Reconstructing the Summer Diet of Wolves in a Complex Multi-Ungulate

System in Northern Manitoba, Canada

by

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ABSTRACT

Understanding wolf (*Canis lupus*) food habits provides critical information for boreal

woodland caribou (*Rangifer tarandus caribou*; forest-dwelling ecotype) recovery

strategies. By incorporating the stable isotope ratios of different caribou ecotypes into a

stable isotope mixing model, I determined the relative importance of boreal woodland

caribou in the summer diet of wolves in northern Manitoba, Canada. Boreal woodland

caribou were primary summer prey for wolves collected in winter in registered trapline

(RTL) districts where these caribou are considered rare, suggesting migratory behaviour

in some wolves. Moose were primary prey in other RTL districts, followed by boreal

woodland caribou, with beaver providing important contributions. Recovery strategies for

woodland caribou should investigate annual wolf, caribou, and moose movement in the

region to complement these findings and gain a better insight into this complex

ecosystem.

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lab. You never complained about the mess I made and I love you for that. The completion

of my thesis is the perfect way to start our lives together.

DEDICATION

This thesis is dedicated to my father, Reza Moayeri. After all these years, I know that you still have no clue what I was studying, but that's alright. As much as it grew on my nerves to have you ask me each day if I was done my thesis since the day I began, I still appreciated it. I learned to love nature from you – thank you for being my biggest supporter and my best friend.

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CHAPTER 1: GENERAL INTRODUCTION

WOLVES IN NORTHERN MANITOBA

Manitoba's wolf (*Canis lupus*) population is estimated between 4,000–6,000 individuals

(V. Crichton, Manitoba Conservation and Water Stewardship, personal communication).

Their range primarily encompasses the boreal forest and taiga, and their numbers are

assumed to decrease southward and westward, through the aspen parkland into

agricultural areas (D. Pastuck, Manitoba Conservation, unpublished report). An exception

occurs in Riding Mountain National Park, which supports a population estimated at 77

wolves (Sallows 2007).

Wolves in the Canadian sub-Arctic and high latitude forested regions of North

America are genetically categorized into two ecotypes based on their habitat and

predatory behaviours (Musiani et al. 2007). The distinction between the ecotypes

corresponds to the southern limit of migratory caribou ranges and the ecological boundary

between boreal forest and tundra-taiga habitats (Carmichael et al. 2007, Musiani et al.

2007). Boreal forest wolves, the forest ecotype, maintain year-round territories and

associate themselves with resident ungulate prey such as boreal woodland caribou

(*Rangifer tarandus caribou*), moose (*Alces alces*), and deer (*Odocoileus* spp.) (Musiani et

al. 2007).

Wolves inhabiting ranges