC (2014a)	Environment Canada (2014)	Other Sources	COSEWIC (2014a)	Environment Canada (2014)	Other Sources
Klinse-Za (Scott)	35 (2014)	43 (2014)	7 (2015)a	Unknown	Unknown	Decreasing[b]
Klinse-Za (Moberly)	18 (2014)	22 (2014)	66 (2017)a	Decreasing	Decreasing	Increasing[b]
Kennedy Siding (Pine River)	29 (2014)	30 (2014)	63 (2018)a	Decreasing	Decreasing	Unknown[a,b]
Burnt Pine (Pine River)	0 (2014)			Extirpated		
Quintette	87 (2014)	106 (2014)	74 (2018)c	Decreasing	Decreasing	Increasing[b]
British Columbia - Narraway (Bearhole, Redwillow, and South Narraway)/Alberta-Narraway	78 (2014)	96 (2012)	26 (2018)c/ 28 (2016)a	Decreasing	Decreasing	Decreasing[c,d]/ Stable[b]
Redrock-Prairie Creek	106 (2012)	127 (2012)	96 (2016)d	Decreasing	Decreasing	Decreasing[b,d]
A La Peche (Jasper/Banff)	75 (2012)	88 (2012)	100 (2016)d	Decreasing	Decreasing	Stable[b]/ Increasing[d]
Tonquin (Jasper/Banff)	30 (2013)	38 (2013)	26 (2015)e	Decreasing	Decreasing	Decreasing[e]
Maligne (Jasper/Banff)	5 (2013)	5 (2013)	12 (2015)e	Decreasing	Decreasing	Decreasing[e]
Brazeau (Jasper/Banff)	6 (2013)	8 (2013)	3 (2015)e	Decreasing	Decreasing	Decreasing[e]
Banff (Jasper/Banff)	0 (2009)			Extirpated		
Total	469	483	474			

[a] BC Gov 2019

[b] Serrouya et al. 2019 – active/adaptive management (e.g., translocation, maternity penning, predator and/or competitor control)

[c] Seip and Jones 2018

[d] Alberta Government 2017

[e] McFarlane et al. 2018

4.2.3 *Southern Mountain*

Historical estimates of the Southern Mountain population were as high as 1850 in 2002 (COSEWIC 2002) (Figure 4.1), 1570 in 2014 (Environment Canada 2014), and 1265 to 1276 over the past three to four years (BC Gov 2019). This represents a decline of about 31.6% since 2002. All subpopulations within the Southern Mountain population consist of fewer than 400 individuals, and only two have more than 300 (Table 4.3).

Additionally, eight subpopulations have fewer than 30 individuals, and three of these have fewer than 5 individuals. Given these very small population sizes, these subpopulations should all be considered functionally extirpated, and probably will be extirpated in the coming years. The George Mountain (2003), Central Purcells (2005), and Monashee (2016) subpopulations are already extirpated. Most of the subpopulations (11 of 15) are declining, one is increasing (Barkerville), and three are considered stable (Groundhog, Narrow Lake, and Purcells South, Table 4.3). Since the COSEWIC and Environment and Climate Change Canada report on Southern Mountain population in 2014, five subpopulations have stabilized, evidently in response to predator population control (Table 4.3).

The Southern Mountain population is listed as “Threatened” in Schedule 1 of SARA. COSEWIC listed these caribou as “Endangered” (Table 1.1) in 2014;. NatureServe listed them as G5T1 (“Globally Secure”- “Subspecies Critically Imperiled”) in 2017; and British Columbia listed the population on its Red-list as S1 (“Critically Imperiled”).

Table 4.3. Subpopulation Estimates and Reported Trend Information for the Southern Mountain Population of Woodland Caribou

Subpopulation (Range)	Estimate (Year Reported)			Reported Trend		
	COSEWIC (2014a)	Environment Canada (2014)	Other Sources	COSEWIC (2014a)	Environment Canada (2014)	Other Sources
South Selkirks	20 (2014)	22 (2014)	11 (2017)a	Decreasing	Decreasing	Decreasing[a,b]
Purcells South	22 (2014)	19 (2014)	16 (2017)a	Stable	Stable	Stable[a,b,c]
Purcells Central	0 (2005)			Extirpated[c]		
Central Selkirks (Nakusp)	54 (2014)	64 (2014)	29 (2017)a 31 (2018)a	Decreasing	Decreasing	Decreasing[a]
Central Selkirks (Duncan)	2 (2012)	2 (2012)		Decreasing	Decreasing	
Central Rockies	4 (2008)	3 (2008)	3 (2008)a	Decreasing	Decreasing	Unknown[a]
Monashee	4 (2011)	4 (2011)	1 (2016)[a] Extirpated[d]	Decreasing	Decreasing	Unknown[a,c]
Frisby Boulder	12 (2013)	13 (2013)	11(2013)a	Decreasing	Decreasing	Decreasing[b,c]
Columbia South	6 (2013)	7 (2013)	4 (2016)a	Decreasing	Decreasing	Decreasing[a,b,c]
Columbia North	157 (2013)	183 (2013)	147 (2017)a	Stable	Stable	Stable[a,b]
Groundhog	11 (2013)	13 (2013)	20 (2017)a 20 (2018)d	Decreasing	Decreasing	Stablea
Wells Gray (North and South)	341 (2013)	422 (2013)	North: 204 (2015)[a] South: 140 (2017)[a] Total: 345 (2018)[d]	Decreasing	Decreasing	N: Decreasing[a,c] S: Decreasing[a,c]
Barkerville	78 (2012)	90 (2012)	58 (2016)a	Increasing	Increasing	Increasing[a]
North Cariboo Mountains	202 (2011)	222 (2011)	187 (2018)d	Decreasing	Decreasing	Decreasing[a]
Narrow Lake	45 (2014)	47 (2014)	36-47 (2016)a	Stable	Stable	Stable[a]
George Mountain	0 (2002)			Extirpated		
Hart Ranges	398 (2013)	459 (2013)	375 (2016)a/ 459 (2016)d	Decreasing	Decreasing	Stable[a,b,c]
Total	1,356	1,570	1,265 - 1,276			

[a] BC Gov 2019

[b] Serrouya et al. 2019; active/adaptive management applied (e.g., translocation, maternity penning, predator and/or competitor control)

[c] COSEWIC 2014a; application of historical adaptive management practice

[d] Wilson and Wilmshurst 2019

4.2.4 *Boreal*

The wide distribution of boreal caribou across multiple political jurisdictions has led to inconsistencies in monitoring efforts, funding, and expertise in estimating subpopulation sizes. Furthermore, given the variation across jurisdictions in adopting improved monitoring methods, range boundaries and population estimates continue to change. Environment and Climate Change Canada (Environment Canada 2012b) formally estimated the population of boreal caribou to be 25,513 individuals across 40 subpopulations, along with an additional 8000 animals for 11 subpopulations that lacked formal estimates, providing a total estimate of 33,000 to 34,000 caribou (Figure 4.1).

The estimated abundance of boreal caribou in British Columbia is 375 individuals, nearly a third of the animals (1040 to 1110) estimated five years earlier in the federal recovery strategy (Environment Canada 2012b). Interestingly, Alberta experienced relatively little loss in overall abundance over the same time frame (from 2074 to 1936 individuals) (Table 4.4). The “minimal” loss may be attributable to implementation of intense predator population control measures across much of the province (Alberta Government 2017; Serrouya et al. 2019), which has directly contributed to stabilization of five of the twelve subpopulations in Alberta. Further, the most recent monitoring efforts by the Alberta government have reported very promising estimates for some subpopulations (e.g., Red Earth, West Side of the Athabasca River, East Side of the Athabasca River, and Cold Lake) of boreal caribou (Table 4.4). Population estimates in Saskatchewan remain incomplete; however, efforts since 2013 have been undertaken to improve estimates in the province. McLoughlin et al. (2016) estimated that 5000 caribou existed in the Boreal Shield (SK1) subpopulation, and estimates for the Boreal Plain (SK2) are scheduled to be released in the near future. Estimates of population sizes of caribou ranges in Manitoba also remain incomplete, although recent efforts have been undertaken with implementation of the provincial recovery strategy in 2015.

Ontario has an estimated boreal caribou population size of 3154 individuals. The population is declining in one-third of the subpopulations (Coastal, Kesagami, Far North), while Nipigon is the only stable subpopulation (Table 4.4). The Far North subpopulation was initially reported in the federal recovery strategy (Environment Canada 2012b) as having no reported estimate; however, the province now estimates it at a minimum of 2047 individuals (Ontario recognizes six subpopulations within the single Far North range identified by Environment and Climate Change Canada). The population trends for these Far North subpopulations are all believed to be either declining or lacking sufficient data to make a trend estimate.

In Québec, the boreal caribou population is estimated to be approximately 6363 (Table 4.4). The federal recovery strategy, however, sets the estimate at 9778 caribou (Environment Canada 2012b). The discrepancy may be because the predominant contributing subpopulation (QC6, Québec) was a rough estimate by Environment and Climate Change Canada (Environment Canada 2012b). Interestingly, population trends in Québec are stable, as indicated by four of the six subpopulations, and the remaining subpopulations are either increasing (e.g., Pipmuacan) or trend data are inadequate (i.e., only partial coverage or minimal repeated surveying) to provide reliable estimates. Québec is undertaking multiple inventories that should offer a complete province-wide assessment by late 2020.

The three woodland caribou subpopulations in Labrador are declining based on the federal recovery strategy (Environment Canada 2012b). Provincial sources confirm these population estimates, except for the estimate reported for the Lac Joseph subpopulation, which is slightly higher (1414, Schmelzer 2015) than that reported by Environment and Climate Change Canada (1282) in 2012.

Table 4.4. Subpopulation Estimates and Reported Trend Information for the Boreal Population of Woodland Caribou

		Estimate (Year Reported)				Reported Trend		
ECCC Range ID	Subpopulation (Range)	Environment Canada (2012b)	ECCC (2017)	Provincial (Year)	Additional Sources	Environment Canada (2012b)	ECCC (2017)	Provincial Report
NT1	Northwest Territories	6,500	≥100	Inuvialuit: 338 (2017)[NT]		N/A	N/A	Variable (increasing in portions, decreasing in others)[NT]
				Gwich'in: 550 (2017)[NT]				
				Sahtu West: 674 (2017)[NT]				
				Sahtu East: 1,003 (2017)[NT]				
				Dehcho N, SW: 2,318 (2017)[NT]				
				S Slave, SE Dehcho 1,236 (2017)[NT]				
				North Slave: 612 (2017)[NT]				
	Northwest Territories Sub-Total	6,500		6,731				
BC1	Maxhamish	300	≥100	100 (2017)[B]		N/A	Stable	Stable[B]
BC2	Calendar	290	≥100	55 (2017)[B]		N/A	Stable	Stable[B]
BC3	Snake-Sahtahneh	360	≥100	169 (2017)[B]		Declining	Stable	Declining[B]
BC4	Parker[B2]	40-60	<100	51 (2017)[B]		N/A	Declining	Declining[B]
BC5	Prohet[B2]	50-100	<100			N/A	Declining	
	British Columbia Sub-Total	1,040-1,110		375				
AB1	Chinchaga	250	≥100	150 (2017)[A]		Declining	Declining	Declining[A]
AB2	Bistcho	195	≥100	257 (2017)[A]		Declining	Declining	Stable[A]
AB3	Yates	350	≥100	236 (2017)[A]		Stable	Stable	Stable[A]
AB4	Caribou Mountains	315-394	≥100	352 (2017)[A]		Declining	Declining	Declining[A]
AB5	Little Smoky	78	≥100	110 (2017)[A,AM]		Declining	Stable	Stable[A]
AB6	Red Earth	172-206	≥100	78 (2017)[A]		Declining	Declining	Declining[A]
AB7	West Side Athabasca River	204-272	≥100	133 (2017)[A]		Declining	Declining	Declining[A]
AB8	Richardson	150	≥100	125 (2017)[A]		N/A	Stable	Stable[A]
AB9	East Side Athabasca River	90-150	≥100	227 (2017)[A,AM]		Declining	Declining	Declining[A]
AB10	Cold Lake	150	≥100	190 (2017)[A]		Declining	Declining	Declining[A]
AB11	Nipisi	55	<100	49 (2017)[A]		N/A	N/A	Stable[A]
AB12	Slave Lake	65	<100	29 (2017)[A]		N/A	N/A	Declining[A]
	Alberta Sub-Total	2,074-2,315		1,936				

(Continued on next page. See notes at end of table.)

Table 4.4. Continued.

ECCC Range ID	Subpopulation (Range)	Estimate (Year Reported)				Reported Trend		
		Environment Canada (2012b)	ECCC (2017)	Provincial (Year)	Additional Sources	Environment Canada (2012b)	ECCC (2017)	Provincial Report
SK1	Boreal Shield	N/A	≥100	5,000 (2016)[S]		N/A	Stable	Stable[S]
SK2	Boreal Plain	N/A	≥100	N/A		N/A	N/A	
Saskatchewan Sub-Total		(Incomplete)		(Incomplete)				
MB1	The Bog	50-75	≥100	>100 (2015)[M]		Stable	N/A	Under review[M]
MB2	Kississing	50-75	≥100	>100 (2015)[M]		Stable	N/A	Under review[M]
MB3	Naosap	100-200	(Naosap-Reed) ≥100		100-200 (2005)[M2]	Stable	N/A	
MB4	Reed	100-200			100-150 (2005)[M2]	Stable		
MB5	North Interlake	50-75	<100	<100 (2015)[M] 183 (2009)[H]	50-75 (2005)[$]	Stable	N/A	Declining[M]
MB6	William Lake	25-40	William Lake: <100	>100 (2015)[M]	25-40 (2005)[M2]	Stable	N/A	Under review[M]
MB7	Wabowden	200-225	Wabowden: ≥100		200-225 (2005)[M2]	Stable	N/A	
			Wheadon: ≥100				N/A	
MB8	Wapisu	110-125	Harding: ≥100	>100 (2015)[M]	100-125 (2005)[M2]	Stable	N/A	Under review[M]
			Wapiu-Wimapedi: ≥100				N/A	
			Wheadon: ≥100				N/A	
MB9	Manitoba North	N/A	N/A			N/A	N/A	N/A
MB10	Manitoba South	N/A	N/A			N/A	N/A	N/A
MB11	Manitoba East	N/A	Norway House: ≥100	>100 (2015)[M]		N/A	N/A	Under review[M]
			Charron Lake: ≥100				N/A	

(Continued on next page. See notes at end of table.)

Table 4.4. Continued.

ECCC Range ID	Subpopulation (Range)	Estimate (Year Reported)				Reported Trend		
		Environment Canada (2012b)	ECCC (2017)	Provincial (Year)	Additional Sources	Environment Canada (2012b)	ECCC (2017)	Provincial Report
MB12	Atikaki-Berens	300-500	Berens: ≥100	>100 (2015)[M]	300-500 (2005)[M2]	Stable	N/A	Under review[M]
			Atiko: ≥100				N/A	
			Bloodvein: <100				N/A	
MB13	Owl-Flinstone	78	<100	<100 (2015)[M]	71-85 (2005)[M2]	Stable	N/A	Under review[M]
	Manitoba Sub-Total	(Incomplete)	-	(Incomplete)				
ON1	Sydney	N/A	<100	55 (2012)[O]		Stable	Declining	Stable-declining[O]
ON2	Berens	N/A	≥100	237 (2012)[O]		N/A	Declining	Declining[O]
ON3	Churchill	N/A	≥100	262 (2012)[O]		N/A	Declining	Stable to Declining[O]
ON4	Brightsand	N/A	≥100	224 (2012)[O]		N/A	Declining	Declining[O]
ON5	Nipigon	300	≥100	172 (2010)[O]		Stable	Declining	Stable[O]
ON6	Coastal	492	≥100	N/A	55 (2016)[O2]	N/A	Declining	Declining[S]
ON7	Pagwachuan	N/A	≥100	164 (2011)[O]		N/A	Stable	Stable-declining[O]
ON8	Kesagami	492	≥100	178 (2010)[O]		Declining	Declining	Declining[O]
ON9	Far North	N/A	≥100	Kinloch: 113 (2010)[O]		N/A	Declining	Declining[O]
				Spirit: 373 (2010)[O]				Declining[O]
				Swan: 491 (2011)[O]				N/A[O]
				Ozhiski:148 (2011)[O]				N/A[O]
				Missisa:745 (2011)[O]				Declining[O]
				James Bay:177 (2011)[O]				Declining[O]
	Ontario Sub-Total	(Incomplete)		3,154				
QC1	Val D'Or	30	<100	14 (2012)[Q]	7 (2020) [Q12]	Declining	Declining	Stable[Q]
QC2	Charlevoix	75	<100	26 (2019)[Q2]		Stable	Declining	Stable[Q2]
QC3	Pipmuacan	134	≥100	247 (2012)[Q3]		Stable	Declining	Increasing[Q3]
QC4	Manouane	358	≥100	357 (1999)[Q]		Stable	Stable	Stable[Q]

(Continued on next page. See notes at end of table.)

Table 4.4. Continued.

		Estimate (Year Reported)				Reported Trend		
ECCC Range ID	Subpopulation (Range)	Environment Canada (2012b)	ECCC (2017)	Provincial (Year)	Additional Sources	Environment Canada (2012b)	ECCC (2017)	Provincial Report
QC5	Manicouagan	181	Manicouagan East: ≥100	Southeast: 236 (2009)[Q7] North: 1,091(2014)[Q6]		Increasing	Stable	Stable[Q6,Q7]
			Manicouagan Ouest: ≥100				Stable	
QC6	Québec	9000	Nottaway: ≥100	Nottaway: 308 (2016)[Q5]		Stable	Declining	N/A
			Assinica: ≥100	Assinica: 580 (2013)[Q4]			Stable	N/A
			Témiscamie: ≥100	Témiscamie: 2,511 (2019)[Q9]			Declining	N/A
				Caniapiscau: 476 (2018)[Q10]			N/A	N/A
			Basse-Côte: ≥100	Basse-Côte: 452-558 (2019)[Q8]			Declining	N/A
			Detour: ≥100	Detour: 72 (2019)[Q11]			N/A	
Québec Sub-Total		9,778	-	6,363				
NL1	Lac Joseph	1,282	≥100	1,414 (2009)[L]		Declining	N/A	Declining
NL2	Red Wine Mountain	97	≥100	97 (2001)[L2]	20 (2015)[L3]	Declining	N/A	Declining
NL3	Mealy Mountain	1,604	≥100	1,604 (2012)[L]		Declining	N/A	Declining
Newfoundland Sub-Total		2,983		3,093				

Northwest Territories: NT=Northwest Territories Government 2018

British Columbia: B=BC Gov 2019

Alberta: A=Alberta Government 2017; AM=subpopulation has undergone some form of adaptive management practice in the past

Saskatchewan: S=McLoughlin et al. 2016

Manitoba: M=MBWMC 2015; M2=MCWEB 2005

Ontario: O=OMNRF 2014a-2014i; O2=Shuter, Asselin, and Rodgers 2016

Quebec: Q=Équipe de Rétablissement du caribou forestier du Québec 2013; Q2=Hins and Rochette 2019; Q3=Dussault 2013; Q4-Brodeur, Bourbeau-Lemieux, and Jutras 2017; Q5=Szor and Brodeur 2017; Q6=Heppell 2015; Q7=Bourbonnais and Rochette 2012; Q8=Heppell 2019; Q9=Szor, Dussault, and Landry 2019; Q10=Heppell 2018; Q11-Rioux, Légaré, and Szor 2019; Q12=Rémillard 2020

Newfoundland: L=Schmelzer 2015; L2=Notzl, Greene, and Riley 2013; L3=Cowan 2015

The Boreal population is listed as “Threatened” in Schedule 1 of SARA; in general, a similar status has been given in each province (Table 1.1). NatureServe has yet to rank the conservation status of the boreal population of woodland caribou.

4.2.5 *Atlantic-Gaspésie*

The Atlantic-Gaspésie population was first estimated in the 1950s to be as high as 700 to 1500 individuals (Moisan 1957) and has since declined steadily. COSEWIC (2014b) estimated that 130 individuals existed across the three subpopulations in 2013 (Table 4.5). The total number of caribou declined to as low as 24 counted individuals in 2015 but have since recovered to some degree. Biologists counted 54 caribou in 2017, providing an estimate of 75 individuals after applying the visibility correction factor (Morin 2018). Additionally, in 2017 caribou were observed (8 individuals) on Mont Logan for the first time since 2011 (9 individuals), while caribou estimates were also their highest at Mont Albert (25 individuals) since 2010 (Table 4.5).

Table 4.5. Observed and Estimated Caribou Counts for the Mont Logan, Mont Albert, and Mont Jacques Cartier Subpopulations of Atlantic-Gaspésie Woodland Caribou

Subpopulation (Range)	Observed Counts								COSEWIC (2014b)
	2017	2016	2015	2014	2013	2012	2011	2010	
Mont Logan (Western)	8	0	0	0	0	0	9	17	
Mont Albert (Central)	25	17	18	12	12	13	10	23	
Mont Jacques-Cartier (McGerrigle)	21	23	6	60	79	46	45	70	
Total	75	40	24	72	91	59	64	110	130

[observed counts from Morin 2018]

The Atlantic-Gaspésie caribou population is listed as “Endangered” in Schedule 1 of SARA and has a status of G5T1Q (“Globally Secure”- “Subspecies Critically Imperiled-Questionable taxonomy that may reduce conservation priority”) with NatureServe, a status that was last reviewed in 1997 (Table 1.1).

4.2.6 *Newfoundland*

The woodland caribou population of Newfoundland was estimated to be 31,980 individuals in 2013 (Figure 4.1, Table 4.6) (COSEWIC 2014b). Newfoundland has a long history of caribou monitoring (since the 1800s), and systematic abundance surveys have been intermittently conducted since the 1960s (Weir et al. 2014). Historically, the subpopulations of Newfoundland caribou have been documented to rise and fall substantially and synchronously (Bastille-Rousseau et al. 2013; Mahoney et al. 2016). COSEWIC estimates a current population one-third the size of the population in 1996 when it was at its peak (93,737 individuals, Mahoney et al. 2016). This rapid and significant decline (-66% over 17 years) has been attributed to several contributing factors, but most prominently to density-dependent food competition, poor calf survival due to predation that eventually led to an aging demographic, and hunting (Weir et al. 2014). These rapid declines are of concern for conservation purposes but are not unique for these boom-and-bust populations of caribou on the island of Newfoundland (Table 4.6). A similar trend occurred in the early 1900s, when an estimated population of 100,000 individuals crashed to 10,000 to 15,000 between the years of 1925 and 1935 (COSEWIC 2014b).

The Newfoundland population of woodland caribou is “Not Listed” in Schedule 1 of SARA but has been assessed as “Special Concern” with COSEWIC (2014b). At the provincial scale, only the Labrador portion of the population has been listed as “Threatened” (Table 1.1). NatureServe has yet to rank the conservation status of the Newfoundland woodland caribou population.

Table 4.6. Subpopulation Estimates and Reported Trend Information for the Newfoundland Population of Woodland Caribou

Subpopulation (Range)	COSEWIC (2014b)	Estimate (Year of Report)	
		NLDFLR (2019)[a]	Other Sources[b]
Buchans		4,023 (2017)	4,157 (2007)
Gaff Topsails		1,637 (2016)	2,182 (2007)
Grey River		1,867 (2016)	854 (2007)
La Poile		3,418 (2016)	5,610 (2007)
Pot Hill		1,475 (2016)	3,066 (2007)
Mount Peyton		561 (2016)	674 (2007)
Gros Morne		360 (2017)	
Hampdon Downs		334 (2017)	413 (2008)
Hodges Hill		259 (2017)	
Northern Peninsula		1,315 (2017)	5,811 (2008)
Aides Lake		201 (2017)	
Gregory Plateau[c]		282 (2017)	
St. Anthony[c]		1,999 (2017)	2,162 (2008)
Middle Ridge		11,547 (2018)	8,860 (2006)
Avalon Peninsula			545 (2005)
Fogo Island		317 (2018)	
Cape Shore[c]			1,410 (2000)
Total	31,980	29,595	

[a] Randell 2019

[b] Bastille-Rousseau et al. 2013

[c] introduced herds during the 1990s, COSEWIC 2014b

5.0 CONCERNS AND THREATS

5.1 Identified Threats and their Severity

Threats to woodland caribou have been identified in numerous federal government (Environment Canada 2012b, 2014; ECCC 2017) and COSEWIC (2014a, 2014b) reports (Table 5.1). Threats are generally consistent within populations but can vary across populations. For example, predation is identified as a high threat across most populations but as a medium threat for the Newfoundland population. Similarly, habitat alteration caused by anthropogenic disturbances (e.g., forestry, tourism and recreation, linear features) is identified as a high risk threat in the Boreal and Atlantic-Gaspésie populations, but a medium or low threat in the Mountain populations. Most (if not all) of these threats interact and can have cumulative impacts, and efforts are increasing to evaluate their cumulative influences (e.g., Sorensen et al. 2008; Johnson, Ehlers, and Seip 2015; Mumma et al. 2018).

Table 5.1. Identified Threats and their Designated Severity by Woodland Caribou Population

Woodland Caribou Population/Designatable Unit (Source)	Identified Threat and Designated Severity				
	High	Medium/Moderate	Low/Slight	Negligible	Unknown
Northern Mountain (COSEWIC 2014a)	Predation	Renewable energy Roads and railways Logging and wood harvesting	Housing and urban development Agriculture Oil and gas Mining Fire and fire suppression Ungulate competition Insect outbreaks Avalanches/landslides	Hunting Dams and water management	Invasive non-native/alien species (disease and parasites) Climate change (habitat changes)
Central Mountain (COSEWIC 2014a)	Predation	Mining Renewable Energy	Tourism Oil and gas Roads and railways Logging and harvesting Fire and fires suppression Avalanches/landslides	Utility and Service Lines Hunting Work and other activities Dams and Water management Apparent Competition Insect Outbreaks Noise and Light	Invasive non-native species (disease and parasites) Climate change (habitat change)
Southern Mountain (Environment Canada 2014)	Predation Military	Mining Renewable energy Roads and railroad Logging and wood harvesting Avalanches/landslides	Annual and perennial non-timber harvesting Utility and service lines Recreation	Livestock farming and ranching	Climate change (habitat changes)

(Continued on next page. See note at end of table.)

Table 5.1. Continued.

Woodland Caribou Population/Designatable Unit (Source)		Identified Threat and Designated Severity				
		High	Medium/Moderate	Low/Slight	Negligible	Unknown
Boreal	Environment Canada (2012b)	Anthropogenic disturbance (habitat alteration) Predation	Natural disturbance Hunting	Vehicle collisions		Parasites and disease Climate change and severe weather Noise and light disturbance Pollution
	COSEWIC (2014b)	Logging and Harvesting Predation	Energy production and mining Linear features (roads and utilities) Hunting	Fire and fire suppression		Recreation activities Parasites and pathogens Climate change Pollution
Atlantic-Gaspésie (COSEWIC 2014b)		Renewable energy Logging and harvesting Predation Tourism and recreation Linear features	Mining and quarrying	Commercial and industrial areas Hunting Recreational activities Avalanches		Fire and fire suppression Parasites and pathogens Climate change (vegetation)
Newfoundland (COSEWIC 2014b)			Predation	Energy production and mining Linear features (roads and utility lines) Hunting Logging and wood harvesting Recreational activities Forage limitations	Fire and fire suppression Parasites and pathogens Introduction of genetic material	

[as identified by COSEWIC 2014a, 2014b and Environment Canada 2012b, 2014]

These threats may reduce adult survival and recruitment rates, two critical demographic rates that are known to drive population dynamics (DeCesare et al. 2012; Hervieux et al. 2013). For example, the scientific review of critical habitat conducted by Environment and Climate Change Canada (Environment Canada 2011) reported that the combination of natural and anthropogenic disturbances explained 61% of variation in mean recruitment rates for 24 boreal caribou subpopulations across Canada. However, the model (commonly referred to as the "65/35 disturbance model") has since come under scrutiny for having low predictive ability and limited transferability outside of Alberta (see Sleep and Loehle 2010 for details). Regardless of these critiques, for many of the woodland caribou subpopulations there is a growing consensus that habitat alteration (temporary or permanent) causes deleterious impacts on the survival and recruitment of caribou.

Historically, woodland caribou ranges have remained relatively undisturbed; however, many caribou subpopulations increasingly face range contraction and extirpation from their southern range limits because of increased anthropogenic disturbance (Venier et al. 2014; McLoughlin et al. 2019). Habitat alteration can compromise caribou's spatial predator-avoidance strategy (spacing-out or away). Caribou may respond to habitat loss by increasing site fidelity to areas within their home range that remain undisturbed (Schaefer, Bergman, and Luttich 2000; Wittmer, McLellan, and Hovey 2006; Faille et al. 2010), which reduces their movement (Smith et al. 2000; Tracz et al. 2010; Lafontaine et al. 2017) and home range size (Beauchesne, Jaeger, and St-Laurent 2014). Cumulatively, these responses may increase caribou location predictability, which in turn may increase the likelihood of predation (Seip 1991; Dyer et al. 2001; Festa-Bianchet et al. 2011).

Sections 5.2 through 5.3.3 herein describe most of the threats outlined in Table 5.1, and while they are generally discussed in isolation, they are not mutually exclusive and can interact directly or indirectly. Assessments of the cumulative effects of disturbance and threats on woodland caribou population dynamics remain limited but are increasing (Ehlers, Johnson, and Seip 2014, 2016; Mumma et al. 2018).

5.2 Levels of Disturbance

This section discusses only disturbances identified within the boreal population of woodland caribou based on the extent of research and disturbance modeling within this population.

The federal scientific assessment to inform identification of critical habitat for woodland caribou describes and measures disturbance as the area bounded by a 500 m buffer around all anthropogenic linear and polygon features, plus the area around natural fires ≤40 years of age to provide a cumulative disturbance level per caribou range (Environment Canada 2011). Anthropogenic disturbance includes roads, trails, industrial developments, land use changes, or fragmentation that is associated with stand-level commercial forestry operations (Environment Canada 2011). A maximum disturbance target of 35% was identified by Environment and Climate Change Canada as a level estimated to provide a 60% probability of sustaining a resident population with a minimum of 300 caribou.

The cumulative disturbance (anthropogenic and fire) estimated by Environment and Climate Change Canada for its 2017 progress report averaged 49% across the boreal population, which represents a +3% increase (anthropogenic +1%; fire +2%) from the original federal recovery strategy for woodland caribou (Environment Canada 2012b) (Table 5.2).

Table 5.2. Boreal Caribou Range Size (ha), Percent Disturbed Habitat (2012, 2017), and Difference (Δ) Based on Range Boundaries

Province/ Territory	Range ID	Range Name	Total Range Area (ha)	Disturbed Habitat (%)									Total Undisturbed Habitat (%)			Risk Assessment
				Fire			Anthropogenic			Total						
				2012	2017	Δ	2012	2017	Δ	2012	2017	Δ	2012	2017	Δ	
Northwest Territories	NT1	Northwest Territories	44,166,546	24	28	+4	8	9	+1	31	35	+4	69	65	-4	SS
		Provincial Average	44,166,546	24	28	+4	8	9	+1	31	35	+4	69	65	-4	
British Columbia	BC1	Maxhamish	710,105	0.5	2	+1.5	57	67	+10	58	68	+10	42	32	-10	NSS
	BC2	Calendar	496,393	8	16	+8	58	53	-5	61	61	0	39	39	0	NSS
	BC3	Snake-Sahtahneh	1,198,752	6	5	-1	86	77	-9	87	79	-8	13	21	+8	NSS
	BC4	Parker	75,222	1	3	+2	57	57	0	58	57	-1	42	43	+1	NSS
	BC5	Prophet	119,396	1	10	+9	77	78	+1	77	78	+1	23	22	-1	NSS
		Provincial Average	519,973.6	3.3	7.2	+3.9	67	66.4	-0.6	68.2	68.6	0.4	31.8	31.4	-0.4	
Alberta	AB1	Chinchaga	3,162,612	8	9	+1	74	79	+5	76	80	+4	24	20	-4	NSS
	AB2	Bistcho	1,436,555	20	40	+20	61	58	-3	71	75	+4	29	25	-4	NSS
	AB3	Yates	523,094	43	42	-1	21	20	-1	61	55	-6	39	45	+6	NSS
	AB4	Caribou Mountains	2,069,000	44	46	+2	23	27	+4	57	62	+5	43	38	-5	NSS
	AB5	Little Smoky	308,606	0.2	0.4	+0.2	95	96	+1	95	96	+1	5	4	-1	NSS
	AB6	Red Earth	2,473,729	30	40	+10	44	48	+4	62	72	+10	38	28	-10	NSS
	AB7	West Side Athabasca R.	1,572,652	4	5	+1	68	70	+2	69	72	+3	31	28	-3	NSS
	AB8	Richardson	707,350	67	74	+7	22	23	+1	82	88	+6	18	12	-6	NSS
	AB9	East Side Athabasca R.	1,315,980	26	28	+2	77	78	+1	81	84	+3	19	16	-3	NSS
	AB10	Cold Lake	672,422	32	33	+1	72	76	+4	85	87	+2	15	13	-2	NSS
	AB11	Nipisi	210,771	6	9	+3	66	75	+9	68	77	+9	32	23	-9	NSS
	AB12	Slave Lake	151,904	37	39	+2	63	74	+11	80	87	+7	20	13	-7	NSS
		Provincial Average	1,217,056.25	26.4	30.5	+4.1	57.2	60.3	+3.2	73.9	77.9	+4.0	26.1	22.1	-4.0	

(Continued on next page. See notes at end of table.)

Table 5.2. Continued

Province/ Territory	Range ID	Range Name	Total Range Area (ha)	Disturbed Habitat (%)									Total Undisturbed Habitat (%)			Risk Assessment
				Fire			Anthropogenic			Total						
				2012	2017	Δ	2012	2017	Δ	2012	2017	Δ	2012	2017	Δ	
Saskatchewan	SK1	Boreal Shield	18,034,870	55	58	+3	3	3	0	57	60	+3	43	40	-3	SS
	SK2	Boreal Plain	10,592,463	26	30	+4	20	20	0	42	45	+3	58	55	-3	NSS/SS
Provincial Average			14,313,666.5	40.5	44	+3.5	11.5	11.5	0	49.5	52.5	3	50.5	47.5	-3	
Manitoba	MB1	The Bog	446,383	4	6	+2	12	14	+2	16	19	+3	84	81	-3	NSS/SS
	MB2	Kississing	317,029	39	39	0	13	15	+2	51	54	+3	49	46	-3	NSS
	MB3	Naosap	456,977	28	28	0	26	28	+2	50	52	+2	50	48	-2	NSS
	MB4	Reed	357,425	7	7	0	20	20	0	26	26	0	74	74	0	SS
	MB5	North Interlake	489,680	4	4	0	14	14	0	17	18	+1	82	82	0	NSS/SS
	MB6	William Lake	488,219	24	25	+1	14	17	+3	34	36	+2	66	64	-2	NSS
	MB7	Wabowden	628,938	10	10	0	19	20	+1	28	28	0	72	72	0	SS
	MB8	Wapisu	565,044	10	11	+1	14	13	-1	24	24	0	76	76	0	SS
	MB9	Manitoba North	6,205,520	23	23	0	10	11	+1	32	33	+1	68	67	-1	NSS/SS
	MB10	Manitoba South	1,867,255	4	4	0	11	12	+1	15	16	+1	85	84	-1	SS
	MB11	Manitoba East	6,612,782	26	26	0	3	3	0	29	29	0	71	71	0	SS
	MB12	Atikaki-Berens	2,387,665	31	29	-2	6	6	0	35	34	-1	65	66	+1	SS
	MB13	Owl-Flinstone	363,570	25	25	0	18	18	0	39	39	0	61	61	0	NSS/SS
Provincial Average			1,629,729.8	18.1	18.2	+0.1	13.8	14.7	+0.9	30.5	31.4	+0.9	69.5	68.6	-0.8	

(Continued on next page. See notes at end of table.)

Table 5.2. Continued

Province/ Territory	Range ID	Range Name	Total Range Area (ha)	Disturbed Habitat (%)									Total Undisturbed Habitat (%)			Risk Assessment
				Fire			Anthropogenic			Total						
				2012	2017	Δ	2012	2017	Δ	2012	2017	Δ	2012	2017	Δ	
Ontario	ON1	Sydney	753,001	28	27	-1	33	25	-8	58	49	-9	42	51	+9	NSS
	ON2	Berens	2,794,835	34	31	+3	7	6	-1	39	37	-2	61	63	+2	NSS/SS
	ON3	Churchill	2,150,490	6	8	+2	28	28	0	31	34	+3	69	66	-3	SS
	ON4	Brightsand	2,220,921	18	19	+1	28	26	-2	42	41	-1	58	59	+1	NSS/SS
	ON5	Nipigon	3,885,026	7	7	0	25	25	0	31	30	-1	69	70	+1	SS
	ON6	Coastal	376,598	0	0	0	16	15	-1	16	15	-1	84	85	+1	SS
	ON7	Pagwachuan	4,542,918	0.9	0.7	-0.2	26	27	+1	27	27	0	73	73	0	SS
	ON8	Kesagami	4,766,463	3	3	0	36	37	+1	38	40	+2	62	60	-2	NSS
	ON9	Far North	28,265,143	14	15	+1	1	1	0	15	16	+1	85	84	-1	SS
Provincial Average			5,528,377.2	12.3	12.3	0	22.2	21.1	-1.1	33.0	32.1	-0.9	67.0	67.9	+0.9	
Québec	QC1	Val d'Or	346,861	0.1	0.2	+0.1	60	65	+5	60	65	+5	40	35	-5	NSS
	QC2	Charlevoix	312,803	4	4	0	77	80	+3	80	82	+2	20	18	-2	NSS
	QC3	Pipmuacan	1,376,899	11	11	0	51	60	+9	59	68	+9	41	32	-9	NSS
	QC4	Manouane	2,716,449	18	18	0	23	26	+3	39	41	+2	61	59	-2	NSS/SS
	QC5	Manicouagan	1,134,129	3	3	0	32	36	+4	33	37	+4	67	63	-4	SS
	QC6	Québec	62,156,186	20	20	0	12	13	+4	30	32	+4	70	68	-2	SS
Provincial Average			11,340,555	9	9	0	43	47	+4	50	54	+4	50	46	-4	
Newfoundland and Labrador	NL1	Lac Joseph	5,802,491	7	12	+5	1	2	+1	8	14	+6	92	86	-5	NSS/SS
	NL2	Red Wine Mountain	5,838,594	5	7	+2	3	3	0	8	9	+1	92	91	-1	NSS
	NL3	Mealy Mountain	3,948,463	0.4	1	+0.6	1	1	0	2	2	0	98	98	0	NSS/SS
Provincial Average			5,196,516	4	7	+3	2	2	0	6	8	+2	94	92	-2	
NATIONAL AVERAGE			4,990,811	17	19	+2	33	34	+1	46	49	+3	54	51	-3	

[Source: 2012 federal Recovery Strategy (Environment Canada 2012b)]

NOTES: disturbance values for 2012 determined from Landsat imagery at 30 m with positional accuracy of 50 m collected between 1993 and 2010 (see Environment Canada 2011, Tables 24 and 25); values for 2017 from Landsat Imagery collected in 2015 (ECCC 2017); risk assessment is status of self-sustainability of range where SS=self-sustaining, NSS=not self-sustaining; NSS/SS=as likely as not to be self-sustaining

Alberta remains the province with the highest proportion of disturbed habitat (77.9%), followed by British Columbia (68.6%). The province with the least area of disturbed habitat is Newfoundland and Labrador (8%). The greatest increase in fire-related disturbance between re-measurement periods (2012 to 2017) occurred in western Canada, in particular in Alberta, where three caribou ranges experienced significant increases in the proportion of fire: Bitscho (AB2 +20%); Red Earth (AB6 +10%); and Richardson (AB8 +7%). Only 4 of the 51 boreal ranges experienced declines in area disturbed by fire, albeit slight ones (<2%) between 2012 and 2017: Snake-Sahtahneh (BC3); Atikaki-Berens (MB12); Sydney (ON1); and Pagwachuan (ON7), probably because of the time (≤40 years) associated with fire disturbance before it is no longer considered disturbed by the ECCC disturbance model (Section 5.5.1, Fire).

For changes in anthropogenic disturbance by province, both Québec (+4.0%) and Alberta (+3.2%) experienced the largest increases, while on average British Columbia (-0.6%) and Ontario (-1.1%) experienced slight declines (Table 5.2). At the range (subpopulation) scale, four ranges experienced noticeable increases in reported anthropogenic disturbances since 2012: Slave Lake (AB12 +11%); Maxhamish (BC1 +10%); Nipisi (AB11 +9%); and Pipmuacan (QC3 +9%). In contrast, only Snake-Sahtahneh (BC3 -9%) and Sydney (ON7 -8%) had noteworthy declines in anthropogenic disturbance (Table 5.2). Overall, in the context of the Environment and Climate Change Canada disturbance model, 15 of the 51 boreal ranges are considered self-sustaining (29.4%), ten are classified as not-self-sustaining/self-sustaining (as likely as not to be self-sustaining) (19.6%), and the remaining 26 have been identified as not-self-sustaining (50.9%).

5.3 Anthropogenic Disturbances

5.3.1 *Industrial*

Industrial activities relevant to caribou populations generally include forestry, mining, oil and gas development, and renewable energy (e.g., wind farms, hydroelectric structures). Caribou are affected by industrial activities because of indirect (habitat alteration, fragmentation, destruction) and direct (noise, pollution, human presence) impacts of their infrastructure and associated actions. Caribou may shift selection and use of habitat in response to anthropogenic disturbances (e.g., Dyer et al. 2001; Schindler et al. 2007; Fortin et al. 2013; Losier et al. 2015; Newton et al. 2017). If high-quality alternative ranges are not available on the landscape or if disturbance rates are (or become) too high, caribou may respond by concentrating more in areas of good habitat, particularly in the spring and summer (Lafontaine et al. 2017), or be forced to use lower quality habitat, which may result in reduced vigor and increased risk of predation (Johnson, Ehlers, and Seip 2015; MacNearney et al. 2016).

An often-used concept to assess relative impacts of industrial activities on woodland caribou is the zone of influence (ZOI) (Polfus, Hebblewhite, and Henemeyer 2011; Johnson, Ehlers, and Seip 2015). ZOI is the area beyond the actual footprint of a specific industrial activity that affects the movement of an animal (Dyer et al. 2001). Considerable variability in ZOI because of a series of factors (e.g., type and extent of disturbance, region, pre- and post-disturbance habitat, interpretation of research results) may significantly influence inferences regarding the potential impacts of various industrial activities.

The extent to which caribou avoid disturbances is variable and can depend on scale of evaluation (Johnson, Ehlers, and Seip 2015). Mahoney and Schaefer (2002) found that caribou avoided a hydroelectric project in Newfoundland by up to 3 km, while Weir et al. (2007) recorded caribou avoiding a gold mine by up to 6 km, twice the distance of avoidance reported by Johnson, Ehlers, and Seip (2015) for caribou in response to a coal mine in the Quintette range of British Columbia. Dyer et al. (2001) reported that caribou avoided well sites by up to 1 km, while MacNearney et al. (2016) reported avoidance of up to 3 km for similar anthropogenic features. In addition to the physical structures or spatial footprint of a given feature, additional factors may influence caribou response (e.g., noise, lights, traffic, or season of activity) (Courbin et al. 2009; Beauchesne, Jaeger, and St-Laurent 2014). Johnson, Ehlers, and Seip (2015) reported avoidance distances and selection for anthropogenic disturbances in four Central Mountain subpopulations (Table 5.3). They concluded that disturbance responses of caribou are complex and variable and depend on the season and specific landscape features within a particular range. Caribou can experience chronic stress and expend more energy when exposed to disturbances, which may affect cortisol concentrations (i.e., stress levels), although the consequences on survival and reproduction remain unknown (Ewacha et al. 2017). As outlined by Johnson, Ehlers, and Seip (2015), caribou can select for disturbed areas, as identified in other studies (Hornseth and Rempel 2016), suggesting that caribou may have some plasticity in their tolerance to disturbance.

Table 5.3. Zone of Influence (km) Resulting from Avoidance Response of Woodland Caribou to Disturbance Features during Summer and Winter in the South Peace Region of British Columbia

Covariate	Moberly/Burnt Pine		Quintette		Bearhole-Redwillow		Narraway	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Roads	1.75	1.75	1.50	1.25	+	1.00	+	1.75
Seismic and pipelines	+	2.00	+	+	2.50	0.50	13.50[a]	+
Cutblocks	+	+	+	0.50	3.00	+	+	5.50[a]
Non-linear oil and gas	4.25	+	+	+	12.50[a]	2.00	4.00	+
Mine	ns	ns	3.00	+	ns	ns	ns	ns
Fire	+	+	2.75	+	+	+	5.25	8.00

[from Johnson, Ehlers, and Seip 2015]

[a] ZOI confounded by more than one asymptote in curve

+=apparent selection by caribou

ns=non-significant or non-applicable disturbance

Forestry

The forest products industry simultaneously manages for production of timber while striving to maintain the necessary forest characteristics required for species to meet their biophysical needs. The degree to which forest management can accommodate these requirements is shaped primarily by three factors: the natural abundance of habitat features already occurring on the landscape; the level and certainty of knowledge of a given species' habitat requirements; and economic incentive. The latter is not considered herein but is of interest to forestry companies.

Strong connections have been made regarding potential negative impacts that anthropogenic disturbances can have on caribou (Environment Canada 2011, 2012b), as forest harvesting is one of the prevalent methods of habitat alteration occurring in the boreal forest (Burton, Kneeshaw, and Coates 1999; Venier et al. 2014; Figure 5.1). The increased expansion of anthropogenic disturbance has been identified as one of the primary reasons for caribou range contraction at its southern limit (Schaefer 2003; Vors et al. 2007). Forest harvesting can (but does not always) remove large tracts of contiguous habitat, which has been documented to influence caribou habitat selection and use, and potentially population dynamics (Environment Canada 2012b).

Reducing the amount of fragmentation caused by forestry on the landscape is expected to reduce the impact on caribou (Environment Canada 2012b). In addition to potentially removing areas of mature and old-growth forests, forestry operations result in a resetting of the age of forest stands, which may increase plant diversity and abundance and lead to an increase in plant species that are preferred forage of ungulates (Rominger, Robbins, and Evans 1996). Early seral plant communities can attract alternative prey species (e.g., moose and deer) and, consequently, their predators, which increases the predation risk to caribou (Seip 1992; Mosnier et al. 2003; Wittmer, Sinclair, and McLellan 2005; Boisjoly, Ouellet, and Courtois 2010; Bowman et al. 2010; Fryxell et al. 2020).

Figure 5.1. Commercial Forest (dark green), Sawmills (blue circles), and Pulp Mills (yellow triangles) within Canada's Boreal Zone (light green, outlined in black) [from Brandt et al. 2013]

In addition, arboreal lichen abundance inherently declines if lichen are present on trees that are harvested. Terrestrial lichen also may decline if sites are sufficiently disturbed by harvesting machinery or covered by woody debris post-harvest (Fisher and Wilkinson 2005). Further, lichen abundance may also decline because of changes in the post-harvest understory microhabitat (interspecific competition from herbs and shrubs) and microclimate (drier and increased temperature) (Coxson, Stevenson, and Campbell 2003; Waterhouse, Armleder, and Nemec 2011; Lafleur et al. 2016). Waterhouse, Armleder, and Nemec (2011) found differences in terrestrial lichen response to partial harvesting treatments, where eight years after harvest forage lichen in a 70% residual treatment (i.e., 30% of trees removed) recovered to pre-harvest levels but lichen abundance within shelterwood treatments (50% removal) were unable to recover to 70% of pre-harvest abundance. These findings are supported by Stone et al. (2008), who studied silvicultural impacts on arboreal lichen in the Gaspé peninsula of Québec and found that a partial and selection harvest (25%, 30%, and 35% residual) resulted in losses of 40 to 60% of the initial lichen biomass across treatments. Terrestrial lichen do not necessarily do well in all undisturbed old-growth forests. For example, Coxson and Marsh (2001) reported that lichen (*C. mitis* and *C. rangiferina*) dominated the forest floor in 50- to 100-year post-fire stands of lodgepole pine (*Pinus contorta*) in northern interior British Columbia. In older stands, however, these lichen were replaced by feathermoss mats (e.g., *Pleurozium schreberi*). This trend was reversed when winter harvesting of trees removed canopy cover without disturbing the forest floor.

Caribou may avoid or abandon areas that have been harvested for periods up to 40 to 50 years (Smith et al. 2000 [winter range]; Schaefer and Mahoney 2007 [summer range]; Courtois et al. 2008 [winter range]). Several studies have reported caribou avoidance of cutblocks at long distances (>10 km, Vors et al. 2007 [modeled]; Schaefer and Mahoney 2007 [summer range]), while others have reported avoidance up to 2 km (Smith et al. 2000 [winter range]). Avoidance of cutblocks in the winter may be attributed to caribou detection by wolves, which can be influenced by the presence of vegetation growth post-harvest (Section 5.3.1, Travel), and snow conditions that may reduce movement rates (Smith et al. 2000) and impede access to forage (Schaefer and Pruitt 1991; Dyer et al. 2001; Seip and Jones 2008; Johnson, Ehlers, and Seip 2015).

Selection and use of recent cutblocks by caribou have also been documented (Briand et al. 2009; Hins et al. 2009; Dussault et al. 2012), where early seral forests can create ample foraging opportunities. These habitats are particularly appealing for caribou during the spring, when the influx of forage coincides with the time of year when nutritional requirements are at their highest (i.e., to replenish body condition post-winter, along with calving and lactation). Hins et al. (2009) found that caribou used older clearcuts (6 to 20 years) throughout the year and twice as much in the spring (39.4% of the time) as any other habitat, but the authors considered this to be underuse compared to their availability on the landscape.

However, as noted, caribou selecting for cutblocks may encounter increased predation risk (Seip and Jones 2008; Briand et al. 2009; Courbin et al. 2009; Hins et al. 2009; Lesmerises et al. 2013). Higher adult and calf mortalities have been reported in areas where cutovers were present (e.g., Losier et al. 2015; Fortin et al. 2017). Habitat alteration caused by forestry activities may also increase the abundance of alternative prey species (e.g., moose, deer) and their predators. For example, Wiwchar and Mallory (2012) documented that forest harvesting in western Ontario changed a primarily three-prey species system (moose, caribou, beaver [*Castor canadensis*]) in an undisturbed forest to a system with more than nine prey species in a harvested forest, where the predator system responded by increased predation on moose (Figure 5.2). Interestingly, the same study showed that the proportion of caribou in wolf diet declined from 21% in non-disturbed forests to 6% in previously harvested stands (0 to 7 years), and to completely absent in older (>7 years) harvests.

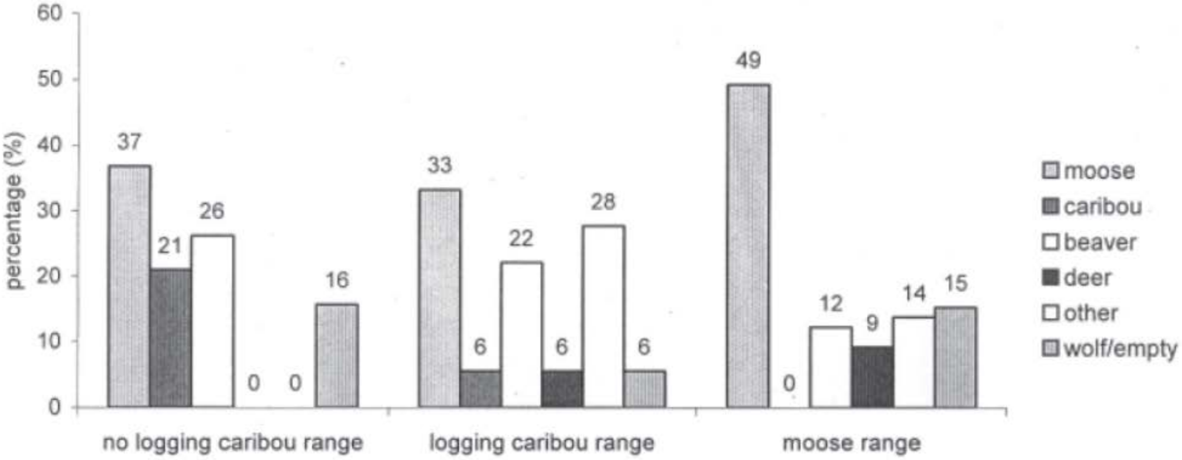

Figure 5.2. Stomach and Scat Contents of Grey Wolves in Three Habitats (no logging/caribou range; logging/caribou range; moose range) in Northwestern Ontario [from Wiwchar and Mallory 2012]

To date, many of the predatory response studies have been conducted in western Canada, where conclusions have been largely consistent that disturbance increases predation risk. In a pre- and post-disturbance study, Latham, Latham, McCutchen et al. (2011) concluded that a numerical response by wolves through the influx of white-tailed deer (~17.5 times pre-disturbance abundances) in response to industrial development contributed to increased incidental predation of caribou by wolves (pre-disturbance wolf diet composition was 0.5%, post-disturbance was 5.0%). These results strongly support the apparent competition hypothesis (Rettie and Messier 2000; Dzus 2001; Wittmer, Sinclair, and McLellan 2005; Latham, Latham, McCutchen et al. 2011).

Selection or avoidance of harvest cutovers also appears to be scale and season dependent. Briand et al. (2009) found that while caribou select for cutovers at a fine scale, presumably to complement foraging sites in the winter, they avoid cutovers at the landscape scale (Rettie and Messier 2000; Courtois et al. 2007; Schaefer and Mahoney 2007; Leblond et al. 2011). Leblond et al. (2011) reported that caribou avoided recent disturbances (clearcuts and natural disturbances) at the landscape scale throughout the year (except in the spring) but did select for both young (<5 years) and old (6 to 20 years) disturbances at the local scale. Recently disturbed sites may be used as complementary food supplies if they are surrounded by old coniferous stands that maintain terrestrial lichen at the coarser scale (Briand et al. 2009; Hins et al. 2009). To help minimize predation risk in these areas, caribou may forage at night (Beauchesne, Jaeger, and St-Laurent 2013) and/or travel faster within them (Avgar et al. 2013). Use of cutblocks comes at the risk of increased predation; Losier et al. (2015) found that caribou that frequented habitats closer to older clearcuts (6 to 20 years) generally died, whereas caribou located further away (>7 km) survived.

Increased forest fragmentation can have a strong impact on caribou home ranges. Caribou may reduce home range size with increasing exterior (in relation to their home range) disturbance but may increase home range size with increasing internal disturbance (Donovan, Brown, and Mallory 2017). Ewacha et al. (2017) reported that cortisol concentrations in caribou increased with increasing proportions of old logging (6 to 21 years) within home ranges and buffer areas. Depending on the intensity and spatial organization of forest harvesting, caribou may increase their search for alternate foraging areas (particularly in the winter) when in the proximity of harvested areas, especially if they are unfamiliar with these new habitats (Courtois et al. 2007; Lafontaine et al. 2017). As forest fragmentation increases caribou may be limited or “trapped” from effectively spacing away, thereby reducing home range size (Smith et al. 2000; Lesmeriers et al. 2013). According to Donovan, Brown, and Mallory (2017), caribou spatial behaviour varied across the landscape independently of forest management and their proximity to harvest blocks at the population-range scale did not decrease through time. These results appear to be related to finer-scale habitat attributes and behavioural responses (Section 2.3.1, Habitat Selection) in the vicinity of disturbed areas or the type of immediate disturbance itself (Mahoney et al. 2001; Briand et al. 2009; Faille et al. 2010).

Forestry guidelines and habitat management

Few studies have compared the capacity of different forest management practices to provide suitable habitat characteristics for wildlife (e.g., Armleder and Stevenson 1996; Vanderwel, Mills, and Malcolm 2009; Leblond, Dussault, and St-Laurent 2015; Nadeau Fortin, Sirois, and St-Laurent 2016). It is difficult to directly evaluate caribou use of harvested stands because of their large-scale habitat requirements and the cumulative factors associated with their responses. A high degree of variability among and between harvesting regimes (e.g., time since harvest, intensity and extent of harvest, road access network), and habitat-specific factors (e.g., caribou habitat use, predator-alternative prey abundances, weather, ecosite classification) may affect habitat suitability simultaneously and thus complicate comparisons. In addition, forest management practices have been significantly upgraded over the last two decades in part to benefit caribou, largely because of near-universal adoption of third-party-audited sustainable forest management certification standards (e.g., Canadian Standards Association, Forest Stewardship Council, Sustainable Forestry Initiative) and guidance from provincial governments. Thus, studies of relationships between forestry and caribou that fail to explicitly account for modernization of forestry practices may inaccurately portray the effects of contemporary forest management on caribou and other wildlife. Some of the management recommendations uncovered during this review of the literature are highlighted herein.

Forestry best practices and strategies (regulatory and voluntary) for the conservation of caribou and management of their habitat have been developed and implemented by the industry (in some cases for several decades, Table 5.4). In general, these strategies occur at the landscape scale (coarse filter approach) and the stand scale (fine filter approach). Examples of these approaches–include retaining large tracts of mature forest (coarse filter), decommissioning or removing inactive forestry roads (fine filter), retention harvesting within cutblocks (fine filter), and deferrals (increasing the rotation time interval between cuts) (coarse filter)–have been proposed and are being implemented (Bergeron et al. 2002; Courtois et al. 2008; Gauthier et al. 2009; Leclerc, Dussault, and St-Laurent 2012; Courbin et al. 2014; Losier et al. 2015). A shift from short-rotation, clearcutting management systems to an ecosystem-based management approach may also provide better alignment with natural disturbance regimes and improve conservation of woodland caribou (Drapeau et al. 2016; Lafontaine et al. 2019). Minimizing the post-harvest flush in forage that encourages alternative prey species is a component of some best practice recommendations.

Caribou habitat management plans have been incorporated into forest management plans in all provinces in which caribou reside; however, there is considerable variability across provinces in terms of how caribou habitat management plans are implemented in practice (Table 5.4). Caribou ranges in forests of Ontario, Saskatchewan, and Alberta are managed within the forest management planning process and targets are developed that align with provincial regulations. The provincial governments of British Columbia, Québec, and Newfoundland delineate habitat protection and management zones to prioritize different categories/facets of caribou habitat that require similar efforts from all forestry companies within a given province (see Supporting Links in Table 5.4).

Table 5.4. Summary of Forestry-Specific Caribou Habitat Management Actions by Province

Prov.	Habitat Management	Document Title	Supporting Link
British Columbia	Provincial government uses a series of legal tools to set habitat protection and/or impose management restrictions in caribou areas Non-habitat management approaches: predator control, maternal penning, supplemental feeding, primary prey management Conservation of higher alpine habitat Aggregation of harvest Variable retention harvesting and vegetation control to minimize early seral forage Forestry road deactivation	*Provincial Caribou Recovery Program: Discussion Paper*	https://engage.gov.bc.ca/app/uploads/sites/373/2018/04/Provincial-Caribou-Recovery-Program-Apr18_Rev.pdf
		Caribou Recovery Program Management Activities	https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/wildlife/wildlife-conservation/caribou/management-activities
Yukon	Deferrals	*Dawson Forest Resources Management Plan*	http://www.emr.gov.yk.ca/forestry/pdf/dawson_frmp_web.pdf
Alberta	Promotion of Integrated Land Management (ILM) - large focus on integrating disturbance activity planning and access across multiple sectors to minimize disturbance Restoration of seismic lines and aggregation of forest areas Harvest patterns that emulate natural disturbance regimes Temporary deferrals	*Draft Provincial Woodland Caribou Range Plan*	https://open.alberta.ca/publications/9781460137055
		Caribou Protection Plan	https://www.alberta.ca/caribou-protection-plan.aspx?utm_source=redirector
Saskatchewan	Combination of: temporary deferrals de-fragmentation of existing disturbances (natural and anthropogenic) implementation of Natural Forest Pattern harvesting practices (i.e., Emulation of Natural Disturbances)	*Conservation Strategy for Boreal Woodland Caribou in Saskatchewan*	https://www.saskatchewan.ca/business/environmental-protection-and-sustainability/wildlife-and-conservation/wildlife-species-at-risk/woodland-caribou

(Continued on next page.)

Table 5.4. Continued

Prov.	Habitat Management	Document Title	Supporting Link
Manitoba	Action plans will guide management activities at the management unit and caribou range levels. Temporary deferrals and road decommissioning	*Conserving a Boreal Icon: Manitoba's Boreal Woodland Caribou Recovery Strategy*	https://www.gov.mb.ca/sd/wildlife/sar/pdf/cariboustrategy_octfall2015.pdf
Ontario	Large tracks are temporarily deferred from harvesting in the short and long term. Use of Dynamic Caribou Habitat Schedule (DCHS) Forestry road decommissioning Harvesting patterns that emulate natural disturbance regimes	*Forest Management Guide for Boreal Landscapes*	https://www.ontario.ca/page/forest-management-boreal-landscapes
		Best Management Practices for Aggregate Activities and Woodland Caribou in Ontario	https://www.ontario.ca/page/best-management-practices-aggregate-activities-and-forest-dwelling-woodland-caribou
		Range Management Policy in Support of Woodland Caribou Conservation and Recovery	https://www.ontario.ca/page/range-management-policy-support-woodland-caribou-conservation-and-recovery
Québec	Preservation of large tracts of mature forest Biodiversity reserves Areas of sensitive operations within management units Large block mosaic system Aggregated harvesting	*Woodland Caribou Habitat Stewardship Plan*	https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiV_bDNqOPpAhUEo54KHbYtBgkQFjAAegQIBRAB&url=https%3A%2F%2Fmffp.gouv.qc.ca%2Fwp-content%2Fuploads%2FNapperon-Caribou-ang-2016.pdf&usg=AOvVaw0evGGPM2PYb-NIr0IszYKX
		La stratégie pour les caribous forestiers et montagnards	https://mffp.gouv.qc.ca/la-faune/especes/habitats-et-biodiversite/amenagement-habitat-caribou-forestier/
Newfoundland	Set-asides and buffers around core caribou habitat from forest management	*Provincial Sustainable Forest Management Strategy – Growing our Renewable and Sustainable Forest Economy (2014-2024)*	https://www.faa.gov.nl.ca/publications/pdf/psfms_14_24.pdf

Mining

As of 2009, there were 99 active mineral and metal mines, six smelters, and nine coal mines in the boreal zone (Figure 5.3), and at least an additional 1300 former mineral and metal mines have been documented to have been in operation (Brandt et al. 2013). While few studies have examined the influence of mining operations on woodland caribou, mineral exploration and mine sites can have a direct influence on the quantity and quality of habitat used by caribou.

Figure 5.3. Active Mines (blue circles) and Smelters (yellow smokestacks) within Canada’s Boreal Forest [from Brandt et al. 2013]

A combination of direct (actual footprint of the mine) and indirect (e.g., noise, pollution, sensory disturbances) characteristics associated with mining can significantly influence caribou movement patterns, increase energy expenditures and stress levels, and ultimately expand the ZOI around mining activities. Polfus, Hebblewhite, and Henemeyer (2011) found that the caribou ZOI for active mines was 2 km but shrank to the size of the actual physical footprint of the mine when inactive. These findings agree with those from Weir et al. (2007), who reported that caribou in the La Poile subpopulation in Newfoundland avoided areas within 4 km of an open-pit gold mine, which was predominately avoided during the pre-calving season. Seasonal avoidance by caribou is reinforced by the findings from Johnson, Ehlers, and Seip (2015) in the South Peace region of British Columbia, where caribou avoided a coal mine by a distance of 3 km in the summer but showed an affinity for the mine during the winter (Table 5.3). Seasonal avoidance by caribou, particularly in the spring and early summer, suggests a lower tolerance for higher human activity and noise during this sensitive time of the year (i.e., calving and lactation periods). Spatial avoidance during these periods provides caribou with an opportunity to reduce their risk of predation, which can be increased by the habitat alterations created with mining and associated activities (e.g., linear features) (Latham, Latham, Boyce et al. 2011; Latham, Latham, McCutchen et al. 2011; DeMars and Boutin 2018). The actual footprint and magnitude of the influences of mining activities on caribou may be specific to woodland caribou, which may be less sensitive to disturbances than their barren-ground counterparts. For example, Boulanger et al. (2012) found a nearly eight-fold increase in avoidance (30 km) by barren-ground caribou to a diamond mine in the Northwest Territories. Such variation indicates that more research is required to understand the variability of responses to different types of mines and associated mining activities across the woodland caribou range.

Oil and Gas

Oil and gas exploration and extraction are widespread in western Canada. The considerable infrastructure and associated features (seismic lines, roads, well sites, pipelines, and related structures) for extraction, processing, and transport of oil and gas can contribute to habitat abandonment and elevated predation within the woodland caribou ranges (Dyer et al. 2001; Hervieux et al. 2013). As of 2011, there were an estimated 222,000 active and abandoned well sites, 441,000 km of pipelines, and 1.7 million km of seismic lines within the boreal forest zone exclusively (Brandt et al. 2013).

Caribou may avoid habitats well beyond the actual development footprint (ZOI). For example, Dyer et al. (2001) documented that caribou avoided well sites by up to 1 km; one-third of the avoidance distance reported by MacNearney et al. (2016) in the mountainous Narraway and Redrock-Prairie Creek caribou subpopulations bordering Alberta and British Columbia. Johnson, Ehlers, and Seip (2015) also showed a comparable avoidance distance within the Narraway subpopulation (4.25 km), but only during the summer. Further, the ZOI for non-linear oil and gas activities varied from caribou selecting these features to avoiding them up to distances of 12.5 km (Table 5.3). As a result, caribou may be limited to suboptimal habitat with an elevated risk of predation (Lesmerises et al. 2013; Johnson, Ehlers, and Seip 2015; Dawe and Boutin 2016).

Linear Features

Industrial activities occurring within forested ecosystems often require creation of linear features (e.g., roads, seismic lines, pipelines, powerlines, roads, railways) as a means of facilitating access and extraction of natural resources (Dabros, Pyper, and Castilla 2018). Much of the research investigating potential impacts to caribou caused by linear features has come from western Canada, predominantly British Columbia and Alberta, because of the intensive and extensive network of linear features present in those provinces. Alberta supports approximately 250,000 km of seismic lines and 25,000 km of pipelines, corresponding to an average disturbance rate within caribou ranges of 65% for seismic lines (range 34 to 98%) and 19% for pipelines (range 0 to 42%) (Table 5.5). Other jurisdictions (e.g., Ontario) also have high rates of linear disturbance (Hornseth and Rempel 2016).

Linear features are thought to contribute to declines in caribou populations through two mechanisms: (1) enhanced predator hunting efficiencies (DeCesare 2012; McKenzie et al. 2012; Dickie et al. 2017); and (2) improved connectivity between peatland complexes and predator-rich upland areas (James and Stuart-Smith 2000; Latham, Latham, Boyce et al. 2011; Latham, Latham, McCutchen et al. 2011; Whittington et al. 2011; DeMars and Boutin 2018). These act to increase encounter rates and predation risk to caribou (James and Stuart-Smith 2000; Johnson, Ehlers, and Seip 2015; McGreer et al. 2015; Mumma et al. 2018). Linear features also contribute to the functional loss of caribou habitat (Latham, Latham, and Boyce 2011) and increased avoidance of these features at broad spatial scales (Dyer et al. 2001; Schindler et al. 2007; Polfus, Hebblewhite, and Henemeyer 2011). Linear features at high densities increase the spatial overlap of caribou, their predators, and alternative prey, especially if alternative suitable habitat options are absent from the landscape (Dawe and Boutin 2016).

Table 5.5. Seismic and Pipeline Disturbance by Woodland Caribou Range

Caribou Population	Subpopulation (Range)	Range Size (ha)*	Length of Seismic Lines (km)	Seismic Line Disturbance (%)	Isolated Seismic Line Segments[a] (%)	Length of Pipelines (km)	Range Disturbed by Pipelines (%)	Isolated Pipeline Segments[a] (%)
Central Mountains	A La Peche	661,500	2,046	84	7	456	5	2
	Narraway	104,066	863	66	14	547	42	11
	Redrock-Prairie Creek	482,892	1,626	41	12	809	14	4
Boreal	Chinchaga	1,764,364	58,812	96	54	4,456	20	9
	Bistcho	1,435,810	61,442	91	69	2,146	11	7
	Yates	522,344	5,806	61	52	39	1	1
	Caribou Mountains	2,065,873	8,601	36	29	0	0	0
	Little Smoky	308,380	9,476	98	28	1,812	44	16
	Red Earth	2,470,203	43,643	68	45	2,595	8	3
	West Side Athabasca River	1,570,712	22,068	79	42	3,533	18	9
	Richardson	707,390	2,201	34	12	38	1	1
	East Side Athabasca River	1,311,902	19,256	84	34	4,377	25	12
	Cold Lake	672,586	7,883	80	34	2,963	33	14
	Nipisi	210,436	3,713	91	40	630	19	9
	Slave Lake	151,623	3,304	95	34	988	40	9

[from Alberta Government 2017]

[a] isolated segments are portions more than 500 m from other disturbances, and thus the sole disturbance within an otherwise undisturbed area

Using a mechanistic first passage time model, McKenzie et al. (2012) determined that encounter rates were significantly higher in landscapes with higher seismic line densities and that these were most pronounced at low prey densities (i.e., low number of prey per individual predator), suggesting that very low populations of prey (e.g., caribou) are at high risk when densities of linear features are highest. These findings can be particularly important considering the current state of caribou populations and densities of linear features in many of the western mountain and boreal woodland caribou ranges (Tables 4.2 through 4.4 and Table 5.5). In a recent study in northeastern British Columbia, DeMars and Boutin (2018) found that linear features increased predator selection of peatlands–habitats that are generally avoided and considered marginal by wolves and their alternative prey due to poorer availability of foraging resources–particularly in the spring (James et al. 2004; Latham, Latham, McCutchen et al. 2011). Predator access to peatlands can be especially concerning in the context of caribou recruitment, as these habitats are generally selected as refugia for calving (Section 2.3.1, Habitat Selection). DeMars and Boutin (2018) found that female caribou respond by avoiding areas with high densities of linear features, a difficult task given their high occurrence within these ranges (Figure 5.4).

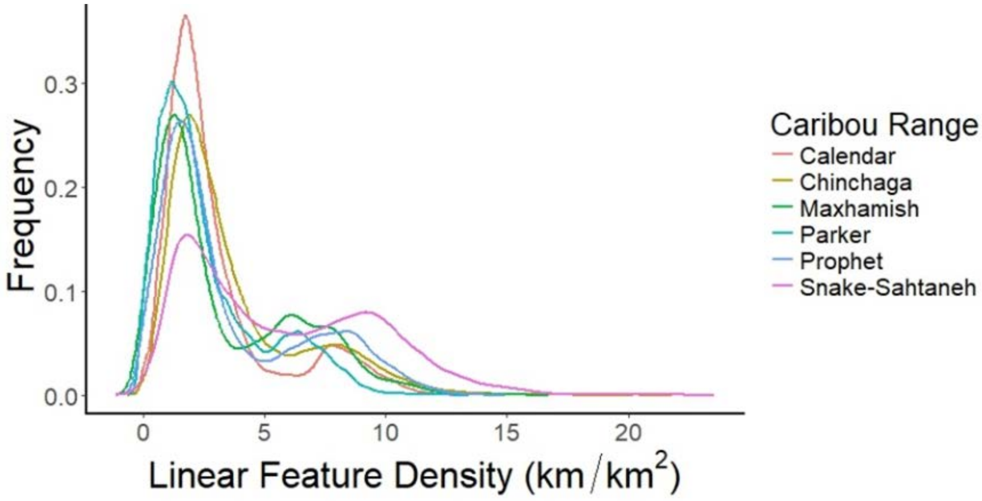

Figure 5.4. Distribution of Linear Feature Densities for Six Boreal Caribou Ranges in Northeastern British Columbia: calculated within a 1 km moving window radius; approximated using kernel density estimation [from DeMars and Boutin 2018]

The degree of avoidance of linear features by caribou can vary by type (e.g., road, seismic line), season, and site (Table 5.3, Figure 5.5). Dyer et al. (2001) found that caribou avoided roads and seismic lines at distances of 250 m, which was extrapolated to reduce landscape use by 22 to 48% within their study area in northern Alberta. Avoidance of these features was highest during late winter and calving periods and lowest during summer. Nobert et al. (2016) also found that caribou avoided linear features most during calving and post-parturition periods. They attributed these seasonal differences to lower traffic densities. Nagy et al. (2011) found that caribou generally avoided these features at distances of 400 m, while others (Mahoney and Schaefer 2002; Hebblewhite, White, and Musiani 2010; Johnson, Ehlers, and Seip 2015) have found longer avoidance distances (0.5 to 5.0 km). Caribou response to roads has generally been similar to responses to seismic lines; however, in addition to their physical footprint, the ZOI for roads is also a function of traffic. Wasser et al. (2011) reported that caribou avoided primary roads in the winter but did not avoid secondary roads, which were used much less by road traffic. In Ontario, Vors et al. (2007) reported that caribou avoided roads at distances of 4 km, while in Québec they were found to avoid road networks at varying degrees: 2 km (Dussualt et al. 2012; Rudolph et al. 2012); 5 km (Fortin et al. 2013); and up to

10 km (Rudolph 2011). Leblond et al. (2011) and Leblond, Dussault, and Ouellet (2013a) reported that caribou in the Charlevoix subpopulation avoided highways at distances of 5 km, primary roads at 1.25 km, and tertiary forestry roads at 750 m. These findings are further supported by those of Cumming and Hyer (1998), who found that caribou avoided haul roads when trucks were present but did not avoid the same roads the year before road use and returned to using them the year following road deactivation.

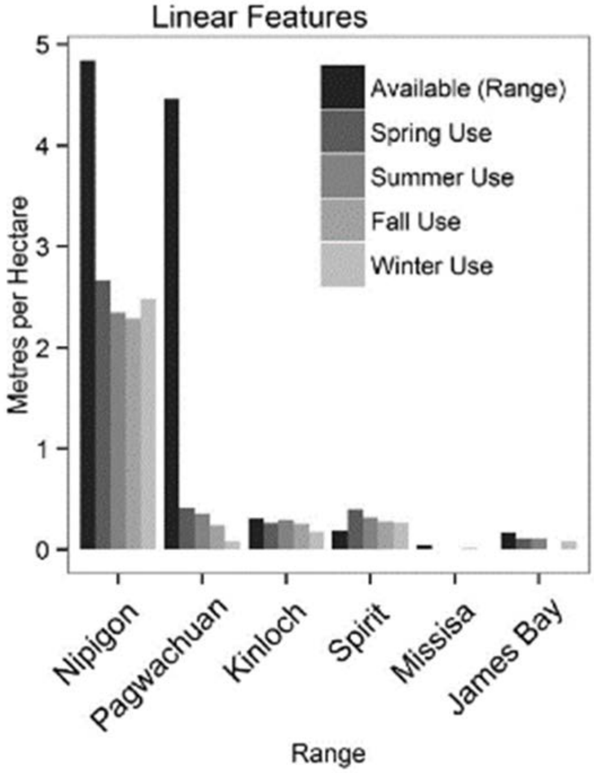

Figure 5.5. Relative Proportional Use by Woodland Caribou of Linear Features vs. Availability for Six Ranges and Four Seasons in Northern Ontario [from Hornseth and Rempel 2016]

Caribou response to linear features is not exclusively unilateral whereby, like predators, their travel can be facilitated and can also offer higher quality forage during the snow-free periods (Edmonds and Bloomfield 1984; James and Stuart-Smith 2000; Dzus 2001). Johnson, Ehlers, and Seip (2015) found that caribou selected for linear features in the summer in two of the four subpopulations they studied in northeastern British Columbia (Table 5.3). Further, McLoughlin et al. (2019) showed that caribou selected for linear features in the winter at the home range scale and across all seasons at the population scale. By using linear features, caribou increase their risk to predation along with their probability of being struck by motor vehicles, hunted, or poached (Bergerud, Butler, and Miller 1984; Seip and Cichowski 1996; James and Stuart-Smith 2000; Ehlers, Johnson, and Seip 2014; DeMars and Boutin 2018). While there have been substantial efforts to assess the impact of linear features on caribou, few direct tests of predator-prey dynamics using empirical data exist (e.g., James and Stuart-Smith 2000; Whittington et al. 2011; DeMars and Boutin 2018).

Predator Travel

Predators generally select for linear features year-round (Finnegan et al. 2018), and in doing so can travel faster (Tigner, Bayne, and Boutin 2014; Dickie et al. 2017; DeMars and Boutin 2018).

McLoughlin et al. (2003) found that during the snow-free season (when caribou mortalities are highest) wolves selected for linear features, but these features were less used for travel during the winter. Compared with the forest interior, travel within linear features during the winter can be facilitated when trails become snow-packed from use of all-terrain vehicles (ATVs) or snow machines (Edmonds and Bloomfield 1984; James 1999; Dzus 2001; Ehlers, Johnson, and Seip 2014). Snowpack depth, compaction, and icing events can all contribute to animal movement rates (Huggard 1993b; Metz et al. 2012; Droghini and Boutin 2017). Dickie et al. (2017) found that travel rates by wolves were less in the winter than in the summer, but in winter wolves generally had higher odds of selecting certain linear features over the surrounding forest: pipelines and seismic lines (two times more likely to be used than intact forest), roads (three times more likely), railways (four times more likely), and transmission lines (eight times more likely). Use was positively correlated with the width of clearing of these features. Tigner, Bayne, and Boutin (2014) evaluated black bear use of seismic lines in areas bordering northern British Columbia, Alberta, and Northwest Territories and found that they used seismic lines more than forest interiors. However, bears did not use narrow (<2 m) seismic lines more often than the forest interior. Seismic lines 3 to 4 m and 5 m wide were 2.6 and 3.5 times more likely to be used than the forest interior, respectively.

During the snow-free months, Dickie et al. (2017) found that wolves selected for linear features with shorter and sparser vegetation that would lead to faster travel rates (+1.5 to 1.7 km/h) than in those with taller vegetation (>0.5 m). Further, the authors determined that movement rates between linear features and the interior forest were comparable only when vegetation reached approximately 4 m in height. Finnegan et al. (2018) also found that wolves traveled fastest when vegetation was shorter (<0.7 m) during the rendezvous period. The authors suspected that seismic lines with shorter vegetation were selected because their use minimizes energy costs, and because these areas were absent of prey species. Selection of anthropogenic linear features can also influence wolf use of natural linear features (e.g., streams and waterways). Newton et al. (2017) found that when anthropogenic linear features were present at higher densities in Ontario, wolf selection for natural linear features declined. Faster travel rates of wolves evidently increase encounter rates with prey (Vander Vennen et al. 2016).

5.3.2 *Recreation*

Several types of recreational activities overlap within woodland caribou ranges, including snowmobiling, skiing (backcountry, helicopter-assisted, cat-assisted), ecotourism, ATV use, mountain biking, camping, and hiking. Caribou may increase vigilance and movement and reduce resting and foraging near recreational activities (Duchesne, Côté, and Barrette 2000; Mahoney et al. 2001; Reimers, Eftestøl, and Colman 2003; Freeman 2008) (Table 5.6); however, only extensive use appears to cause habitat abandonment (Seip, Johnson, and Watts 2007). Further, increased snowmobile use leads to snow compaction on trails that can facilitate the travel of predators and increase predation risk on caribou in winter months (Bergerud 1988; Whittington et al. 2011). In the presence of deeper snow, caribou fled shorter distances (60 to 237 m) and responded more slowly to snowmobiles in Newfoundland, where adult-only groups responded sooner and traveled further than groups with calves, perhaps to limit energy expended (Mahoney et al. 2001).

Table 5.6. Wintertime Budgets[a] of Woodland Caribou According to Presence or Absence of Ecotourists in Charlevoix Biosphere Reserve

	n[b]	Vigilance	Foraging	Resting	Standing	Walking	Others
Without Ecotourists	22	6.9±1.7	22.2±1.8	31.9±3.0	18.2±1.9	19.2±2.0	3.1±1.3
During Visits	11	13.7±2.5	11.9±2.6	24.8±4.4	26.3±2.8	17.1±3.0	6.2±1.9
After Visits	11	7.5±2.2	14.5±2.4	34.5±3.9	22.6±2.5	13.0±2.6	7.9±1.7

[from Duchesne, Côté, and Barrette 2000] [a] % ± SE

[b] number of groups observed

Based on fecal stress hormones, skiing displaces and stresses caribou (COSEWIC 2014a, 2014b) up to 10 km away (Freeman 2008). Backcountry skiing has been linked to spatial displacement in the Atlantic-Gaspésie population (Lesmerises et al. 2018). Caribou did not significantly displace within the first 6 hours but did move away to lower elevations for approximately 48 hours (displacement for upwards of 120 hours in some instances); they did eventually return to these ski areas. The extent of displacement was corrected to the number of skiers based on RSF analysis, and some caribou did not displace when few skiers were present. Wilson and Wilmshurst (2019) assessed the behavioural response of Southern Mountain caribou to helicopter and skiing activities and concluded that encounter distance was the most important factor in both helicopter and skiing Bayesian network models. Larger helicopters elicited a stronger response than smaller machines. Further, encounters with helicopters at shorter distances (100 to 500 m) had a 78% probability of eliciting a concerned-to-very-alarmed response, while encounters with skiers at a similar distance had a 60% probability of obtaining a similar response (Figure 5.6).

Hikers have been found to impact the Atlantic-Gaspésie caribou population (Dumont 1993). Hiking trails, a form of linear feature, evidently facilitated the movement of coyotes and black bears within this population (Gaudry 2013). Hiking by eco-tourists near caribou in the winter did not cause caribou to run but did reduce the time they spent feeding and resting and resulted in increased vigilance and standing (Table 5.6). After hiking visits, caribou were found to rest more than during control days (Duchense, Côté, and Barrette 2000). These changes in behaviour over prolonged or repeated periods may affect body condition, recruitment, survival, and vulnerability to predation (Bergerud 1988; Parker, Barboza, and Gillingham 2009; McLellan et al. 2012).

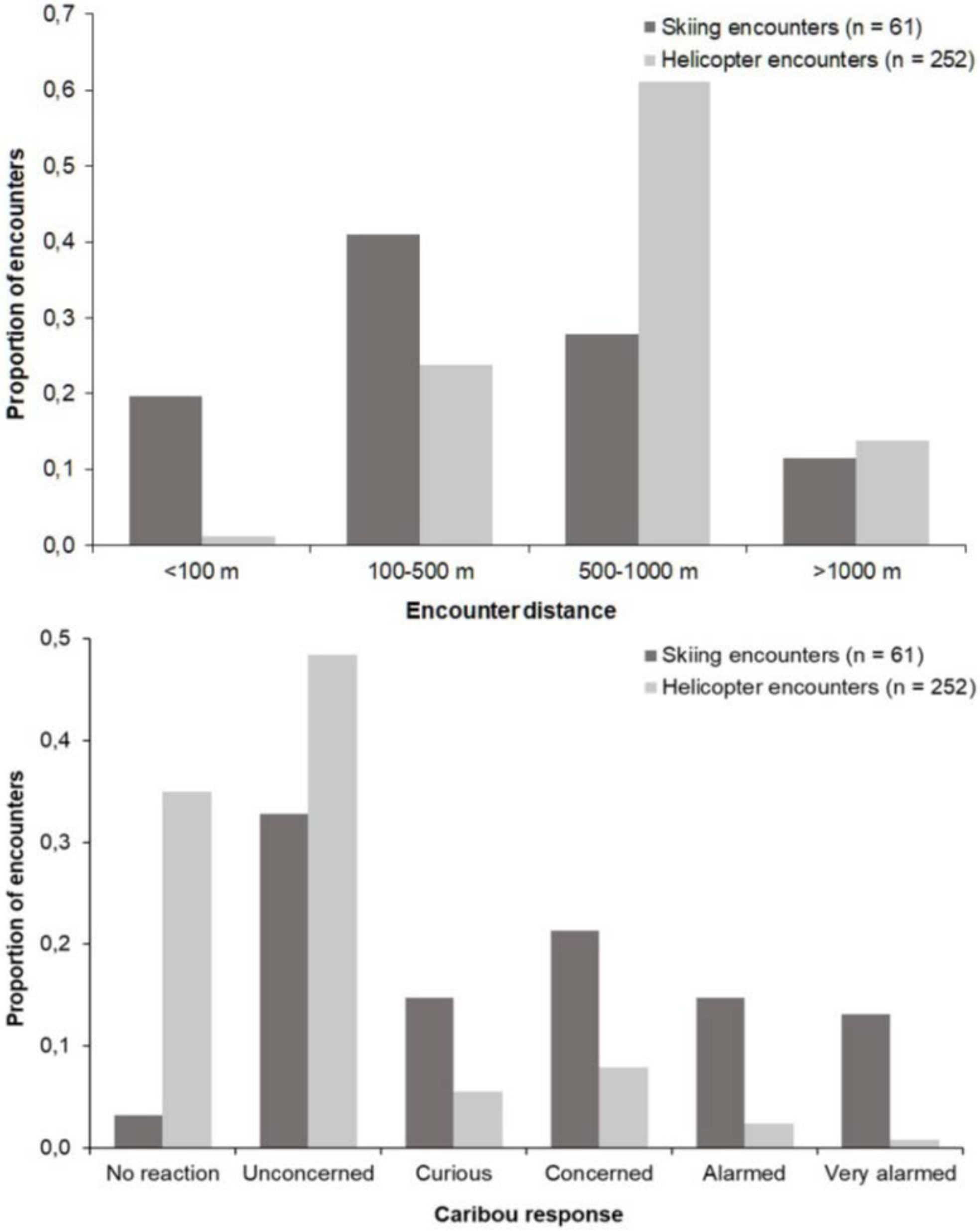

Figure 5.6. Proportion of Caribou Encounter Distances (top) and Proportion of Different Caribou Reactions to Encounters (bottom) by Means of Travel [from Wilson and Wilmshurst 2019]

5.3.3 *Hunting and Poaching*

Hunting continues to contribute to the decline and impacts conservation/recovery efforts for woodland caribou (Festa-Bianchet et al. 2011). Because of the combination of limited information on harvests and remoteness of many of these populations, it is difficult to accurately assess the relative degree to which hunting contributes to declines, particularly because reporting varies across jurisdictions (Festa-Bianchet et al. 2011). In the federal recovery strategy, Environment and Climate Change Canada (Environment Canada 2012b) indicated that hunting remains a significant contributor and identified it as a “medium” threat to caribou. For example, it is suspected that upwards of two-thirds of the subpopulations of woodland caribou in British Columbia are directly impacted by hunting and poaching (Spalding 2000). Subsistence hunting of all caribou populations by aboriginal people is constitutionally guaranteed by treaty rights and land claim agreements (COSEWIC 2014a, 2014b). Nevertheless, many new regulations and restrictions have been enforced or agreed upon, some of which have challenged aboriginal rights and resulted in dissent and political backlash (Festa-Bianchet et al. 2011; Kutz et al. 2014).

Sport hunting of woodland caribou is still occurring and is limited to Newfoundland, British Columbia, and the Yukon. It is banned in Alberta (1985), Saskatchewan (1987), Manitoba (2006), Ontario (1929), and Québec (2001) (COSEWIC 2014b). Other caribou populations within certain jurisdictions can still be hunted to some extent (e.g., migratory caribou in Québec). Improved hunting access to woodland caribou has resulted from increased density and maintenance of linear features extending to even more remote areas. Further, advances in equipment and tools (e.g., GPS, guns, ATVs) have led to improved tracking and hunting of these animals.

The cost of a caribou hunting license varies across jurisdictions that allow hunting. In Newfoundland, residents can acquire a hunting license for $52.00CAD and a resident senior can hunt woodland caribou for $33.80CAD, while a non-resident hunting permit costs $675.00CAD (NLDFLR 2019). In British Columbia and Yukon, respectively, resident licenses cost $20.00 and $10.00 and non-resident licenses cost $230.00 and $150.00CAD (BC 2019; Yukon 2019). Caribou hunting regulations are set by the province or territory and their co-management boards (BC 2019; NLDFLR 2019; Yukon 2019).

An overall quota of 575 licenses was awarded in Newfoundland in 2019, but because of low numbers in the northern peninsula, a hunting closure was enforced for that area (NLDFLR 2019). An estimate of 80 to 200 boreal caribou are harvested per year in the Northwest Territories (CMA 2017). Concern has been raised over harvesting of boreal caribou in the Dehcho and South Slave regions, and that illegal harvest may be occurring in the Hay River area (NWT Species at Risk Committee, Yukon 2019). In the Yukon, 237 caribou were hunted in 2018-2019 (Yukon 2019). In British Columbia, hunting restrictions are limited to resource management units (and inclusion of corresponding subpopulations of caribou). The caribou hunting season in British Columbia is limited to August 15 to October 15 annually (BC 2019), and inspection and reporting is required following a kill (hunter must provide the incisor tooth, antlers, and for a caribou without at least one main beam measuring over 60 cm (24 inches) in length, the hide with evidence of sex attached (BC 2019).

To provide some context for the extent of hunting in British Columbia, the numbers of animals hunted between 1976 and 2015 have been reported by subpopulation (BC 2019):

- Atlin: 2069 (avg. 53/year)
- Horseranch: 2733 (avg. 70/year)
- Level Kawdy: 3648 (avg. 94/year)
- Little Rancheria: 2982 (avg. 76/year)
- Spatsizi: 1627 (avg. 42/year)
- Swan Lake: 1435 (avg. 37/year)

Caribou poaching is an additional source of mortality and can have a profound impact on the population (Johnson 1985). The current extent of illegal hunting is unknown (Environment Canada 2012a, 2012b, 2014). The impact could be substantial if it occurs within a small population, where any illegal take could have significant demographic ramifications.

5.4 Predation

Predation, particularly by wolves (with the exception of Newfoundland, where wolves were extirpated circa 1911), is considered the primary proximate cause of woodland caribou declines across its range (Bergerud 1974; Seip 1992; James et al. 2004; Boisjoly, Ouellet, and Courtois 2010;

Festa-Bianchet et al. 2011; Pinard et al. 2012; Fryxell et al. 2020). Across much of the boreal forest of North America, the primary prey species for wolves has historically been moose, which generally occur in upland forests. Although the spatial separation response by caribou has historically facilitated their co-existence with moose and wolves across much of their species distributions (James et al. 2004), more recently, habitat alterations (Section 5.3, Disturbance) across the forest landscape (e.g., influx of alternative prey, climate change, disturbance) has changed the predator-prey dynamics within the woodland caribou species range (Apps et al. 2016; DeMars and Boutin 2018; Fryxell et al. 2020).

5.4.1 *Wolves*

Wolves play a critical role in the population dynamics of woodland caribou, as they are thought to limit caribou distribution and abundance at multiple scales (Rettie and Messier 2000; McLoughlin et al. 2003; Fryxell et al. 2020). Predation by wolves is believed to intensify with landscape disturbance (anthropogenic or natural), as post-disturbance conditions can improve hunting efficiency (e.g., facilitated travel corridors) for wolves. Increases in alternative prey species populations have been found to occur via creation of more favourable habitat (i.e., creation of early seral forage) following disturbance, thus resulting in a numerical response in wolves (Seip 1992; Hervieux et al. 2013; Fryxell et al. 2020) (Section 5.4.5, Apparent Competition). For example, Latham, Latham, McCutchen et al. (2011) found that wolf densities within the western area of the Athabasca River subpopulation increased after disturbance from 0.6 wolves/100 km^2 (1994 to 1997) to 1.15 wolves/100 km^2 (2005 to 2009), increases that mirrored the decline of caribou in this range. Boreal caribou subpopulations are thought to decline when wolf density surpasses a density threshold of 0.65 individuals/100 km^2 (Bergerud and Elliot 1986) or even less (Hebblewhite et al. 2007). Although estimates of wolf densities are poor across much of the woodland caribou population range (Hervieux et al. 2013), many of the caribou ranges have much higher densities of wolves. For example, Webb (2009) estimated that wolf density in the lower foothills (2.23 wolves/100 km^2), upper foothills (1.49 wolves/100 km^2), and mountain (0.97 wolves/100 km^2) regions of Alberta exceeded the threshold estimates of 0.65.

Habitat Selection

Habitat selection by wolves reflects that of their primary prey (Seip 1992; Courbin et al. 2014; Roffler, Gregovich, and Larson 2018). Selecting for prey resource distribution means that wolves spend much of their time in early seral successional forests where their primary prey concentrate (Cumming, Beange, and Lavoie 1996; Kuzyk, Kneteman, and Schmiegelow 2004). In Alberta, Latham et al. (2013) found that wolves selected for upland forests, rivers and streams, and seismic lines, while they generally avoided bogs and fens except during the caribou calving season. In fact, Latham et al. (2013) reported that >25% of all wolf packs selected for bogs and fens during a time when caribou are most vulnerable to predation. Wolves also selected for rivers and streams; these habitats provide high availability of prey species, particularly moose and beavers (Mech and Boitani 2003; Osko et al. 2004). During their denning period, wolves selected for conifer stands with lichen understories, deciduous-mixed-wood forests, and open areas and tended to avoid highly disturbed areas (Houle et al. 2010). This strategy probably offered the best tradeoff to minimize risk to their young while increasing their ability to hunt. Other studies have also identified these habitats (i.e., lowlands or riparian habitats) as important sites for wolf natal dens and homesites (Packard 2003; Latham 2009). During the rendezvous period wolves tended to select for roads, but only at low densities (Houle et al. 2010), which may suggest that they were able to increase travel rates without increasing their risk of interaction with humans.

Diet Composition

Prey selection by wolves depends on several factors, including prey abundance, prey species range overlap, injury risk, encounter rate, and likelihood of capture (Huggard 1993a). Further, seasonal variation in prey species dynamics can also lead to prey switching (Table 5.7), where wolves actively select prey based upon the timing of their life-history events (e.g., denning) and that of their prey (e.g., calving period). These factors are all affected by the size of the wolf pack, their feeding habits, and environmental conditions within their home range (Spaulding, Krausman, and Ballard 1998; Milakovic and Parker 2011).

Table 5.7. Isotopic Signatures (%) of Prey[a] Use in Diet Composition Models for Wolves by Season in the Besa-Prophet Area, Northeastern British Columbia. RBC indicates red blood cells

Prey	Sample	n	δ^{13} C±SE	δ^{15} N±SE	Winter	Early Spring	Summer	Fall
Elk	Hair	6	-24.42±0.09	2.41±0.13			X	
	Meat	9	-24.68±0.10	3.12±0.17	X	X		X
Sheep	Hair	34	-23.75±0.05	2.81±0.12	X	X	X	X
Caribou	RBC[b] 2001	12	-23.28±0.06	2.77±0.19				X
	RBC[b] 2003	15	-23.02±0.13	1.96±0.11	X			
	Hair 2003	24	-23.14±0.06	2.46±0.09			X	
Moose	Hair	15	-24.47±0.11	1.53±0.15			X	
	RBC[b]	15	-24.67±0.04	0.61±0.07	X	X		
	Meat	12	-24.39±0.09	1.58±0.20				X

[from Milakovic and Parker 2011] [a]
mean±SE
[b] RBC=red blood cells

Wolves are typically opportunistic, with very diverse diets. Ungulates (e.g., moose, elk, caribou, sheep) generally compose the vast majority of their diet across much of their European and North American ranges (Okarma 1995; Spaulding, Krausman, and Ballard 1998; Tremblay, Jolicoeur, and Lemieux 2001; Latham, Latham, McCutchen et al. 2011). When the prey species' range is sympatric it increases the likelihood that wolves will persist on the landscape (Figure 5.7). Prey switching can occur when a particular species reaches a lower density threshold on the landscape, so wolves actively hunt another species because the energy amassed in searching and hunting the species is greater than the energy gained from killing it. Dale, Adams, and Bowen (1995) found that when caribou densities fell below 0.2/km^2, wolves would prey-switch to moose in Alaska. Messier (1985) concluded that wolves in southwestern Québec would also increase their prey search range when moose fell below this same density threshold (0.2/km^2). While these thresholds can provide some potential insight into prey-switching dynamics and when they may occur, there can be considerable variability in prey-switching thresholds. Much more study is warranted.

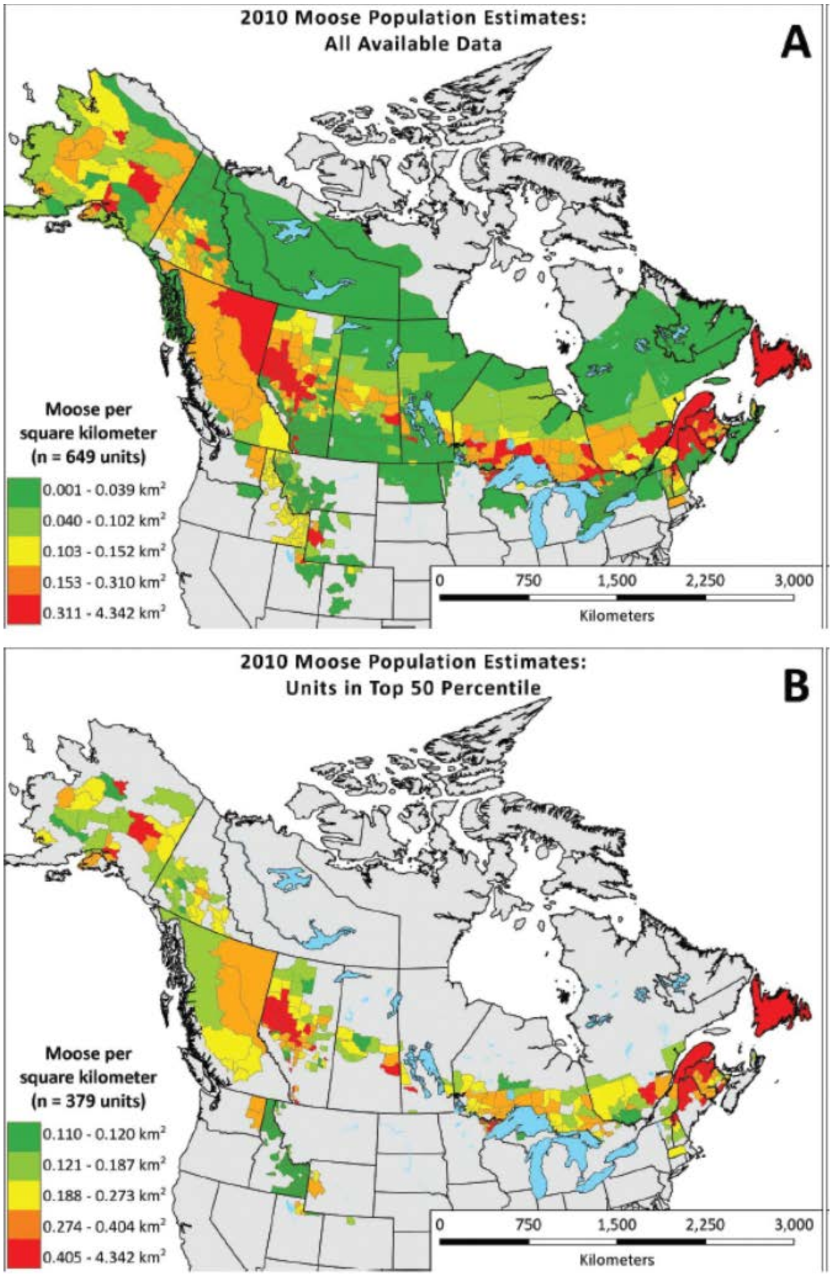

Figure 5.7. Moose Population Density Estimates by Management Unit for North America (ca. 2010): (A) all available management unit data (n=649); (B) top 50th percentile of management units with highest population densities [from Jensen et al. 2018]

The relative proportion of caribou in wolf diets is variable but typically low (<5%). In a meta-analysis of wolf population dynamics conducted across North America, Fuller, Mech, and Cochrane (2003) failed to identify caribou as either a primary or secondary prey species of wolves across its species range. Further, Tremblay, Jolicoeur, and Lemieux (2001) concluded that moose (0.08 moose/km^2) was the primary prey species consumed by wolves in Québec (65.2 to 96.3% of biomass), while caribou (0.03 caribou/km^2) composed <2% of wolf diets. In another example of low caribou consumption, Latham, Latham, McCutchen et al. (2011) reported that caribou composed only 0.5% of wolf diets vs. moose at 64%, beaver at 14.7%, and deer at 9.4%. These findings were reinforced by

Wasser et al. (2011), who found that the winter diet of wolves in the Alberta oil sands region consisted of low amounts of caribou (11%) vs. deer at 65% and moose at 24%, results similar to those from a nearby study. Finally, Hayes et al. (2000) reported that wolf winter diet in the Yukon was primarily composed of moose (94% of biomass and 89% of total wolf kills), while predation on caribou was relatively low (9.2% of total wolf kills).

While each of these examples suggests that caribou are only a token portion of wolf diets, that is not always the case. For example, Merkle et al. (2017) recently reported that in the boreal mountains of northwestern British Columbia, caribou comprised up to 50% of the summer wolf diet, even though their abundance in this area was half that of moose (Figure 5.8). These findings suggest that prey availability alone does not determine the final prey selection of wolves (Huggard 1993a). Latham et al. (2013) found that deer was the primary prey species of wolves in northeastern Alberta in winter (October to March), whereas beaver predominated in the summer (April to September); proportions of moose and caribou in wolf diets were constant among seasons (Figure 5.9). Further, Latham et al. (2013) found that 76% of all caribou mortalities occurred in the summer months when wolves tend to hunt in smaller groups or as individuals and, as a result, can increase the number of hunting units and prey encounter rates occurring on the landscape (Fuller, Mech, and Cochrane 2003; Merkle et al. 2017). Not only are caribou exposed to increased predation pressure during the summer, but they may also be deemed an easier or more vulnerable target (particularly pertinent to calves) than their ungulate counterparts (moose), which are typically two to three times larger in overall size. Although moose remain a primary or secondary prey species for wolves across much of their overlapping species ranges (Figures 5.7), in northeastern Alberta, deer appear to have replaced moose as the primary prey species, at least during the winter months (Figure 5.9). Although caribou often make up a small proportion of the overall diet for wolves, the relative proportion of caribou lost to predation can have a dramatic effect on local populations (McLoughlin et al. 2003; Wittmer, Sinclair, and McLellan 2005; Latham, Latham, McCutchen et al. 2011). More research is needed to assess the annual diet of wolves while incorporating multi-prey species to objectively assess variations that may exist in wolf behaviour, habitat use, and interspecies dynamics (Fryxell et al. 2008; Basille et al. 2013; Latham et al. 2013). Conducting studies in one season may over- or underestimate predation rates and could lead to misguided inferences or incorrectly conclude the drivers of predator-prey dynamics (Wasser et al. 2011; Merkle et al. 2017).

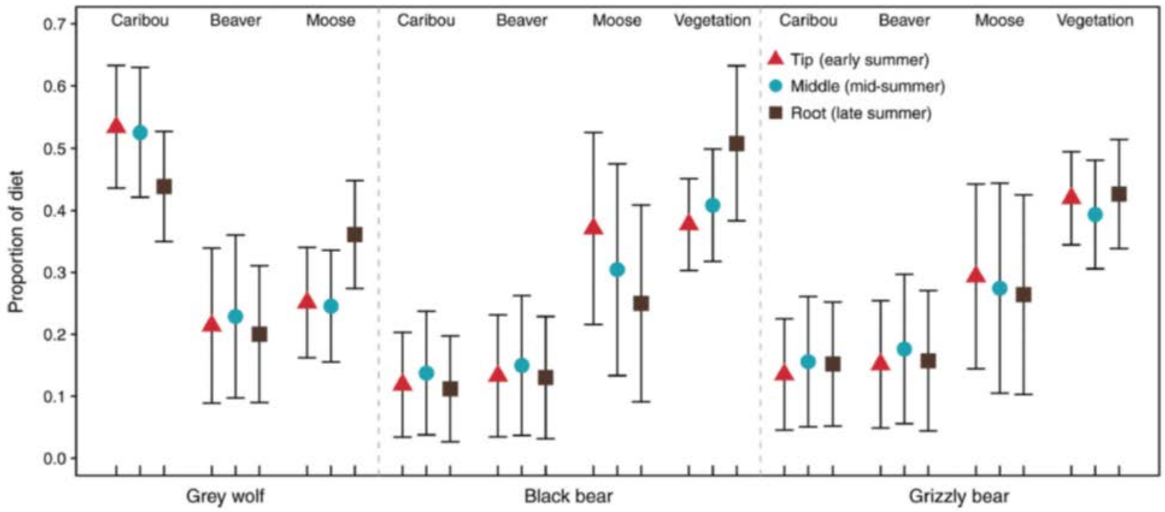

Figure 5.8. Proportional Contribution of Caribou, Beaver, Moose, and Vegetation in Diets of Grey Wolves, Black Bears, and Grizzly Bears in Early, Middle, and Late Summer in Taku River Tingi First Nation, Northwestern British Columba [from Merkle et al. 2017]

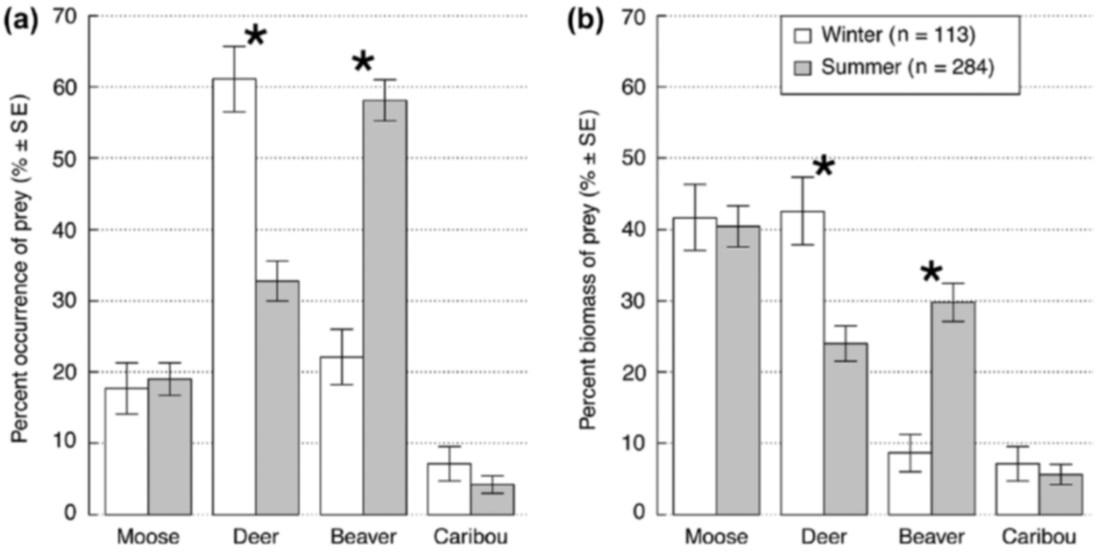

Figure 5.9. Seasonal Variation in Wolf Diet between Winter (October-March) and Summer (April-September) in West and East Sides of Athabasca River Caribou Ranges, Northeastern Alberta: (a) percent of occurrence of prey; (b) percent biomass of prey [from Latham et al. 2013]

5.4.2 *Bears*

While wolves remain the dominant predator of woodland caribou, other species also hunt them, most notably black bears (*Ursus americanus*) and brown bears (*U. arctos*). Black bear densities in the boreal forest are an order of magnitude greater than those of wolves (Latham, Latham, and Boyce 2011), and while adult caribou rarely fall victim to predation from bears (Ballard 1994; Zager and Beecham 2006), calves are more susceptible. Bears are considered the primary predator of caribou neonates (i.e., newborns, typically less than four to six weeks old) (Mahoney et al. 1990; Seip 1991; Ballard 1994; Zager and Beecham 2006; Merkle et al. 2017). Mortality of caribou calves more than six weeks old is comparable to that of adults, particularly by about 90 days, coinciding with increased mobility and strength (Mahoney et al. 1990, 2016; Latham, Latham, and Boyce 2011). After a decade of monitoring (2003 to 2013) caribou neonates in Newfoundland (wolves were extirpated circa 1911), Rayl et al. (2018) reported that predation by black bears was the primary cause of mortality (32% of deaths, 1763 of 5524 total calves), nearly 2.5 times more than those killed by coyotes (Figure 5.10). Bastille-Rousseau, Schaefer, et al. (2016) reported that for 1384 neonates the mortality rate for caribou calves was approximately 20%, of which the primary cause was comparable between black bears and other all other causes (Table 5.8). These results are reinforced by other studies investigating the impact of bear predation on neonates. Pinard et al. (2012) reported that in the Laurentides Wildlife Reserve region of Québec ≤94% of all predatory-related mortalities of caribou neonates in the first 50 days of their lives were caused by bears. Further, Leclerc, Dussault, and St-Laurent (2014) reported that black bear predation accounted for 52% of caribou calf deaths in the Charlevoix and Saguenay regions of Québec.

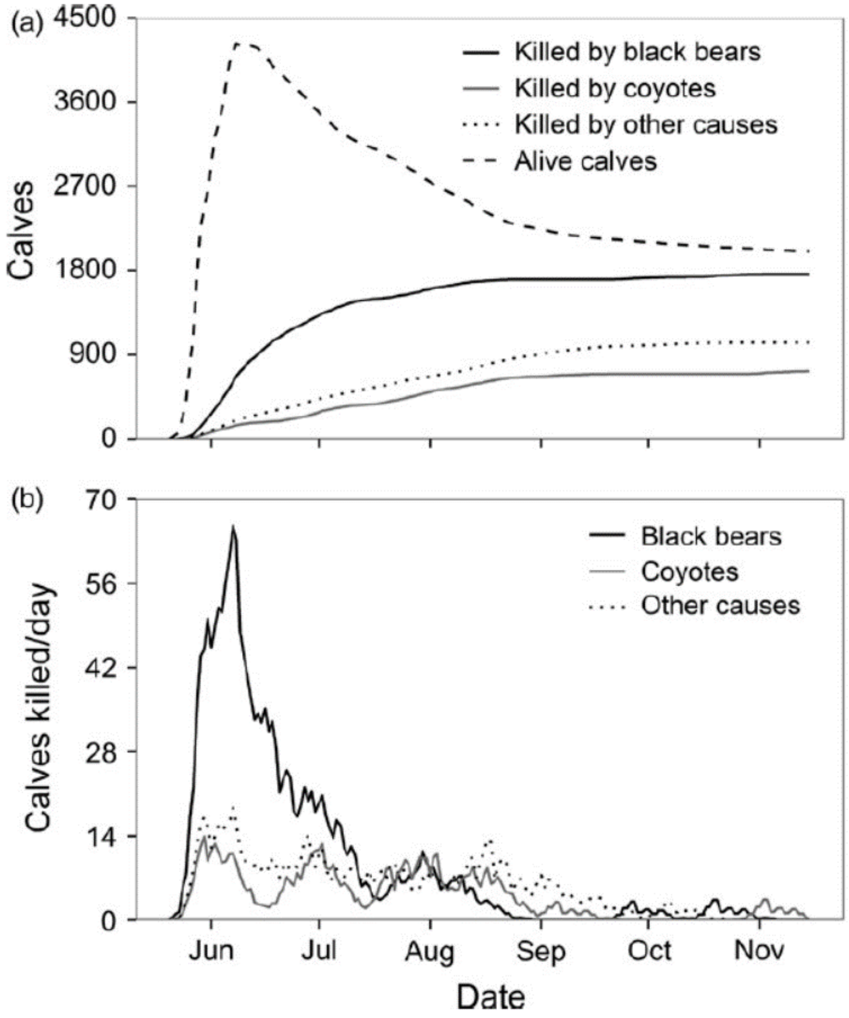

Figure 5.10. Estimated Daily Cumulative Number of Caribou Calves Killed by Black Bears, Coyotes, and Other Causes and Estimated Daily Number of Alive Calves (a); and Estimated Daily Number of Caribou Calves from Middle Ridge North Killed by Black Bears, Coyotes, and Other Causes (b), Newfoundland, 2003 to 2013 [from Rayl et al. 2018]

Table 5.8. Summary of Survival Monitoring of Neonatal Caribou, Newfoundland, 1979 to 2013

Subpopulation (Range)	Years Monitored	Population Peak Year	Cause of Mortality (%)			
			Black Bear	Coyote	Other	n[a]
Corner Brook Lakes	1994-1997	1998	10.87	0.00	4.35	46
Gaff Topsails	2003-2004	1996	2.08	18.75	43.75	48
Grey River	1979-1992	1991	7.31	0.00	9.59	219
Gros Morne	1993-1996	1998	19.12	0.00	13.25	68
Lapoile	1985-2012	1988	10.69	17.72	17.93	290
Middle Ridge	1983-2013	1995	23.35	16.15	16.54	514
Mount Peyton	1993-2003	1996	15.79	0.00	21.05	19
Northern Peninsula	2008-2012	1996	13.79	11.03	17.24	145
Pot Hill	1980-1982	1998	0.00	0.00	28.57	14
Sandy Lake	1982-1984	1998	4.76	0.00	14.29	21

[from Bastille-Rousseau, Schaefer, et al. 2016]

[a] number of collared neonates

Bears are highly opportunistic omnivores that consume a wide variety of plants, insects, and animals and take advantage of clustered food resources during spring and fall pulses (Welch et al. 1997; Brodeur et al. 2008; Mosnier, Ouellet, and Courtois 2008). Further, bears frequently switch across multiple trophic levels depending on the availability and abundance of vegetation and other food resources (Nielsen et al. 2010; Bastille-Rousseau et al. 2011). Bear diets vary considerably across regions and can be influenced by season, sex, age, life-history stage, and reproductive status (Bacon and Burghardt 1983; McDonald and Fuller 2005) (Figure 5.11). Caribou calves may provide an important source of protein for bears; however, ungulate availability does not typically limit growth in bear populations when other food sources are available (Schindler 2018). Gut analysis of black bears and grizzly bears conducted by Merkle et al. (2017) found that black bear diets in early summer consisted primarily of vegetation (43%), moose (31%), and to a lesser extent caribou (12%), but shifted to mostly vegetation in late summer. Similar proportions were found for grizzly bears in early summer; however, their dietary composition was constant throughout summer.

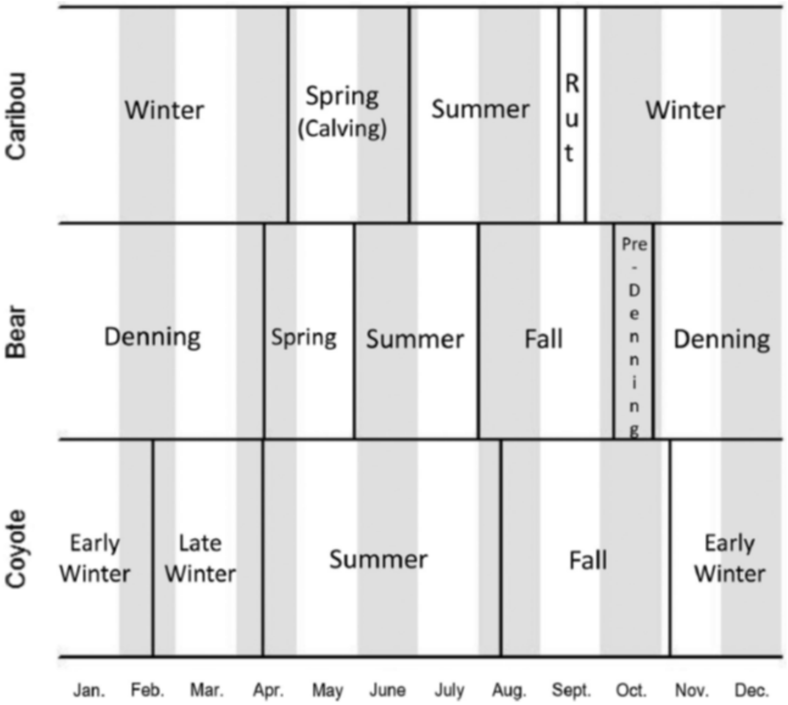

Figure 5.11. Geographical Representation of Biological Seasons for Woodland Caribou, Black Bears, and Coyotes on Insular Newfoundland: shading indicates months of the year [from Bastille-Rousseau, Rayl, et al. 2016]

It remains unclear whether bears actively hunt neonates (Rayl et al. 2018) or if they are merely feeding opportunistically (Ballard 1994; Kinley and Apps 2001; Bastille-Rousseau et al. 2011), driven by site-specific factors (e.g., alternative prey, forage abundance and quality, disturbance) (Faille et al. 2010; Pinard et al. 2012). Regardless of the reasons, bears can significantly influence the ability of woodland caribou populations to recover within some of their subpopulations (Wittmer, Sinclair, and McLellan 2005; Pinard et al. 2012). McLoughlin et al. (2019) stated that there is no evidence thus far that predation pressure imposed by bears is regulating caribou populations, noting that the predation rate is more a function of relative bear density and than that of caribou. Habitat selection generally differs between bears and caribou; black bears select for rivers and streams, well-drained upland mixed-wood forests, and anthropogenic features, while caribou select for bogs and fens and avoid anthropogenic features (Latham, Latham, McCutchen et al. 2011). There are few empirical population studies for bears in North America, and much of the available information concerning habitat use and response to disturbance is dated (Schindler 2018).

5.4.3 *Other Predators*

Additional predators and scavengers of woodland caribou include coyotes (*C. latrans*), cougars (*Puma concolor*), lynx (*Lynx canadensis*), wolverines (*Gulo gulo*), and eagles (bald eagle [*Haliaeetus leucocephalus*] and golden eagle [*Aquila chrysaetos*]) (Bergerud 1974; Gustine 2005; COSEWIC 2014a, 2014b; Scrafford and Boyce 2015). Coyotes are the best studied of these other predators. They share similar hunting styles to those of their canine counterparts, where they chase their prey (Murray et al. 1995) rather than ambush it like bears (Zager and Beecham 2006). Much of the research conducted on caribou neonate predation by coyotes has occurred on the island of Newfoundland (Mumma et al. 2014; Bastille-Rousseau, Rayl, et al. 2016; Bastille-Rousseau, Schaefer, et al. 2016; Mahoney et al. 2016; Bastille-Rousseau et al. 2017). A relatively recent addition to the fauna of Newfoundland, coyotes have contributed to the island-wide decline of caribou (McGrath 2004; Bastille-Rousseau et al. 2017). Coyotes killed about one-third of all neonatal caribou from 1979 to 2013 (Bastille-Rousseau, Schaefer, et al. 2016). There is some concern, but little empirical support, that with increased rates of disturbance and the subsequent influx of early seral forage (Crête and Desrosiers 1995) an expansion of coyote range will further exacerbate caribou decline. For example, Latham et al. (2013) analyzed coyote scat in Northeastern Alberta and found that caribou were uncommon (<1.0%) in their diet, but coyotes did tend to select for the same habitats as caribou during the calving season. Similarly, a low occurrence of caribou within the coyote diet was also found in the Atlantic-Gaspésie population, where Boisjoly, Ouellet, and Courtois (2010) found no evidence of caribou in any coyote fecal samples (n=100) in their study area. However, they did find that 4% of 50 additional samples collected at 700 m in the Mount Logan sector of their study contained caribou remains, compared with moose at 73%, hare at 18%, and berries at 4%. While the authors did not find an overlap between coyotes and caribou calving grounds in their study, they indicated that increases in early seral vegetation communities facilitated coyote range expansion and would increase predation risk in the future.

5.4.4 *Caribou Response to Predation*

The consensus among caribou research biologists is that woodland caribou reduce their risk of predation by spacing out from predators, other caribou, and alternative prey by selecting for old-growth forests and peatlands (Table 5.9). These habitats evidently are avoided by wolves and other ungulates and thus may represent safer habitats.

The landscape-of-fear model (i.e., the predation risk allocation hypothesis) proposes that natural landscapes can be viewed as heterogeneous matrices composed of patches of habitat with varying forage quality/quantity and predation risk (Brown 1999; Laundré, Hernandez, and Altendorf 2001). In any given environment, animals must cope with the costs and benefits associated with environmental variability by deciding between resource acquisition and mortality risk (Lima and Dill 1990). Because one mechanism of dealing with predation for caribou is to spatially separate from other ungulates (and each other, Table 5.9), caribou may sacrifice nutrition, body condition, reproduction, and increased vulnerability to predation (Section 2.4, Diet and Nutrition). To help address nutritional demands, caribou may select for patches at very fine spatiotemporal scales (e.g., selecting poor habitats during the day vs. good habitat at night) (Briand et al. 2009; Mayor et al. 2009; Leblond, Dussault, and Ouellet. 2010). Ultimately, prey species such as caribou are under constant pressure to balance nutritional requirements and the risk of predation across their range, where the balance can be tipped at any time by outside contributing factors (e.g., alternate prey, new disturbance, climate change).

Table 5.9. Primary Caribou Tactics to Reduce Rates of Predation

	Tactics to Reduce:		
	Encounter Rate	Detection Rate	Capture Rate
Migratory Caribou, Aggregated (spaced away)	Migrate away from predators and alternative prey, including non-calving caribou; remain mobile	Calve on brown substrates, spaced out briefly at parturition	Share risk and vigilance plus swarming, long flushes
Woodland Caribou, Dispersed in Open (spaced out)	Space away from travel routes of wolves and alternative prey, remain sedentary	Calve on brown substrates, spaced out; remain upwind of predator routes	Remain vigilant for long lead time, flee uphill
Woodland Caribou, Dispersed in Forest (spaced out)	Shift to habitats with low numbers of predators and alternative prey, remain sedentary	Give birth spaced out in forest cover	Use cover and predator obstacles, water barriers

[from Bergerud and Page 1987]

What is poorly understood about such tradeoffs is the extent to which the magnitude of the sacrifice reflects the nutritional adequacy of the range occupied by caribou. If nutritional resources are quite good and generally satisfy caribou requirements, the tradeoff will be trivial. If, however, nutritional resources are usually inadequate relative to requirements, decisions regarding predator avoidance vs. sacrificing nutrition may have substantial implications for body condition, reproduction, and vulnerability to predation and disease (Cook et al. 2018). Virtually no work has been conducted to determine the nutritional adequacy of landscapes occupied by woodland caribou. In addition, the landscape-of-fear hypothesis explaining distributions of ungulate prey in North America remains poorly tested and generally controversial. Considerable evidence supporting the hypothesis arose from elk research in Yellowstone National Park (Creel et al. 2005, 2007; Creel and Christensen 2009; Creel, Winnie, and Christianson 2009). However, conclusions from that work are controversial, remain unverified, and evidently are largely discredited (White et al. 2009, 2011; Kauffman, Brodie, and Jules 2010; Boonstra 2013; Middle et al. 2013). Rigorous testing regarding its relevancy for woodland caribou is needed.

5.4.5 *Apparent Competition*

The primary mechanism argued to explain the decline of woodland caribou is based on the apparent competition hypothesis (Holt 1977). In short, disturbances create early seral forests, which in turn increase the abundance and quality of forage (i.e., deciduous shrubs) preferred by caribou and alternative prey species (e.g., moose and deer). With the influx of prey species, predators (e.g., wolves, coyotes, bears) respond numerically to the increased densities in prey and the encounter rate and risk of predation on caribou increases (Figure 5.12) (see McLoughlin et al. 2019 for a review of this topic). In addition, this leads to a negative correlation between the abundance of the two prey species as well as between their population growth trajectories. This theory was adopted by Bergerud and Elliot (1986) to help explain predator-prey dynamics between wolves, moose, and mountain caribou, where predation on calves evidently was driven by increases in moose biomass, elevated wolf populations, and higher incidental mortality of neonatal caribou.

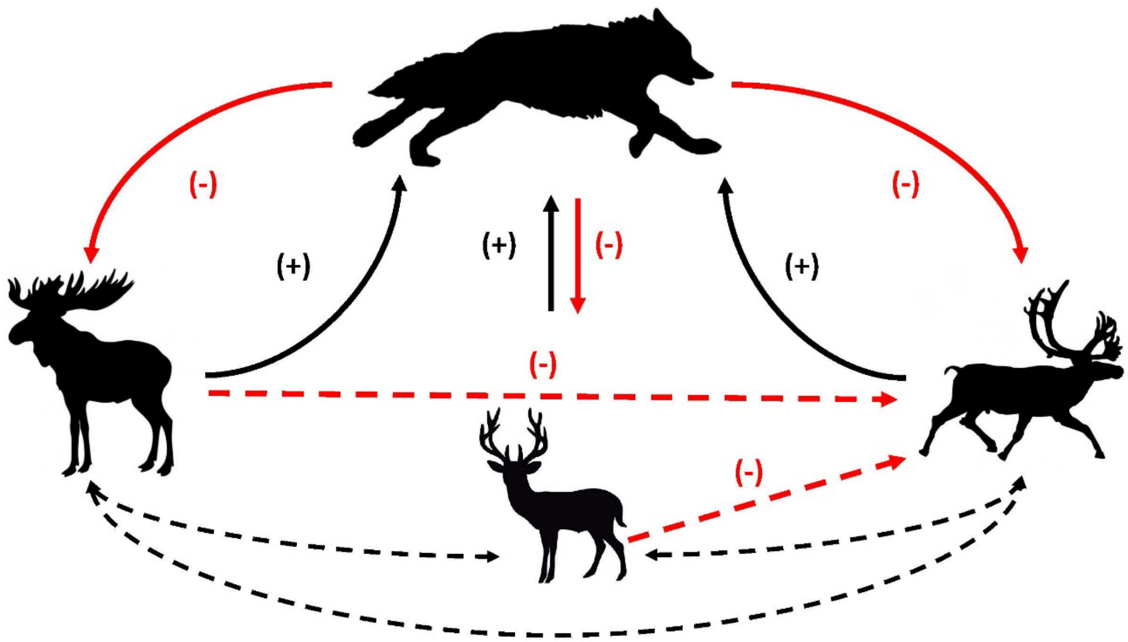

Figure 5.12. Food Web Schematic Depicting Direct (solid line) and Indirect (dashed line) Interactions Characteristic of Apparent Competition Dynamics between Wolves, Moose, Deer, and Caribou: (+) indicates increase, (-) indicates decrease in abundance

After decades of research investigating linkages between disturbance (anthropogenic or natural), increases in predator numbers, and abundances of alternative ungulate prey, habitat-mediated apparent competition has led to near consensus among caribou researchers (McLoughlin, Dunford, and Boutin 2005; Wittmer et al. 2007; DeCesare et al. 2010; Hervieux et al. 2013;Serrouya et al. 2015; Fryxell et al. 2020).

Apparent competition within much of the woodland caribou range typically involves wolves as the primary predator, with moose and, in Alberta, white-tailed deer (*O. virginianus*) as the primary alternative prey species. Warmer winters and creation of early seral forests may be extending and increasing abundance of deer across much of the boreal forests of Canada (i.e., habitat-mediated apparent competition) (Dawe 2011; Latham et al. 2013). Latham, Latham, McCutchen et al. (2011) found that deer have increased 17.5-fold in northeastern Alberta since the mid-1990s, and have replaced moose as the primary prey species. There is some evidence in these regions that caribou have consequently increased in wolf diets since the mid-1990s (Latham, Latham, McCutchen et al. 2011; Latham et al. 2013). Increased densities of alternative prey may further contribute to the decline of caribou where spatial overlap of species ranges occurs. Further, habitat-mediated apparent competition is argued as the principal mechanism with respect to anthropogenic disturbance (e.g., Ehlers, Johnson, and Seip 2016; Hornseth and Rempel 2016), and recent efforts with experimental reductions of alternative prey to reduce wolf densities have been shown to stabilize specific populations of mountain caribou (Serrouya et al. 2017, 2019). On the other hand, there is some evidence that wolf movement and densities may not respond to disturbances. McLoughlin et al. (2019) showed a potential decoupling between how alternative prey respond to a disturbance in Saskatchewan, where they suggest that the alternative-prey hypothesis should not be universally applied across the woodland caribou range to describe the causal effects of caribou decline and that additional site- and region-specific factors must be considered.

5.5 Natural Disturbances

5.5.1 *Fire*

Forest fire is one of the principal natural disturbance agents within the boreal forest and is known to drive dynamics of this ecosystem (Bergeron et al. 2001, 2002, 2004; Flannigan et al. 2005). In general, fire return intervals are shorter in western Canada than in the East (Bergeron et al. 2001; COSEWIC 2014a, 2014b). For example, the boreal shield region of Saskatchewan has a return interval of approximately 70 years, while fire return intervals can vary from 100 to 500 years in Québec (Bouchard, Pothier, and Gauthier 2008). Fire has historically played a role in the distribution and size of woodland caribou populations (Thomas and Gray 2002; Environment Canada 2012b), where caribou are believed to be adapted to the traditional fire cycle occurring on the landscape, but their response can be highly variable due to site-specific factors and the characteristics of the fire (e.g., extent, intensity, and return intervals, types of habitats burned) (Klein 1982; Boulanger, Gauthier, and Burton 2014; Mansuy et al. 2014). According to the federal recovery strategy for the boreal population of woodland caribou (Environment Canada 2012b), fire disturbance (defined as previously-burned areas ≤40 years of age) attributed to 17% of burned area within the boreal caribou range in 2012 on average, increasing to 19% five years later (ECCC 2017, Table 12). Overall, the proportion of area disturbed by fire was highest in provinces in western Canada (Alberta 30.5%, Saskatchewan 44.0%) and lowest in the coastal provinces (British Columbia 7.2%, Newfoundland 7.0%). In recent decades the largest fire on boreal caribou range was the Richardson fire that burned 700,000 ha in 2011 in Alberta, although this palls in comparison to the nearby Chinchaga fire that burned ~1.5 million ha along the Alberta-British Columbia border north of Fort St. John in 1950.

Natural disturbance may negatively affect caribou when it reduces the abundance of lichen or if alternative foraging habitat is not available (e.g., Faille et al. 2010). Negative impacts of fire on caribou populations are believed by some to be overemphasized (e.g., Bergerud 1974), in that caribou have probably developed interdependencies and possible interactions with fire (Skatter et al. 2017). For example, woodland caribou subpopulations in Manitoba did not experience increased cortisol concentrations (i.e., stress hormones) in response to any of the post-fire categories considered (recent, 0 to 5 years; old, 6 to 21 years; regenerating, 22 to 41 years). In other words, caribou did not perceive fire as a chronic stressor (Ewacha et al. 2017). Overall, the influence of fire on caribou has garnered much less attention than anthropogenic disturbances (McLoughlin et al. 2019), and fire has been identified as either a “low,” “negligible,” or “unknown” threat to woodland caribou (Table 5.1). Caribou are believed to avoid stands in the initial post-fire decades; in general, those that are less than 60 years of age (Schaefer and Pruitt 1991; Dunford et al. 2006). However, post-fire vegetation abundance, composition, and structure are inordinately variable and highly dynamic over the first several decades after fire, and it is logical that caribou responses to fire would be similarly variable (Eberhart and Woodard 1987; Johnson, Ehlers, and Seip 2015; Kansas et al. 2016; Mumma et al. 2018).

Fire influences habitat quality (Coxson and Marsh 2001; Dunford et al. 2006; Dalerum, Boutin, and Dunford 2007); however, it remains largely unknown how fire and forage availability influence caribou demographics. In the short term, fire can alter habitat quality by reducing or removing terrestrial and arboreal lichen (Klein 1982; Schaefer and Pruitt 1991; Dunford et al. 2006; Barrier and Johnson 2012; Lafleur et al. 2016). Eventually, lichen regenerate in post-fire disturbed areas through succession (Morneau and Payette 1989), and fire may be needed over longer-term periods to maintain and improve forest conditions by returning old-growth forests to stands that generate lichen (Klein 1982; Coxon and Marsh 2001; Sulyma and Coxon 2001), particularly within sites where mosses have outcompeted lichen in the understory (Culling and Cichowski 2017). Schaefer and Pruitt (1991) found that caribou continued to use remnant lichen patches in unburned residual patches within young burns. Accumulated deadfall of fire-killed trees also may impede movement and discourage use by caribou (Schaefer and Pruitt 1991) and may support greater snow depths in winter that also impede movement and access to lichen (Schaefer and Pruitt 1991; Metsaranta and Mallory 2007; Seip and Jones 2008). Younger burns can have higher densities of early successional trees regenerating, which some authors have theorized may act to obstruct predator detection by caribou and increase their risk to predation (Pinard et al. 2012; Kansas, Charlebois, and Skatter 2015). Further, the influx of early successional forage may enhance habitat conditions and attract alternative prey for wolves (Maier et al. 2005; Courtois et al. 2007; Latham, Latham, McCutchen et al. 2011; Dussault et al. 2012). Kansas et al. (2016), using LANDSAT for fire mapping, reported that the federal recovery strategy overestimated the area burned in northern Saskatchewan by more than 25% because it failed to account for unburned residuals found within the burned area. Fires often leave unburned patches within burned areas (Eberhart and Woodard 1987) that may provide foraging sites and refuge for caribou from predators (Mumma et al. 2018). It has generally been assumed that fire might also influence predation risk through apparent competition, but that remains to be tested (McLoughlin et al. 2019).

Studies document that caribou response to fire varies among ranges and sites. For example, in the South Peace Region of British Columbia, Johnson, Ehlers, and Seip (2015) found that caribou showed affinity for burned areas in two of the four ranges studied, avoided burned areas in summer exclusively, and in one range avoided burned areas by up to 8 km (Table 5.3). These findings highlight that selection for burned areas is probably driven at the range scale, where other habitat characteristics are also in play. Culling et al. (2006) found that boreal caribou actively selected for burned habitats (<50 years) during snow-free months, where highest use occurred in fall and early winter, a response also found within older burned areas (>50 years). Darby and Pruitt (1984) reported that caribou selected for burned areas in southeastern Manitoba. Lafontaine et al. (2019) found that caribou similarly selected for younger burns (0 to 5 years) but tended to avoid older burns (6 to 20 years). Further, they found that historical exposure to burned areas modulated the behavioural response of caribou to contemporary burned areas (<20 years), where caribou that had previously been exposed to burned areas generally avoided recently (<5 years) burned areas, while caribou that inhabited areas that previously were not burned selected for them. The authors called these caribou "naïve," theorizing that caribou only develop cues for dealing with a particular disturbance if they have been exposed to it in the past. Caribou use of burned areas may vary depending on the intensity and extent of the fire, where sufficient range size can provide adequate habitat regardless of the disturbance. For example, Dalerum, Boutin, and Dunford (2007) found that despite having over three-quarters of their home range burned, caribou experienced no change in use of the same home range area in the year following fire; a finding supporting Lafontaine et al. (2019).

5.5.2 *Parasites, Disease, and Insects*

As populations of caribou continue to decline across much of the species range, scientists are evaluating the role that parasites, disease, and insects may play in contributing to that decline and the overall health status of woodland caribou (e.g., Klein 1991; Albon et al. 2002). These factors have been recognized as important drivers of caribou health status and are known to influence the reproductive capacity of many other ungulate species (e.g., deer, moose, muskoxen) across much of the northern latitudes (Gunn and Irvine 2003; Kutz et al. 2012; Schwantje et al. 2014). Although there have been a limited number of studies (Section 6, Caribou Research), empirical evidence shows that parasites, disease, and insects may influence caribou body condition, reproductive capacity, and habitat use, and in some severe cases can cause death (see reviews by Kutz et al. 2012, 2014). Furthermore, as Johnson et al. (2010) pointed out, even the simplest health indicators (e.g., serum biochemistry analytes) are not well understood for woodland caribou, which significantly inhibits the ability to control and manage for diseases and parasites. This section reviews the prominent parasites, diseases, and insects that are known to impact *Rangifer* spp. at the species level.

Parasites

Parasites are dependent on host animals for either a portion or the entirety of their life, during which they acquire food either directly or at the expense of their host. Many species of parasite have been identified for caribou (Table 5.10), so many that caribou are believed to have more specialized forms of parasites than any other large ungulate species (Kutz et al. 2012; Jenkins et al. 2013). Because of their close genetic lineages and often similar use of habitat, the presence of other ungulate species can exacerbate the presence of additional parasites (e.g., white-tailed deer and moose in proximity with caribou could facilitate transmission of meningeal worm or brainworm (*Parelaphostrongylus tenuis*) (Anderson 1972; Trainer 1973; Anderson and May 1978). Ultimately, the relative impact a given parasite may have on an individual animal will be highly variable and is influenced by a number of contributing factors (e.g., body condition, climate, region, habitat), which makes it challenging to isolate the severity of a single parasite. That said, parasites have been documented to have a range of severities, from being a minor nuisance to weakening an animal to the point that it becomes more susceptible to other parasites or environmental stressors (e.g., predation), and in the most extreme case, to directly causing death (Hughes et al. 2009; Schwantje et al. 2014).

As outlined in Section 2.5 herein, caribou build up reserves prior to winter as a means of enduring the long, cold winters of the northern latitudes. Developing these reserves, ensuring their survival, and achieving successful reproduction may be hindered if they are infected with parasites (Thomas 1982; Gerhart et al. 1996; Hughes et al. 2009). Parasites can have a particularly high impact on smaller populations and can lead to a higher risk of stochastic events or allee effects that may accelerate declines (De Castro and Bolker 2005). For example, it is suspected that the parasite *Teladorsagia boreoarcticus* contributed to the decline of the now-extirpated Banff caribou subpopulation (De Bruyn 2010).

Nematoda

Nematoda (roundworms) are small, slender worms known to parasitize caribou via the gastrointestinal tract or within the lungs or tissues. The gastrointestinal nematode fauna in woodland caribou can only be identified through fecal examination, contributing to the difficulty in differentiating among species of roundworms and thus the relative impact on an individual animal (Johnson et al. 2010; Kutz et al. 2012). The severity of nematodes infestation is generally based on fecal egg count; however, this measure requires an intimate understanding of host-parasite dynamics, and the ability to identify the signs of infestation is limited (Kutz et al. 2012; Turgeon et al. 2018). A number of gastrointestinal nematoda have, however, been identified in caribou (Table 5.10). *Ostertagia gruehneri* and *Marshallagia marshalli* are the most common (Dallas, Irvine, and Halvorsen 2000). Parasitism from *M. marshalli* has been shown to affect body condition of the host and pregnancy rates (a decline of 5 to 14% in infected animals) (Albon et al. 2002; Stien et al. 2002). Caribou also have some host-specific nematoda (e.g., *T. boreoarcticus*) that are absent in other ungulate species (Hoar et al. 2009). Like many other species, nematoda can be region- or subpopulation-specific. For example, the Atlantic-Gaspésie caribou population have *Trichuris* spp. and *Capillaria* spp. (Turgeon et al. 2018), both of which are uncommon in other populations of caribou (Kutz et al. 2012).

Nematoda from the families Metasrongylina and Spirurina are the most threatening variety of tissue-specific parasites for caribou (Kutz 2007). The prominent genus of nematode, *Parelaphostrongylus*, has been identified as a risk to woodland caribou populations, where a high prevalence (56%) occurs in younger animals (<3 years old) and may impact future recruitment rates (Lankester and Hauta 1989). Prevalence across populations can be highly variable. For example, Turgeon et al. (2018) found that the Atlantic-Gaspésie population had relatively low rates of nematode occurrence (9 to 15%).

Table 5.10. Known Types of Parasites that Affect Caribou in North America

Type of Parasite	Nematoda (Roundworms)		Cestoda (Flatworms)	Trematoda (Flukes)	Protozoa		Arthropod Ectoparasites
	Enteric	Tissue			Gastrointestinal	Tissue	
Species	*Ostertagia gruehneri* *Teladorsagia boreoarcticus* *Marshallagia* cf. *marshalli* *Nematodirella longissimespiculata* *Nematodirus tarandi* *Skrjabinema tarandi* *Trichuris* spp.	*Dictyocaulus* spp. *Parelaphostrongylus andersoni* *Parelaphostrongylus odocoilei* *Varestrongylus* spp. nov. *Setaria* spp. *Setaria yehi* *Onchocerca cervipedis*	*Taenia hydatigena* *Taenia krabbei* *Echinococcus granulosus* *Avitellina arctica*	*Fascioloides magna* *Paramphistomum* spp.	*Giardia* sp. *Cryptosporidium* spp. *Eimeria* spp.	*Besnoitia tarandi* *Neospora caninum* *Sarcocystis* spp. *Toxoplasma gondii* *Trypanosoma* spp.	*Cephenemyia trompe* *Hypoderma tarandi* *Melophagus ovinus* *Bovicola tarandi* *Solenoptes tarandi* *Chorioptes texanus* *Dermacentor albipictus* *Linguatula arctica* *Tabanus* spp.

[adapted from Kutz et al. 2012]
Some parasites identified may be specific to barren-ground caribou

Cestoda, Trematoda, and Protozoa

Several species of tapeworms (Cestoda) parasitize caribou (Table 5.10). In general, tapeworms begin their lifecycle in an immature form that hatches from an egg in the host and forms into a cyst on either an organ or a muscle. The cyst can be directly transferred to a new host when the infected portion of the animal is consumed through predation or scavenging. Cysts then hatch into tapeworms in the stomach of the new host. Once fully developed, the tapeworm produces eggs that are passed through excrement and then passively transmitted to the new host via ingestion of contaminated forage , thus completing the cycle. Little empirical data exist regarding these types of parasites in caribou, but infected animals are reported to have lethargic behaviour and emaciation in both adults and their young (Kutz et al. 2012). *Echinococcus granulosus*, a complex of taeniid, is the cestode responsible for a cystic hydatid disease that impacts humans (Kutz et al. 2012).

Trematoda fauna (liver flukes) are limited in caribou, with only two types identified: *Fascioloïdes magna* (giant liver fluke) and *Paramphistomum cervi* (rumen fluke). Both require an aquatic medium for transmission–typically through an intermediate host (Lymnaeidae snails) (Kutz et al. 2012). *F. magna* overwinter in snails, their intermediate host, where their development is temperature dependent (Pybus 2001; Kutz et al. 2012). Infected snails are usually accidentally consumed by caribou, and the parasite larva enters the body through the endothelium of the gastrointestinal tract. Liver fluke parasitism in caribou can cause damage to the liver, where lesions are produced that can create copious amounts of viscous grey-brown-black fluid that can lead to blood pooling in the animal (Lankester and Luttich 1988). Although liver flukes can cause internal damage to caribou, few tell-tale signs exist to identify infected caribou hosts. However, their impact is intensified with the age of the animal (Lankester and Luttich 1988). The occurrence of liver flukes in caribou populations is considered patchy (Kutz et al. 2012) but widespread in western Canada, with expansion via natural migration or translocation of infected individuals (Pybus 2001).

The rumen fluke is a pear-shaped worm characterized by a large ventral sucker (Kutz et al. 2012). The lifecycle of the liver fluke begins as miracidia (ciliated, nonfeeding larva) that develop eggs that hatch and infect aquatic snails and then develop into cercaria (free-swimming larva). This process is thermally regulated (>13°C), generally occurring during the non-winter months (Kutz et al 2012); however, infected snails can shed cercaria for upwards of a year (Dinnik and Dinnik 1957). As with other parasites, little is known about the impact on caribou. Clinical signs are difficult to identify, but juvenile parasites in the small intestine have been known to cause severe bouts of diarrhea (de Waal 2010).

Protozoa are primitive, single-celled organisms that can play a role in the health status of caribou. These types of parasites can cover a wide array of gastrointestinal and tissue-specific species, and while many are present in caribou, the prevalence of gastrointestinal protozoa (e.g., *Giardia* spp., *Cryptosporidum* spp.) is relatively low (<12%) (Kutz et al. 2012; Jenkins et al. 2013). The most familiar protozoan species for caribou is probably *Cryptosporidum*, which is also responsible for the disease known as cryptosporidiosis or “crypto” in humans. This disease affects the distal small intestine and respiratory tracts, resulting in watery diarrhea and often a persistent cough (Fayer, Santín, and Macarisin 2010). A common and widespread tissue-specific parasite, *Bensoitia tarandi*, is a cyst-forming parasite commonly located in the skin or soft tissues of caribou (Kutz et al. 2012). Like many other parasites, its transmission remains poorly understood; however, it has been reported in as many as 44% of the studied caribou in Québec and has been identified as the cause of significant declines in survival and reproductive success (Ducrocq et al. 2012). In addition, *B. tarandi* can cause alopecia (hair loss) and weakening of bones and tendons that may impact strength and resistance to predation and other threats (Ducrocq and Lair 2007; Ducrocq et al. 2012). *Neospora caninum*, another tissue-specific protozoan that is predominantly found in canids (i.e., wolves), has been found in 2% of the studied boreal caribou population and can lead to calf abortion and poor calf health overall

(Schwantje et al. 2016). Like *Neospora* spp., *Toxoplasma gondii* can cause fetal abortion and abnormalities, as well as neurological diseases in caribou (Kutz et al. 2012). The actual parasite has not yet been isolated, but it is believed to be transmitted through both felids and canids.

Ectoparasites

Ectoparasites (referred to as insects hereafter) can have a substantial impact on caribou either directly (e.g., sucking blood from the animal) or indirectly (e.g., mountain pine beetle [MPB] destroying caribou habitat). Several insects are known to harass caribou (Table 5.10). Predominantly during the warmer months, these insects can have a substantial influence on how caribou act and use the landscape (Gunn and Skogland 1997; Mörschel and Klein 1997; Vistnes et al. 2008; Raponi et al. 2018), particularly because they can be cued by host odors (Schofield and Brady 1997). Caribou attempt to deter the harassment through a range of avoidance behaviours that include ear flicking, tail wagging, head tossing, shaking, foot stamping, biting, sneezing, kicking, rearing, bucking, lowering the head, running, or any combination of these (Mörschel and Klein 1997; Colman et al. 2003). Insect harassment can influence feeding rate (Colman et al. 2003), body condition, fecundity, and ability to breathe (Helle and Tarvainen 1984; Hagemoen and Reimers 2002; Fauchald et al. 2007; Hughes et al. 2009; Raponi et al. 2018). Helle and Tarvainen (1984) reported that blood loss from insect parasitism could amount to as much as 125 g/day. Under the most extreme cases, insect harassment can even lead directly to caribou death (Helle and Tarvainen 1984).

Flies

The predominant fly species that harass caribou are the nose bot (*Cephenemyia trompe*) and warble (*Hypoderma tarandi*) flies. Both species can cause caribou to expend copious amounts of energy trying to rid themselves of this constant harassment. Caribou respond to harassment from the nose bot fly (host-specific to caribou) by dropping their heads to inhibit deposition of its larvae in their noses (Kutz et al. 2012)–where if they enter, the flies can obstruct breathing, making it particularly difficult when the animal is active or if the climate is warm (Kutz et al. 2012). In general, warble flies lay eggs in the hair, and once the larvae hatch they burrow into the caribou’s skin (the nose bot fly does this under the skin of the nose) and overwinter prior to dispersing as adults in the spring. Similar to other flying insect harassers, temperature, wind, and cloud cover may contribute to their activity and productivity (Heggberget, Gaare, and Ball 2002). Insect activity is significantly reduced when temperatures are cool (<11°C) or windy, and under inclement weather or heavy cloud cover (Anderson and Nilssen 1996; Colman et al. 2003; Weladji, Holand, and Almøy 2003).

Lice

Lice are generally small (<2 mm in length) and highly mobile, and although they chew and feed off the blood of animals, they generally have only a minimal direct effect on caribou (Kutz 2007). Lice can cause skin lesions and hair loss, which in turn may facilitate the attack of other parasitic species (Kutz 2007).

Ticks

Ticks are common parasites of many ungulate species and are predominantly associated with moose and deer but also infect caribou. The magnitude of their impact on caribou is dependent on susceptibility, grooming behaviour, and the intensity of tick-related infection, and thus varies among individuals. In comparison to other ungulate species, with moose having the highest burden, tick loads on caribou tend to be moderate (Samuel and Welch 1991). Attacks from ticks induce an animal to itch and groom. Heavy tick loads lead to dramatic hair loss, and when grooming becomes excessive, wounds may develop and increase the likelihood of infection and exposure to other insects or parasites. No study has shown that caribou have died as a result of tick infestation; however, it has been documented in moose (Allan 2001).

Insect Outbreaks

Insects can also have substantial indirect effects on woodland caribou populations; for example, in the most recent MPB (*Dendroctonus ponderosae* Hopkins, 1902) epidemic of western Canada. Insect outbreaks have historically played a relatively minor role in influencing caribou populations (Culling and Cichowski 2017), but with increased average winter temperatures coupled with prolonged growing seasons, forest insect activity is expected to increase (Price et al. 2013). Over the past two decades, the MPB outbreak in the pine-lichen forest habitat in western Canada has killed (as of 2011) >700 million m^3 of trees spread over 18 million ha of pine forests, representing ~50% of merchantable timber within the managed land base in British Columbia (COSEWIC 2014a). The majority of caribou that are or have been impacted by this outbreak has been confined to the mountain subpopulations but has expanded into those in Alberta (first detected in the Chinchaga range in 2007) (Westfall and Ebata 2015). As MPB expands eastward into the other prairie provinces, there is a rising concern that it may infect jack pine stands further east (Walton et al. 2008; Windmuller-Campione 2018).

Unfortunately, limited research on the impacts of MPB on caribou exists (but see Seip and Jones 2008). There is evidence that arboreal and terrestrial lichen will decline as deciduous shrubs and/or mosses increase as MBP infestation increases (Seip and Jones 2008; Cichowski and Haeussler 2013). Some caribou abandon portions of their range due to canopy dieback from MPB outbreaks (Cichowski and Willisoton 2005). Canopy dieback caused by MPB can be delayed over several years, and thus the extent of the impact on caribou habitat use and selection should also be expected to be delayed. There is some evidence that caribou continue to use post-MPB attack forests for up to eight years (Cichowski 2010; Cichowski and Haeussler 2013), which also coincides with the period (~10 years) required for dwarf shrub abundance to decrease following an outbreak and lichen abundance to begin to stabilize (Culling and Cichowski 2017). Stands infected by MPB may have more and drier fuel loads, which may increase the intensity and hazard to fire (Weber and Flannigan 1997; Page, Jenkins, and Runyon 2012; Page, Jenkins, and Alexander 2014) (e.g., reduced foliar moisture, increased flammability). For example, Perrakis et al. (2014) reported that the rate of fire spread was two to three times greater in MPB affected stands than in unaffected stands in central British Columbia.

Insect outbreaks are not exclusive to western Canada. In eastern Canada, recurring (typically every 30 to 40 years) spruce budworm (*Choristoneura fumiferana* (Clemens)) outbreaks are one of the most important natural disturbances affecting millions of hectares of forest (Blais 1983; Boulanger and Arseneault 2004; MacLean 2004). During a typical outbreak, spruce budworm larvae feed on current-year growth of balsam fir and white spruce (the two main host species), leading to high rates of defoliation that can cause significant declines in vigor and increased mortality of overstory trees (MacLean and Ostaff 1989; Boulanger and Arseneault 2004). By 2017, the current outbreak of spruce budworm in Québec (beginning in 2006) had caused moderate to severe defoliation in over 7 million ha (NRCan 2020) and was occurring farther north than in the past, including occurrences in areas that had not previously been affected by this defoliator (Pureswaran et al. 2015, 2019). Under warming conditions defoliation caused by spruce budworm could begin earlier in the season, which in turn would lead to increased herbivory due to earlier budburst, thus increasing the risk of defoliation to secondary hosts (e.g., black spruce) in the more northern regions of the boreal forest (Pureswaran et al. 2019; Navarro et al. 2020). Little information exists on how caribou and caribou habitat may respond to the current spruce budworm outbreak.

Chronic Wasting Disease

Chronic wasting disease (CWD), a transmissible spongiform encephalopathy of cervids, is increasing across North American (see review by Mysterud and Edmunds 2019). Since first identified in captive deer in Colorado in 1967 (Mitchell et al. 2012), CWD has been detected in several other US states and Canadian provinces, and because of the continued reliance of some hunting communities on the meat of cervids, human health concerns associated with consumption of CWD-infected animals remain (Mitchell et al. 2012). CWD has spread among species and is now present in all classes of North American species, but it has not yet been documented to occur naturally in caribou. It was recently confirmed in reindeer in Norway (Benestad et al. 2016), and experimental trials have confirmed that CWD can be orally transmitted in North American caribou (Mitchell et al. 2012). Cheng et al. (2017) recently evaluated the susceptibility of prion proteins of woodland caribou from nine Albertan subpopulations (including both boreal and mountain populations). They found that the Chinchaga boreal population along the British Columbia-Alberta border had a significantly higher frequency of the 138N allele that has been linked to reduced susceptibility to CWD. Why it confers reduced susceptibility is unknown, but some researchers have postulated that it may be related to the increased genetic diversity of the subpopulation (Robinson et al. 2012; Cheng et al. 2017). CWD is transmitted through peripheral tissues and bodily fluids (Mathiason et al. 2006; John, Schätzl, and Gilch 2013), and is an increasing threat to caribou as their ranges increasingly overlap with moose and deer ranges. No effective treatment or management strategy exists, but containment strategies limit transport of hunter-killed carcasses in both Canada and the US.

5.6 Climate Change

The mean annual temperature is predicted to increase in the boreal forest region by ~2°C by mid-century and ~5°C by 2100 (Price et al. 2013), and more so at higher latitudes (Balshi et al. 2009; Boulanger, Gauthier, and Burton 2014). Increased spring temperature may lengthen growing seasons up to 14 days within the next few decades (Kint et al. 2012; Price et al. 2013). Earlier and warmer spring temperatures will also influence snowmelt, and models have predicted that snowmelt will occur one month earlier by 2050 compared to 1971 to 2000 (Houle et al. 2012). Although heat stress can be mediated to some extent by moisture availability, precipitation and water stress is expected to be spatially variable (Price et al. 2013) and likely to contribute to increased frequency and intensity of drought events, especially in western Canada (Michaelian et al. 2011; Price et al. 2013; Worrall et al. 2013; Loehle and Solarik 2019). In turn, increased drying events are likely to contribute to increased natural disturbances (e.g., fire and insect outbreaks) (Kurz et al. 2008; Flannigan et al. 2013; Boulanger, Gauthier, and Burton 2014). For example, Wang et al. (2017) projected that the fire window (i.e., fire-conducive weather, or favourable conditions for a fire to occur) is expected to increase between 50 and 100% in western boreal regions of Canada and up to 150% elsewhere in Canada. Further, more favourable winter temperatures and fewer prolonged cold periods can increase insect outbreaks, where fewer overwintering mortalities for MPB may occur. Undoubtedly these changes and similar ones are likely to lead to unique forest ecosystem responses to climate change and may lead to emergence of novel ecosystems and feedbacks (Schneider et al. 2016).

Wildlife and plant species have already begun to shift geographic distributions in response to climate change. As a result, novel community and species interactions may be created as changes in colonization and extinctions occur (Parmesan and Yohe 2003; Solarik et al. 2020). Changes in vegetation species and/or snow conditions as a result of climate change could result in rapid contraction of the woodland caribou southern species limit. Although caribou maintain a wide distribution across varying landscapes that has led to differences in behavioural, genetics, adaptivity, and subspecies (Section 3, Distribution), the relative impact of climate change on caribou populations remains unknown (but see Mallory and Boyce 2018).

Climate change is expected to have several direct and indirect effects on caribou at varying scales, which may impact population dynamics. These include changes in habitat use and selection, predator-prey dynamics, forage availability and quality, disturbances (both frequency and intensity), extreme weather events (e.g., icing and wind events), and the prevalence of diseases and parasites (Schneider et al. 2009; Vors and Boyce 2009; Latham, Latham, McCutchen et al. 2011; Pickles et al. 2013; Price et al. 2013; Raffa, Powell, and Townsend 2013). Although considerable research has been undertaken to identify and better understand the relative relationship of individual factors on the continued decline of woodland caribou, responses of caribou to these factors in the context of climate change could change. More recently, there has been increased effort and focus on better predicting the current and future impacts of climate change and its relative impact on caribou (Grayson and Delpech 2005; Sharma, Couturier, and Côté 2009; Yannick et al. 2014; Murray et al. 2015; Masood et al. 2017; Mallory and Boyce 2018).

5.6.1 *Extreme Weather Events and Winter Range*

Warmer winter temperatures coupled with the uncertainty of precipitation events are expected to increase extreme climatic events. These events may hinder caribou mobility and impact energy expended and ability to access forage, which in turn may lower body condition (Kinley et al. 2007; Couturier, Côté, Otto, et al. 2009; Vors and Boyce 2009; Tyler 2010; Hansen et al. 2011). An increase in the frequency of temperatures below freezing may increase snow accumulation or ice formation if temperatures fluctuate above and below the freezing point. Increased ice crusting could increase the vulnerability of caribou to predation, where their heavier bodies make them more prone to breaking through the snow-ice layer and result in slower travel than wolves and other, lighter predators (Schramm et al. 2002). Although caribou tend to select areas with lower snow depth, potentially as a means of reducing energy to access forage, starvation and even death can occur under repeated icing and snow events–something that has been documented historically (Klein 1968). More recent examples in the Arctic have also been recorded in both the Svalbard reindeer and Peary caribou populations (Solberg et al. 2001; Tews, Ferguson, and Fahrig 2007; Langlois et al. 2017). When possible, caribou abandon ranges altogether if unfavourable snow conditions persist. Seip and Jones (2008) reported that caribou abandoned the Kennedy Siding range when the snow became too hard to crater.

5.6.2 *Summer Range*

Caribou summer ranges are likely to experience longer growing seasons, increases in plant productivity, and earlier and more abrupt springs (i.e., faster snowmelt), all of which may positively contribute to improved caribou body condition and reproductive success, particularly around the time of birthing and the neonatal period (Cebrian, Kielland, and Finstad 2008; Mallory and Boyce 2018). On the other hand, warmer temperatures in the summer are also likely to increase insect harassment and parasite and disease prevalence (Kutz et al. 2013), and to reduce forage quality in late summer because forage plants senesce earlier (Hebblewhite, Merrill, and McDermid 2008). Mismatches between peaks in forage quality and peaks in nutritional demands of females and their young calves may result in caribou health declines (i.e., for lactation and juvenile growth) (Parker, Barboza, and Gillingham 2009). Post and Forchhammer (2008) reported this phenomenon with caribou in western Greenland, where a decline in reproductive success occurred because of deviations in the timing of calving and the emergence of forage species. Even if caribou are able to align their calving period with the emergence of forage species, expected changes in abundance and quality of forage available in response to the changes predicted with climate change should influence habitat suitability (Mallory and Boyce 2018).

5.6.3 *Habitat Suitability*

Changes to caribou habitat and its suitability will undoubtedly occur, but where they will occur, to what extent, and in which direction (+/-/unchanged) remain uncertain. Balzter et al. (2014) found that permafrost thawing associated with climate change across the boreal peatlands (permafrost covers approximately 37% of boreal peatlands) has resulted in a 9% loss in the last 40 years, a rate that has tripled since the beginning of the century (e.g., Parker et al. 2000; Price et al. 2013). Although peatlands are believed to be relatively resistant to climate fluctuations because they can maintain large volumes of water (Waddington et al. 2015), shallower peatlands are likely to experience the effects of climate changes first (Kettridge et al. 2015). Widespread vegetation changes are expected to occur over much longer time frames (Mallory and Boyce 2018), but risk will be accelerated with natural or anthropogenic disturbances. For example, landscape-scale drought events in western Canada have led to significant tree mortality that has contributed to changes in many ecosystem processes, causing a shift to earlier seral forest stages (Price et al. 2013; Hogg et al. 2017). Barber et al. (2018) projected that by the year 2080, more than half of the area of the oil sands region in northeastern Alberta may convert from boreal mixed-wood and coniferous forests to grasslands. Potential changes occurring within peatlands are especially crucial for caribou, as these areas are considered critical habitat across much of the woodland caribou range (Section 2.3.1, Habitat Selection).

Overall, habitat suitability is expected to decline significantly across the woodland caribou range. Murray et al. (2015) projected a decline of 51.5% under an A2 global carbon emissions scenario (IPCC 2007, more severe projections), and a 28.7% loss under a B1 global carbon emissions scenario (IPCC 2007, best case scenario) by the year 2080 for caribou across the boreal forest. Similarly, Masood et al. (2017) showed a positive association with caribou decline in western Ontario, where the caribou range is projected to contract by 57 to 100% by 2050 and 59 to 100% by 2070. In addition, they predicted that woodland caribou could be extirpated from Ontario as soon as 2070 if winter temperatures increased by more than 5.6°C (Figure 5.13).

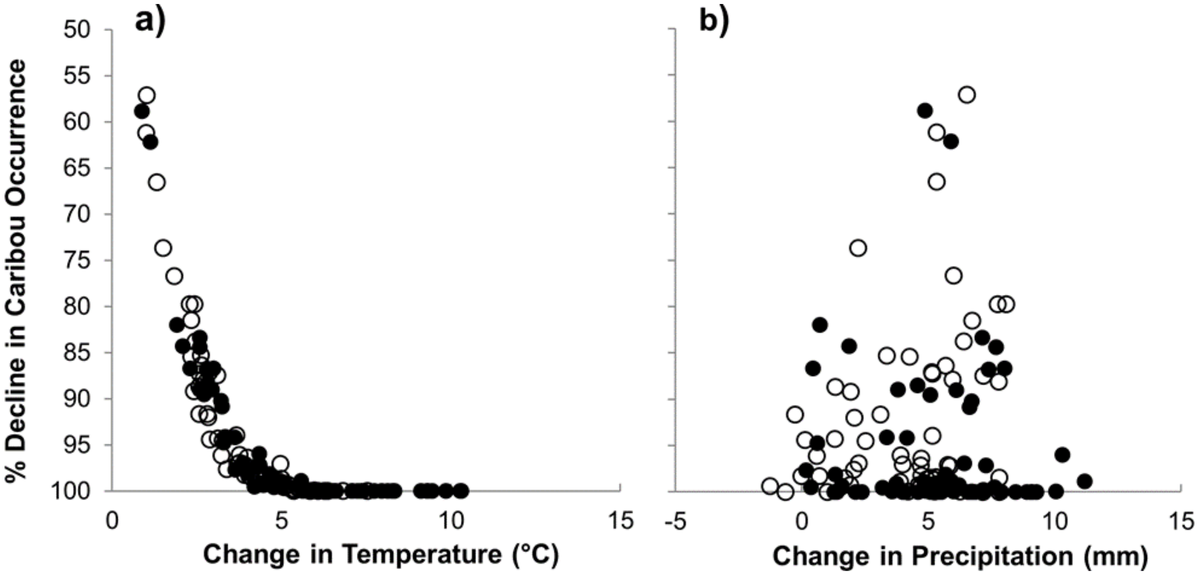

Figure 5.13. Percent Reduction in Range Extent of Caribou with Forecasted Changes in (a) Minimum Winter Temperatures and (b) Annual Precipitation for 2050 (open circles) and 2070 (closed circles) Climate Change Scenarios: each point represents average percent of caribou reduction across all grid cells in Ontario for one General Circulation Model [from Masood et al. 2017]

5.6.4 *Physiological Responses*

Caribou are a cold-adapted species; their thick coat contains insulating semi-hollow hair, they possess a furred muzzle, and they rely on shivering and metabolic thermogenesis to remain warm under colder temperatures (Timisjärvi, Nieminen, and Sippola 1984; Soppela, Nieminen, and Timisjärvi 1986; COSEWIC 2014a). It remains uncertain how well caribou adapt to increasingly warmer conditions associated with climate change. Although some experimental evidence indicates that caribou can tolerate a temperature of 45°C, this was only possible with access to unlimited water (Rosenmann and Morrison 1967). Yousef and Luick (1975) suggested that caribou may be as well adapted to heat as some desert herbivores; however, increasing evidence suggests that caribou are poorly adapted to warmer temperatures. For instance, caribou maintain their dark and insulated coats during the summer season and maintain very few functional sweat glands, making it difficult for them to endure heat stress even under moderately warm temperatures (Soppela et al. 1986). Caribou calves have been documented to sharply increase oxygen consumption and respiration and heart rates when temperatures surpassed 20°C; increases are first detected at temperatures as low as 12°C (Blix and Johnsen 1983; Soppela et al. 1986; Soppela, Nieminen, and Timisjärvi 1986). Heat resistance can be buffered through ingestion of snow, when available, as a means of reducing internal temperatures. Ion and Kershaw (1989) found that peak snow ingestion occurred at approximately 16°C.

5.6.5 *Parasites, Disease, and Insects*

The extent and duration of insect harassment are expected to increase with climate change (Brotton and Wall 1997). For example, Russell (1993) reported that peak mosquito activity correlated with low winds (<6 m/s) and temperatures around 18°C (Figure 5.14). According to Russell’s (1993) energetic model, if climate change were to lead to a warming trend of 2 to 4°C it could cause a 7% decrease in foraging. While mosquito abundance tends to decline at much warmer temperatures (>20°C), other insects (e.g., horse flies, black flies, deer flies) may become significantly more abundant and of greater concern (Raponi et al. 2018). Mörschel (1999) reported that the presence of oestrid flies increased with increasing temperatures up to 30°C, and nasal botflies have been reported to have increased activity under warmer temperatures (20 to 30°C) (Catts 1964). An upper thermal limit does exist for insects. Warbler flies were found to be unable to metabolically cool down in air temperatures of 25 to 38°C (Anderson, Nilssen, and Folstad 1994). Caribou may be able to avoid insect harassment by feeding at night (Downes, Theberge, and Smith 1986), but there remains no documented evidence that feeding at night fully compensates for abbreviated feeding during the day (Colman et al. 2003; Witter et al. 2012). Insect harassment appears to cover the full spectrum of temperatures during the non-winter season, where it is probably not a question of whether caribou will be harassed, but by which insect.

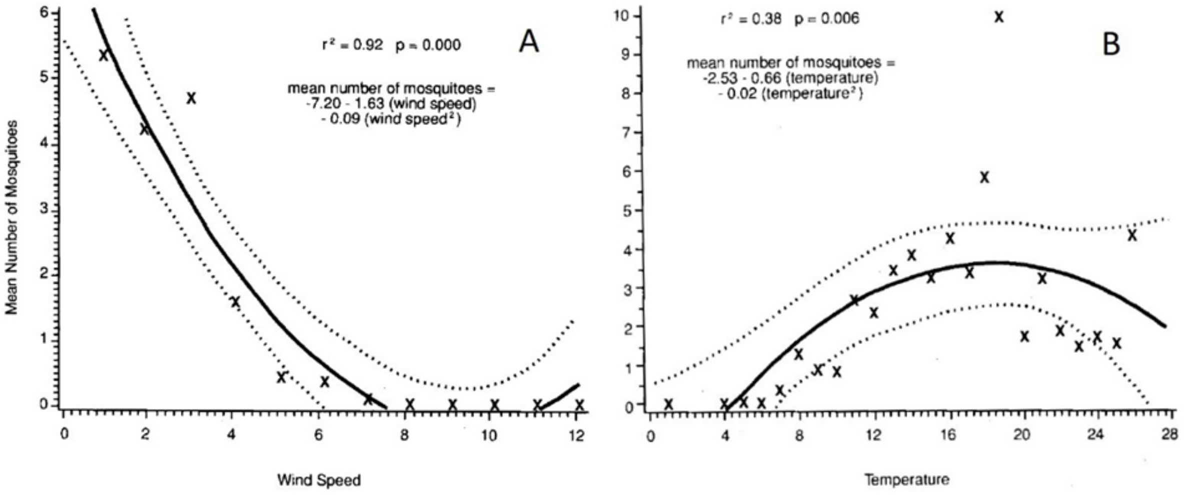

Figure 5.14. Quadratic Regression (95% confidence intervals) of Mean Number of Mosquitoes on (A) Wind Speed (m/s) and (B) Temperature (°C) [from Russell 1993]

Warming temperatures are also expected to impact the distribution, rate of transmission, host-parasite dynamics, and life cycles of pathogens (Kutz et al. 2014; Simard et al. 2016). These changes could increase susceptibility to parasitic infections that may further threaten body condition and the ability to fight off additional pathogens (Bradley et al. 2005; Beldomenico and Begon 2010; Mallory and Boyce 2018).

5.6.6 *Alternate Species*

Climate change may contribute to the recent northward expansion of other ungulate species (Norment, Hall, and Hendricks 1999; Dawe and Boutin 2016). For example, white-tailed deer have extended into boreal caribou ranges into Alberta, where improved winter conditions were considered the primary factor responsible for this expansion (Latham, Latham, McCutchen et al. 2011; Dawe, Bayne, and Boutin 2014). Increased spatial overlap between caribou and other ungulates could facilitate transmission of novel pathogens (Section 5.5.2, Parasites, Disease, and Insects) (Kutz et al. 2009, 2014) and further increase predation risk (Section 5.4, Predation).

6.0 WOODLAND CARIBOU RESEARCH LANDSCAPE, TRENDS, AND FUTURE OPPORTUNITIES

As a means of more successfully managing for conservation of woodland caribou in the future, it is vital to have a clear understanding of current knowledge and information gaps. This can provide guidance for future research and lead to more robust, successful conservation actions. To better understand the research landscape for woodland caribou, an evaluation of the literature was undertaken using methodology developed by NCASI (2007, 2011). This section outlines the search and selection methodology used to compile the synthesis and report on findings, followed by a list of knowledge gaps identified for research on woodland caribou in Canada for the period from 2009 to 2019.

6.1 Search, Selection Criteria, and Methodology

To compile a library of published literature over the decade (2009 to 2019), a keyword search within the title or body of articles was conducted (e.g., "*Rangifer tarandus*," "caribou," "woodland caribou") through Google Scholar and various other scientific databases (e.g., Web of Science and Academic Search Complete). Articles were included in the analysis (and resulting NCASI Woodland Caribou Research Database) if the focus was directly on caribou and/or results/findings of the study directly impacted caribou (e.g., vegetation sampling of lichen within the boreal forest). The analysis only included peer-reviewed articles and excluded the rather voluminous "grey" literature (i.e., industry, environmental consultant, and provincial and federal government reports, as well as graduate student theses). Articles that had not been peer-reviewed may have been included in the previous sections of this report, but they have not been considered in the database and related analysis.

6.1.1 *Research Themes and Keywords*

To maintain consistency with previous NCASI caribou-related reports (NCASI 2007, 2011), one of the following research theme descriptors was assigned to each peer-reviewed article:

(1) Basic Ecology – An article in which the primary research question examined the basic relationship between caribou and the abiotic or biotic environment. Factors of interest may include population demographics, habitat selection, or behaviour.

(2) Disturbance Driven – An article in which the primary research question examined any caribou-related parameter as it directly related to various disturbance factors (e.g., roads and other linear features, forest harvesting, wildfire, insect infestation, sensory disturbance).

(3) Predator/Prey – An article in which the primary research question examined altered or increased predation rates on caribou, the causes of such changes, and the underlying causes of changes to predator/prey dynamics.

(4) Energetics/Nutrition – An article in which the primary research question examined use and availability of forage resources (including vegetation assessments/surveys) and the physiological relationship between individual- and population-level demographics.

(5) Genetic – An article in which the fundamental research question examined genetic information (e.g., genetic diversity, allelic frequency) or methods (e.g., sample capture techniques).

(6) Administrative – An article in which the primary research question examined use of mitigative or best management practices to minimize effects of human activity on caribou, and related effects on the activities of such actions.

In addition to identifying articles by research theme, each article was also assigned the same keyword identifiers that were used in previous NCASI caribou-related reports (NCASI 2007, 2011). However, to improve the classification of a particular article, rather than using a single keyword, up to three keywords were applied, providing a more flexible classification scheme. For example, an article that focused on increased travel rates of predators on linear disturbances would be classified using two keywords: Disturbance and Predators. Thus, up to three keywords were included to further classify the articles:

(1) Traditional Ecological Knowledge – The article wass based on or included knowledge available through aboriginal peoples or local knowledge.

(2) Alternative Prey – The article included dynamics or abundances of other sympatric ungulates (e.g., moose, white-tailed deer) that directly or indirectly influence the caribou population or habitat.

(3) Predators – The article focused on the dynamics and effects of predation on caribou populations.

(4) Population Dynamics – The article included measurements or a model on population metrics such as population growth rates, herd demographics, birth rates, recruitment, survival, and mortality.

(5) Range Dynamics – The article investigated the dynamics of state or area of occurrence or area of caribou occupancy.

(6) Habitat Selection and Use – The article described or modelled current or probable habitat selection or use by caribou individuals or herds.

(7) Genetics – The article had measurements or descriptions of the genetic makeup of caribou populations.

(8) Disturbance – The article investigated impacts of natural (e.g., insect infestation, blowdown, wildfire) or anthropogenic (e.g., harvesting, oil and gas development) disturbances on caribou and caribou landscape/habitat.

(9) Forage – The article investigated the supply and/or dynamics of caribou forage.

6.1.2 *Article-Specific Information*

Article-specific information was collected as a means of providing additional insight into the caribou research landscape. Additional information (when available) is included in the synthesis and database:

(1) Year of publication

(2) Digital Object Identifier (DOI)* – A unique and permanent string of letters and numbers representing the article that allows a user or interested party to find the article wherever it is located on the World Wide Web

(3) Article title*

(4) Principal investigator’s family name*

(5) Principal investigator’s institution or associated organization*

(6) Study years (reviews, opinion pieces, historical, and models are identified as such)

(7) Study duration

(8) Study province(s)

(9) Caribou population (identified by subspecies population or COSEWIC’s DU) studied: Atlantic-Gaspésie, Central Mountain, Northern Mountain, Southern Mountain, and Boreal

(10) COSEWIC’s Caribou Designatable Unit: Newfoundland (DU5), Boreal (DU6), Northern Mountain (DU7), Central Mountain (DU8), Southern Mountain (DU9), and Atlantic-Gaspésie (DU11)

(11) Boreal population range ID (Environment and Climate Change Canada range identification)*

(12) Range name(s)

(13) Number of ranges studied*

(14) Number of caribou studied (or specimens)*

(15) Sex of caribou studied (male, female, calves)*

(16) Type of surveying*

(17) Other species studied (e.g., wolves, bears, etc.)

(18) Number of other species studied

(19) Study method*

(20) Location remeasurement frequency (i.e., collars, telemetry)*

(21) NCASI primary research category (see Section 6.1.1 for description)

(22) Keywords (up to three keywords per publication)

* *Database-specific, not assessed in synthesis due to lack of robustness in reporting methods or significance to overall research trends*

6.2 Research Trends

6.2.1 *Woodland Caribou Research, 2009 to 2019*

A total of 320 peer-reviewed articles on woodland caribou were published over the review period (2009 to 2019). The greatest number of publications in an single year occurred in 2019 (46 publications), while the fewest publications occurred in 2009 (14). The boreal population was most frequently studied within the publications, with 214 occurrences, followed by the Northern Mountain (39) and Newfoundland (31 publications) populations. The least studied population was the Atlantic-Gaspésie (14 publications) (Figure 6.1).

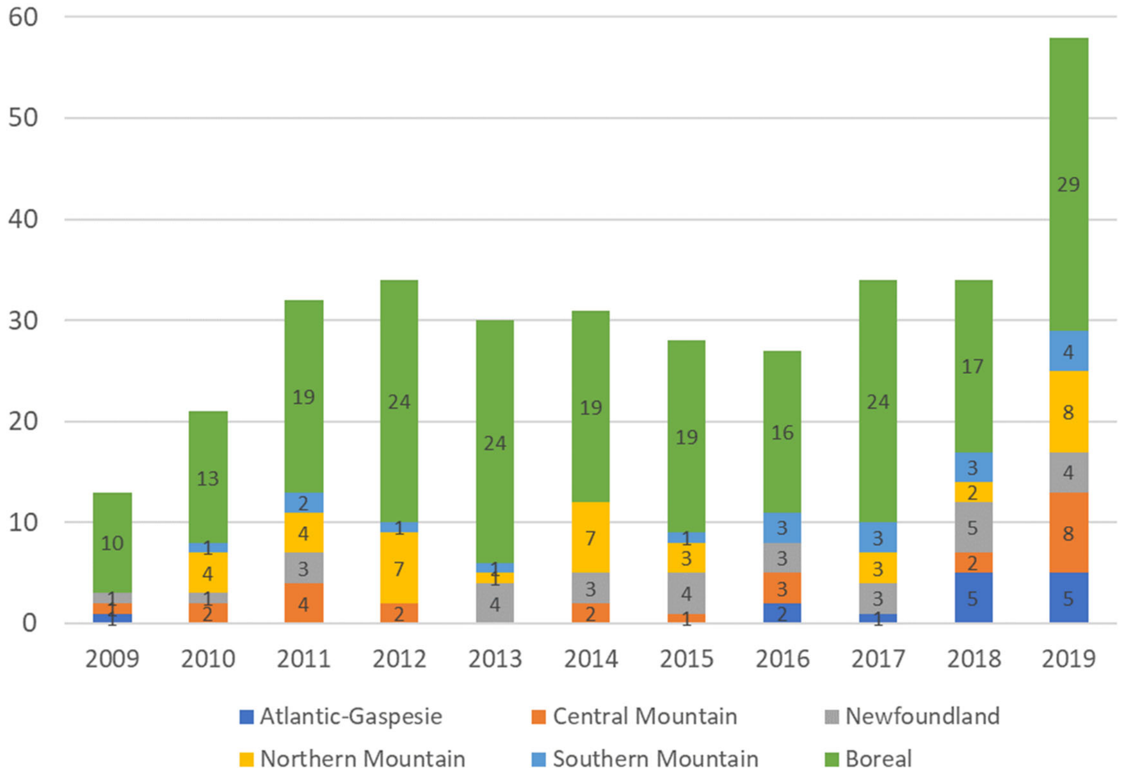

Figure 6.1. Annual Frequency of Woodland Caribou Subpopulation Occurrences within Peer-Reviewed Published Articles (2009 to 2019): multiple populations can be represented in a single publication, which increases the number of occurrences within the published literature

In terms of study duration (determined by the range of years of data or the length of the field component), most woodland caribou studies reported start and end dates (77.8%, 249 publications). Interestingly, over 20% of all studies failed to report study duration. Most were shorter than five years in length (53.8%, 134 publications), but a significant proportion (36.2%, 115 studies) were more than six years, and 21% were more than eleven years (Figure 6.2).

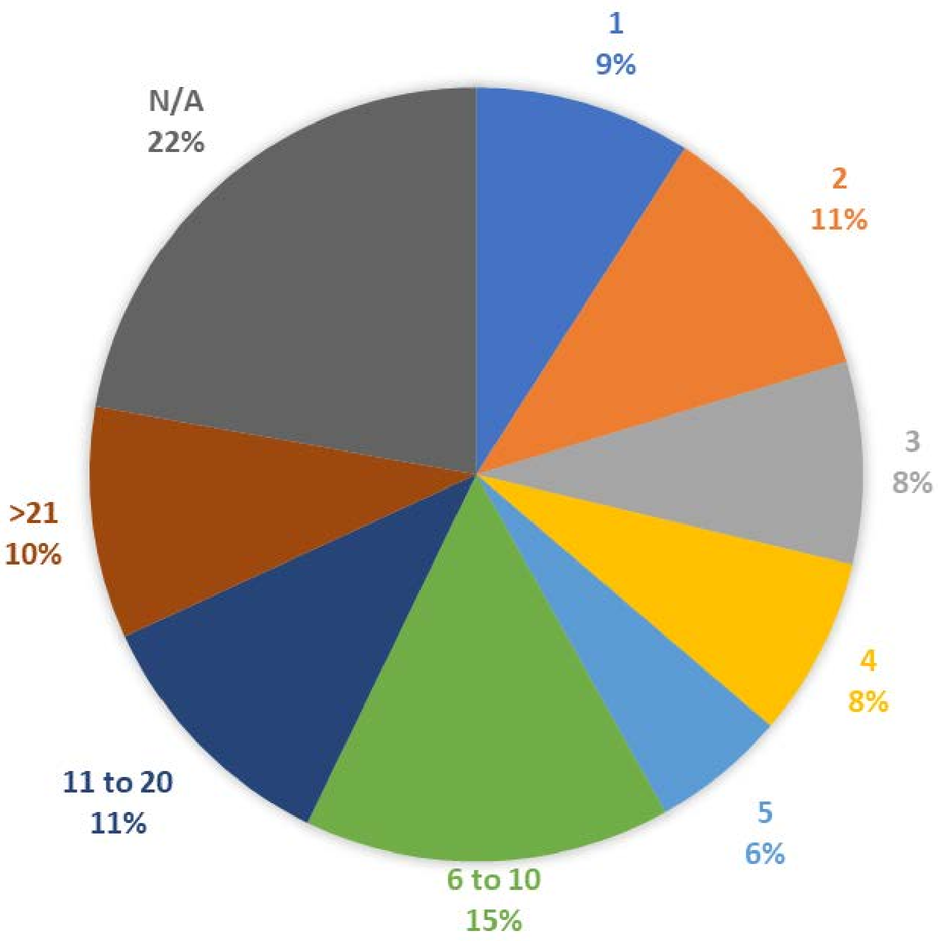

Figure 6.2. Duration in Years (relative proportion of studies) of Woodland Caribou Studies (2009 to 2019): n=320); N/A=study failed to report start date, end date, or both, so duration could not be calculated

6.2.2 *Study Area*

Woodland caribou research (including experimental design, findings, topics, funding, and so on) can be profoundly influenced by the region in which it is conducted, as can results and subsequent recommendations regarding management and/or conservation efforts. Publication frequency shows that woodland caribou research predominantly occurred in Alberta (97 publications) and Québec (79 publications) (Figure 6.3). The fewest publications were from the other two prairie provinces (Saskatchewan, 20 publications; Manitoba,14 publications).

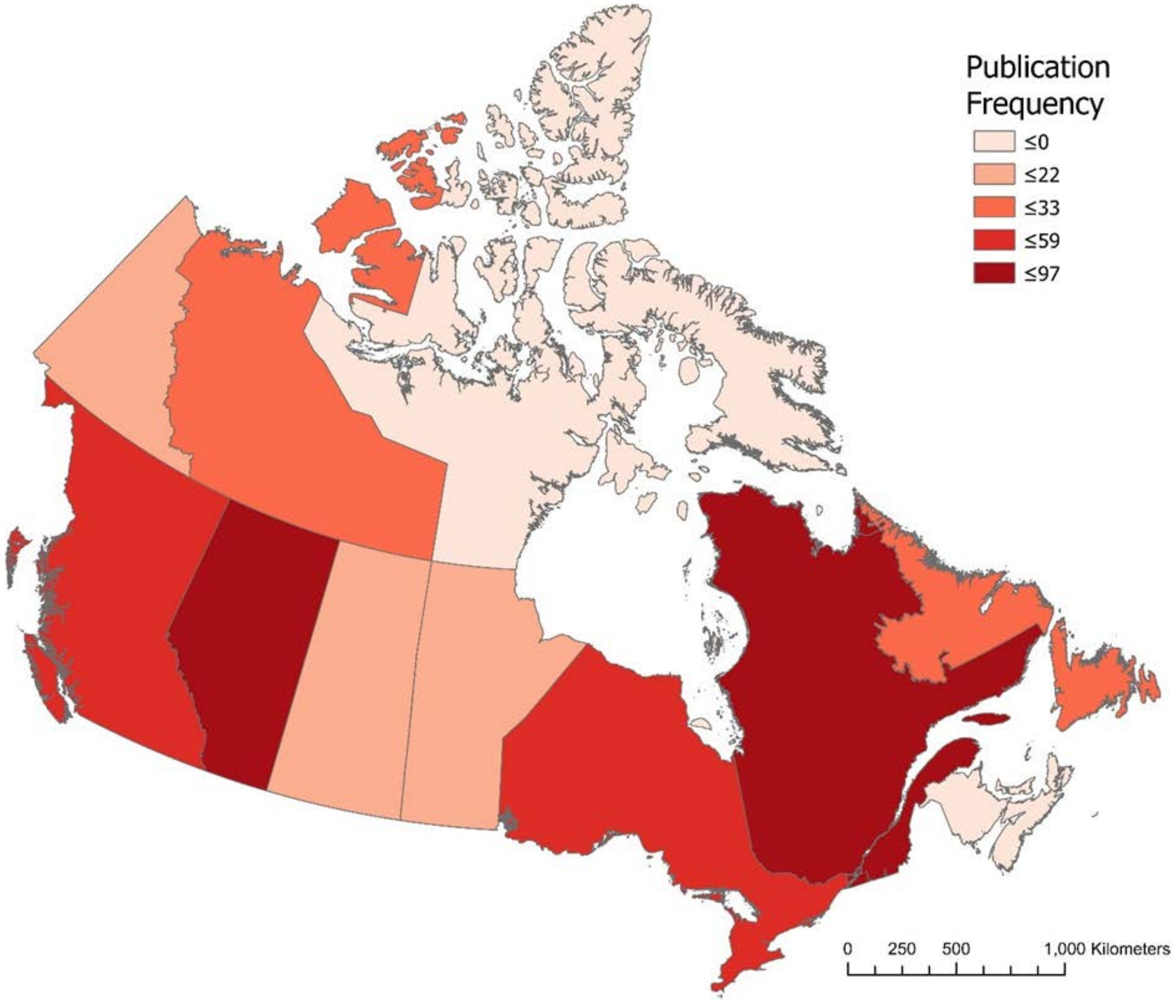

Figure 6.3. Frequency of Peer-Reviewed Publications on Woodland Caribou (all subpopulations) by Province Study Area (2009 to 2019)

6.2.3 *Specific Range*

The greatest number of publications by specific woodland caribou range occurred in the Far North range of Ontario (n=30) and in the Little Smoky (n=28) and Manicouagan (n=26) ranges (Figure 6.4). The federal park region had the highest frequency reported (n=43), but this included multiple ranges that were often considered together (Banff 13; Brazeau 7; Jasper 8; Maligne 8; Tonquin 7). These are combined here due to their small range size and limitations in study-specific reporting. Woodland caribou research has clearly focused within four specific regions: (1) Central Rocky Mountains; (2) Oil Sands Region of Eastern Alberta; (3) northcentral Ontario; and (4) the Côte-Nord of Québec. Caribou in other areas have received much less research focus, most notably the Northern Mountain regions of British Columbia, northern Saskatchewan, Manitoba, and Labrador, all of which had few (<4) range-specific publications.

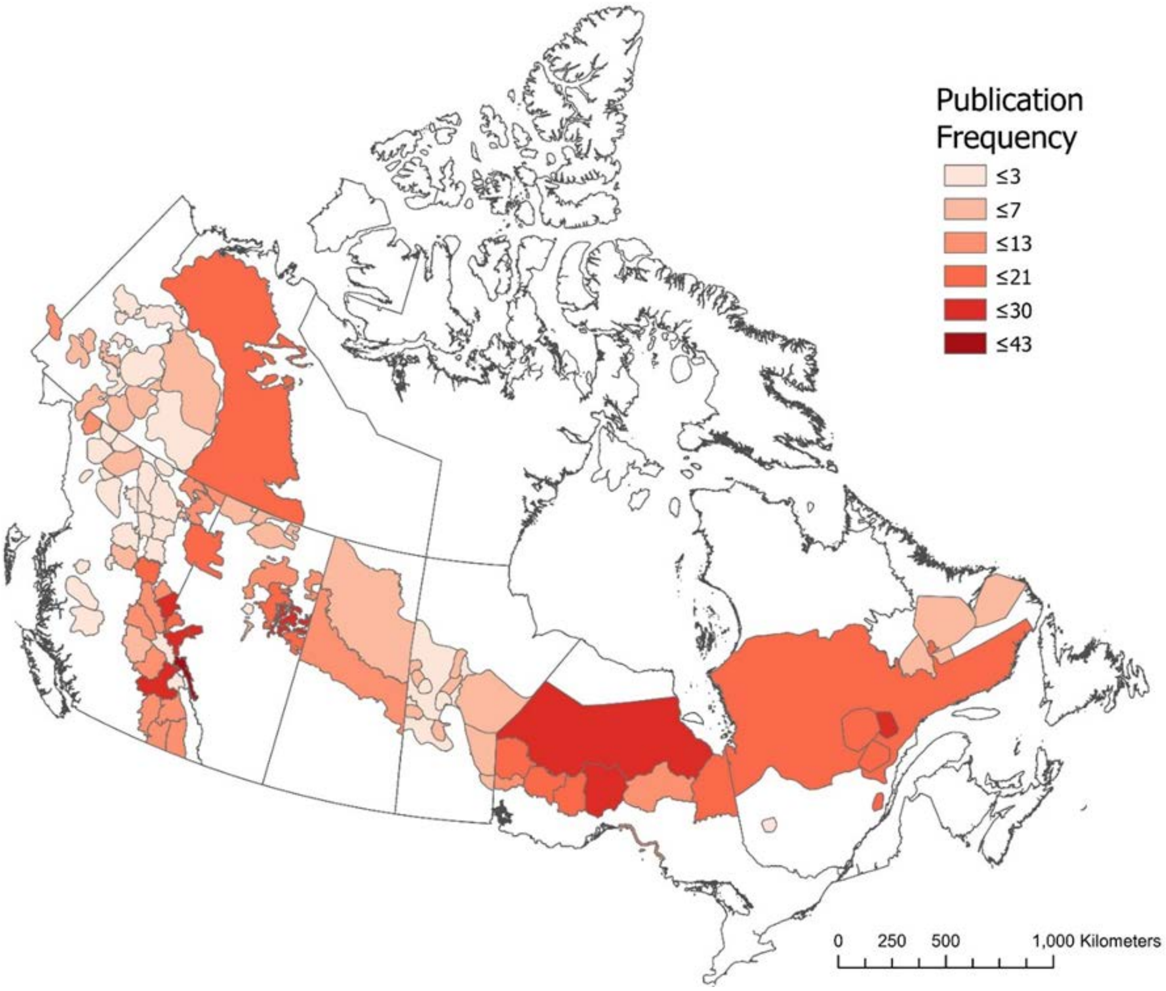

Figure 6.4. Frequency of Peer-Reviewed Publications by Specific Woodland Caribou Subpopulation/Range (2009 to 2019): Newfoundland ranges (n=95 from 18 ranges) are absent due to their small size on the map

6.2.4 *Research Themes*

Substantial differences in research effort among subpopulations were evident. On average, the relative proportion of research was highest in the basic ecology (25.0%) and administrative (21.8%) themes, while the lowest occurred within the genetic (9.8%) and energetics/nutrition (9.1%) themes (Figure 6.5). Administrative research was highest within subpopulations that had higher threat levels (Atlantic-Gaspésie 25.0%; Central Mountains 33.3%; Southern Mountains 26.3%). No studies with the primary research focus of predation and administrative themes were found for the Atlantic-Gaspésie and Newfoundland populations, respectively. In conjunction with the absence of administrative-themed research in Newfoundland, a greater focus was on basic ecology (43.3%) and predation (33.3%). Research among themes was relatively equally distributed within the Northern Mountain subpopulation.

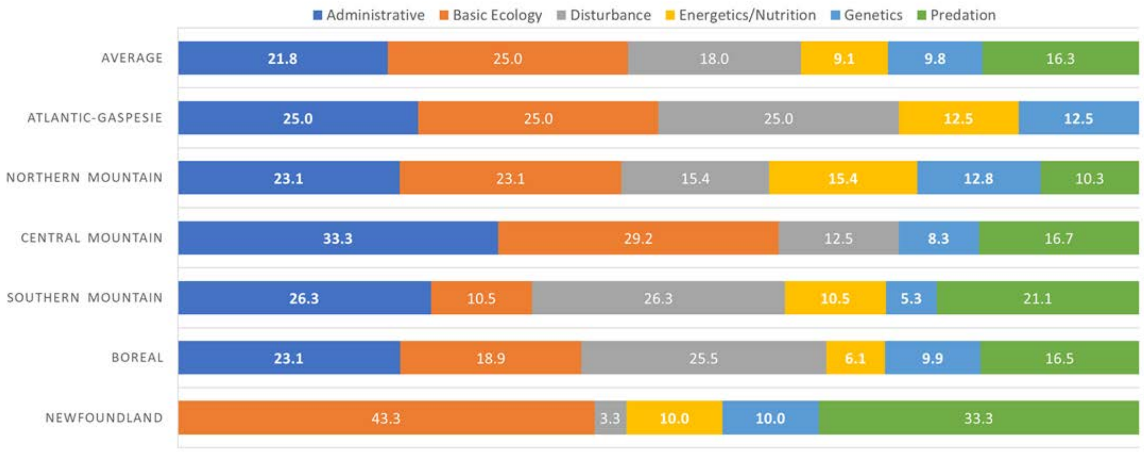

Figure 6.5. Relative Proportions of Peer-Reviewed Publications by Research Theme across Woodland Caribou Populations (2009 to 2019); (n=320)

Because research conducted on woodland caribou can be greatly influenced by provincial policy and regulations, research themes were also assessed by province/territory. On average, basic ecology (23.7%) and administrative (21.5%) themes were best represented, unlike research focused on better understanding the energetics/nutrition of caribou (6.2%). Some very noticeable trends were found at the provincial level, most notably the proportion of research focused on basic ecology in Newfoundland (43.2%), disturbance in Québec (36.0%), and administrative in Alberta (34.1%) (Figure 6.6). Unfortunately, with such a large proportion of research focused on specific themes, other research areas have been deemphasized. For example, in Québec and Alberta, research on energetics/nutrition, genetics, and basic ecology were below the national average. Similarly, in Newfoundland almost no research was focused on disturbance (2.7%). Understandably, the results reported here can be skewed by areas of study and/or expertise of researchers in each jurisdiction, and where some may have larger research budgets than others. Further, funding tends to be awarded for topics that a given jurisdiction considers to be of greatest concern. While results of this literature review are inherently driven by this issue, the intent herein is to highlight the extent to which primary research themes have been examined across the woodland caribou research landscape as a whole.

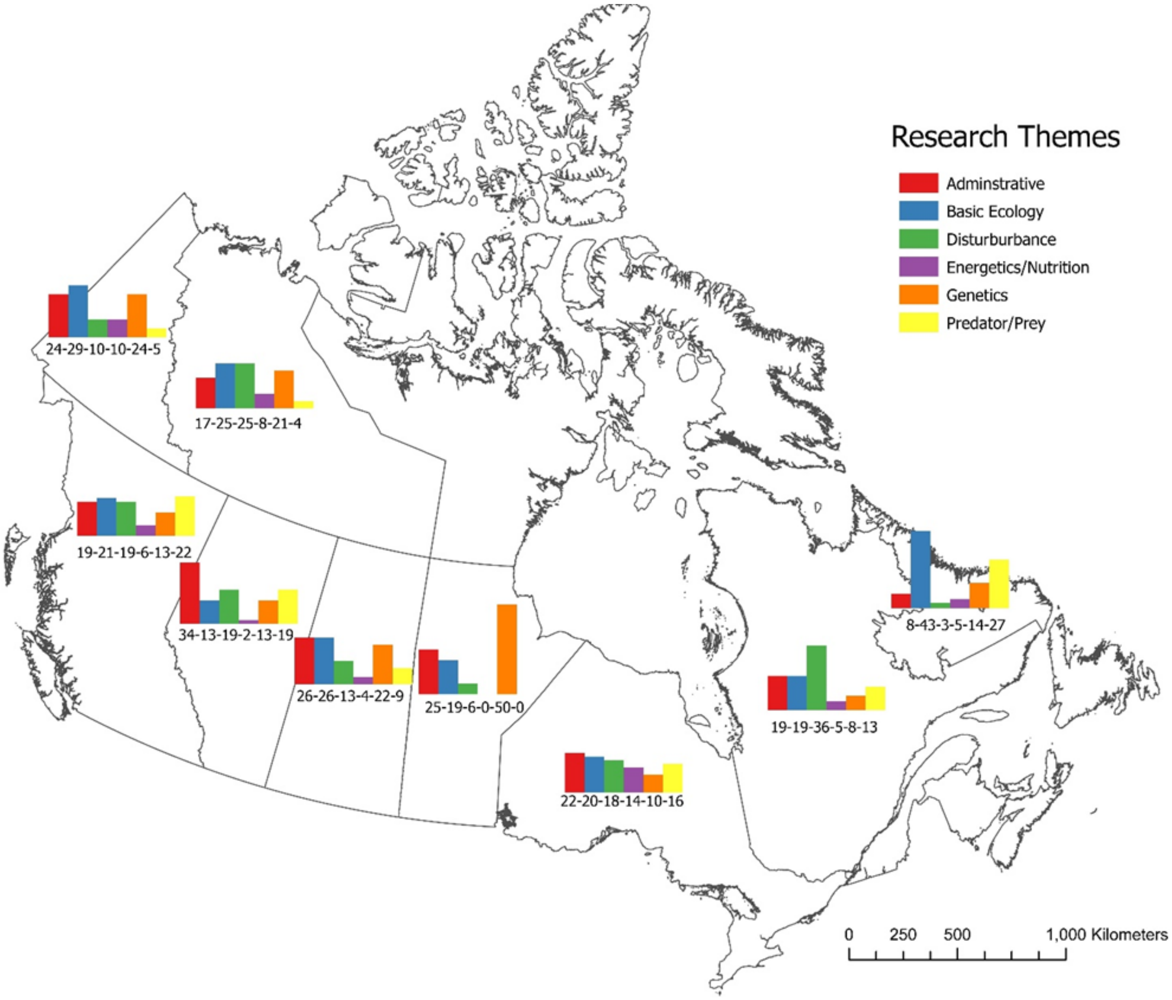

Figure 6.6. Relative Proportions of Peer-Reviewed Publications by Research Theme across Provinces/Territories where Woodland Caribou are Present (2009 to 2019); (n=320)

6.2.5 *Keywords*

As described in Section 6.1.1, keywords were included in classifications of the peer-reviewed publications. The highest proportion of keywords identified by publication (upwards of three keywords per publication) was “disturbance” (27%), followed by “habitat selection and use” (18%) and “population dynamics” (18%, Figure 6.7). The least identified keywords by publication were “alternate prey” (3%) and “traditional ecological knowledge) (1%). “Range dynamics” (10%) and “predation” (9%) were identified at the intermediate level, both slightly higher than “forage” (7%) or “genetics” (6%) (Figure 6.7).

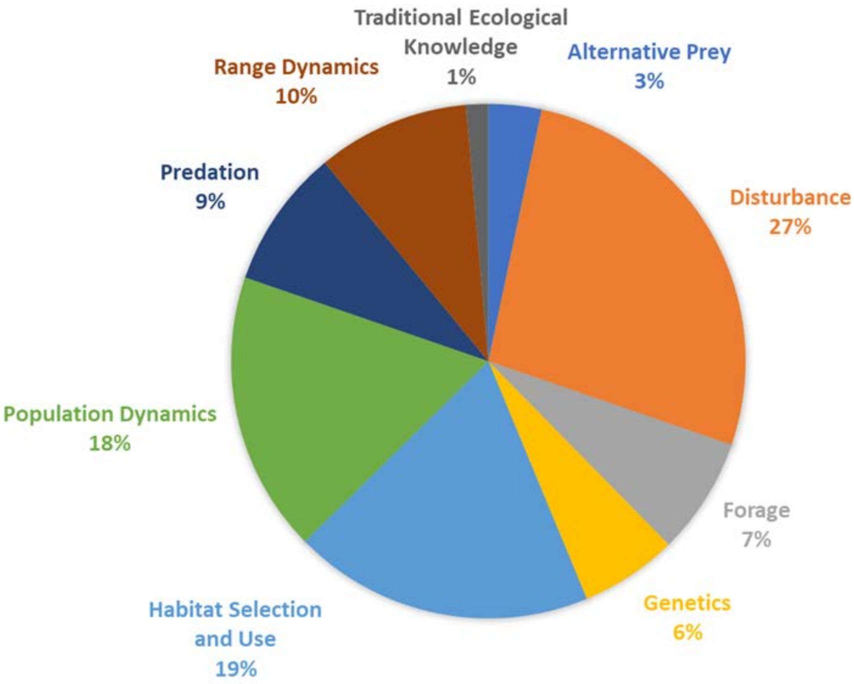

Figure 6.7. Relative Proportions of Identified Keywords for Woodland Caribou Peer-Reviewed Publications (2009 to 2019)

7.0 KNOWLEDGE GAPS

A significant body of research was undertaken on woodland caribou from 2009 to 2019, leading to an increased understanding of the species. However, a number of important aspects remain poorly understood. Substantially increasing the depth and breadth of scientific information about woodland caribou will improve the robustness and efficacy of resulting conservation programs. Increased scientific understanding will also enhance the ability to forecast potential effects of future threats from changes in climate, ecosystems, and disturbance regimes, all of which can vary considerably across the species range and can be difficult to measure or separate into relative contributions. Indeed, such information may prove crucial for the recovery and conservation of woodland caribou over the long term in Canada. This section provides examples of research areas that have been identified through this literature review as either knowledge gaps or research needs.

7.1 Research Needs – Biology and Ecology

- Genetics
    - Improve understanding of geneflow and interactions between woodland caribou subpopulations (and in isolation).
    - Help identify susceptibility/resilience to various changes in environmental factors (e.g., disease, parasites, temperature, precipitation) by undertaking fine-scale genetic assessment.
- Habitat Selection and Use
    - Incorporate multiple scales when assessing habitat selection to understand contributing factors in response to varying disturbance types.

  - Address the fact that although there is a significant amount of information on habitat selection, little is known about how selection changes over time and space, reasons for habitat selection patterns, and ultimately how these influence caribou distribution and demographics. The reasons are fundamental for finding solutions. For example, the tendency of caribou to avoid cutblocks may be a result of poorer food, increased predation risk, avoidance of increased human activity, less or greater visibility, greater insect harassment in summer, or greater snow depth in winter, to name a few. Understanding reasons for habitat selection could contribute to modifications in forestry practices that may increase the compatibility of forest practices and caribou conservation.
  - Improve understanding of how different types and intensities of disturbance and different environmental conditions (season, ecological context, and so on) influence responses of caribou to disturbed areas. Further, extents and types of responses (e.g., site fidelity, ZOI, energy balance, body condition, health, susceptibility to predation) are poorly understood, but have substantial implications for management and planning.
  - Investigate RSF models across regions as a means of validating their accuracy and robustness.
  - Expand limited research comparing habitat selection across reproductive states.
- Diet and Nutrition
  - Achieve a better understanding of foraging ecology to examine how nutritional values of habitats vary as a function of forest structure, disturbance and succession, geoclimatic variation, season, plant composition and abundance, and other factors. This may provide greater opportunities to incorporate nutritional considerations into management and conservation plans. Substantial research from around the world has documented that spring, summer, and fall forage quantity and quality have significant effects on reproduction, survival, and population growth for a wide range of ungulates. However, detailed studies on woodland caribou forage and nutritional dynamics are rare. Much of the understanding of this topic comes from work on other ungulate species and, to some extent, barren-ground caribou, which may or may not be relevant to the forested environments of woodland caribou.
  - Increase understanding of the annual diet (considering all seasons) of caribou at the regional and range scales, with emphasis on which plant species provide high nutrition and low toxicity and contribute disproportionally to the nutritional well-being of caribou.
  - Achieve a greater understanding of how well caribou can satisfy nutritional requirements in each season, and how this varies as a function of plant community types, type of disturbance and subsequent succession, and phenological and geoclimatic influences.
  - Undertake range-specific body condition measurements of caribou across seasons to improve insight into their health status. Evaluations of body condition provide perhaps the best, most effective first-step approach to identify if, where, and what season nutritional limitations may operate.
  - Develop a validated protocol for conducting bottom-up evaluations of forage quality and quantity as a means to evaluate the nutritional value of habitats and caribou ranges or to evaluate the carrying capacity of caribou ranges.
  - Improve understanding of tradeoffs between avoiding predation and acquiring adequate nutrition. Even with the growing perception that caribou sacrifice nutrition to reduce predation risk, in some situations this may under-account for nutrition’s fundamental role in

the fitness of ungulates such as caribou. Advances in understanding tradeoffs between nutrition and predation are hindered by substantially incomplete knowledge of the nutritional ecology of woodland caribou.

    - Evaluate dietary overlap with other ungulate species to investigate potential drivers in areas used by multiple species.

- Distribution

    - Update subpopulation and range boundaries to improve stand- and landscape-level management. Greater knowledge of caribou ranges will ultimately improve survey design for population assessments and minimize overestimations for ranges that overlap.

7.2 Research Needs – Population Size and Trends

- Develop detailed, realistic, and tested models for caribou demographics as they relate to both natural and anthropogenic factors. Recent attempts at modeling caribou persistence and forestry have met with some success but remain untested in the long term. Understanding and adapting such models to field conditions is vital to managing caribou over medium and long terms.

- Monitoring

    - Improve population, trends, health, and body condition assessments across the species range. Improved monitoring programs that accurately assess population size over the long term are needed at the provincial level.

    - Develop a commonly accepted monitoring protocol for woodland caribou to provide a systematic means for consistently estimating populations that could be compared across regions. These protocols should also be established for predators and alternative prey.

    - Improve reliability and availability of population estimates, which now vary by herd, subpopulation, and population. Estimates of both population numbers and demographics are either outdated, measured too infrequently to provide a sound estimate of population size, or unknown.

7.3 Research Needs – Disturbance

- Mapping and Modeling

    - Develop disturbance modeling. Lack of a 65/35 disturbance model for mountain caribou populations inhibits the ability to compare the impacts of disturbance between mountain and boreal caribou populations.

    - Achieve higher resolution and updated mapping of layers of disturbances (natural and anthropogenic) to improve estimations of relative impacts on woodland caribou.

- Cumulative Impacts

    - Investigate responses in reproductive success, body condition, and immune responses to chronic stress on caribou. Although there is some evidence of increased stress response (i.e., cortisol concentrations) in caribou, little to no research exists.

    - Examine interplay and relative effect size of the variety of factors that contribute to declines of caribou in a cumulative effects analysis. Research is needed not only to assess relative contributions but, in many cases, to test and quantify direct causative links between specific factors and caribou demography.

  - Develop an understanding of cumulative effects of anthropogenic disturbance on predator-prey dynamics. The primary focus has been on effects of a single disturbance rather than the cumulative response of disturbances at the range scale.
- Forestry
  - Undertake research into silvicultural practices that promote winter and summer forage and discourage proliferation of less desirable forage species, after achieving an increased understanding of forage needs through all seasons. This knowledge may help increase the compatibility of forestry and caribou conservation.
  - Increase understanding of how forestry influences predation risk, with an emphasis on developing harvesting strategies that minimize these increases. Rigorous research that explicitly addresses forest management practices that alleviate increases in predation risk early in succession or in subsequent stages may be valuable for management and planning.
  - Enhance understanding of how woodland caribou respond to variable retention harvesting patterns (e.g., aggregated vs. dispersed) over the long term, including how results may vary between caribou ranges. Previous studies have documented behavioural response to forest harvesting in the short term (<6 years), but there are minimal longer-term studies.
  - Determine variables/factors driving habitat selection of female caribou during the calving period for application in a forest management context, especially in highly managed landscapes where availability of suitable habitats might be limiting.
  - Examine legacy effects of past disturbances on current habitat use by caribou.
  - Achieve a better understanding of the extent and configuration of managing for habitat connectivity and the impact it may have on woodland caribou population dynamics.
  - Evaluate forage availability, quality, and possible successional change over time (short and long term) post-harvest.
- Hunting and Poaching
  - Improve documentation and monitoring of hunting (where applicable) to evaluate its extent and contribution to overall declines.
- Predation
  - Identify the relative strength of the apparent competition relationship and how it may change as a function of disturbance type (e.g., fire vs. cut-block vs. linear features) and ecological setting.
  - Examine the extent to which the apparent competition hypothesis is region specific; for example, where more northern populations lack the density or diversity of alternate prey species (e.g., Yukon and Northwest Territories).
  - Identify the relative role(s) of alternate predators (e.g., wolverine and lynx) and how they may influence caribou population dynamics.
  - Increase field assessments of seasonal diets of predators across regional and subpopulations of woodland caribou.
  - Examine the additive and compensatory nature of predation, which is poorly understood and rarely addressed in predator-prey studies involving caribou.

- Fire
  - Investigate the influence of fire-disturbed habitat on caribou demographics.
  - Undertake a more thorough assessment of caribou habitat availability and quality post-fire (i.e., residuals islands).
  - Examine effects of long-term fire suppression on distribution, abundance, and quality of terrestrial lichen.
- Parasites, Diseases, and Insects
  - Undertake research on understanding host/pest dynamics of known parasites and diseases that have been identified as influencing caribou health status.
  - Undertake research on woodland caribou health indicators (e.g., serum biochemistry analytes) for use in determining the health status of an animal.
  - Undertake research on medium- and long-term effects of the extensive MPB epidemic on caribou habitat in British Columbia and Alberta.
  - Undertake research on the current spruce budworm epidemic and its effects on caribou habitat in Québec.
- Climate Change
  - Evaluate and document interrelationships among abiotic factors and the spatial distribution of woodland caribou.
  - Examine changes in vegetation and forage responses to climate change in order to improve the ability to predict where caribou might be present in the future and how these changes may influence nutrition and body condition of caribou.
  - Examine pathways through which climate may influence predator/prey dynamics, woodland caribou population dynamics, and ecosystem processes.
  - Undertake further evaluation of the capacity of local adaptation in caribou and how changes in climate may affect resilience to environmental changes.
  - Undertake an investigation of regions within the caribou species range that would be most likely to experience increased temperature/precipitation variability, as a means of predicting possible freeze-thaw events.
  - Examine interactions of climate change and spread of disease and parasites and their vectors in the context of caribou population dynamics.
- Traditional Knowledge
  - Incorporate indigenous knowledge whenever possible across knowledge gaps. This is critical in furthering the understanding of caribou biology, responses to disturbances, and implementing conservation strategies.

8.0 CONCLUSIONS

Research from 2009 to 2019 has produced a substantial body of information about populations of woodland caribou in Canada. Nevertheless, there are significant gaps in knowledge about topics of importance to the management and conservation of these populations. For example, necessary information about the status and trends of woodland caribou populations is lacking for many subpopulations (Figure 6.6). Disturbances (both anthropogenic and natural) to woodland caribou habitat have been hypothesized as major threats to caribou in some areas. The leading hypothesis is that habitat disturbance increases vulnerability of woodland caribou to predation, and two-thirds of all research over the decade had some focus on either disturbance (n=75, 22.0%), predator/prey dynamics (n=57, 16.7%), or administration (n=75, 22.2%). Understanding the energetic and nutritional requirements of a species at the individual, subpopulation, and population levels is vital for a range of key parameters, including survival, recruitment, longevity, and persistence. Given the demonstrated importance of these topics in several species related to caribou and the small number of publications that address the subjects (n=26, 7.6%), it is reasonable to suggest a need for more research.

Finally, there are probably a limited number of ways in which management efforts can significantly affect caribou populations over the long term. Managing disturbance regimes through modifying forest harvesting practices within the range of social, silvicultural, and economic limitations shows promise for mitigating adverse effects and aiding caribou conservation efforts. However, little to no effort has been made to evaluate the effectiveness of these strategies, even though enhanced forest management for caribou has been undertaken for decades. It is not the purpose of this review to recommend types of field studies; however, large-scale adaptive management monitoring/studies (Holling 1978; Walters and Holling 1990) may be required to improve understanding of how managing disturbance activities might best be used to improve compatibility with caribou, particularly in caribou subpopulations at the greatest risk (Serrouya et al. 2019).

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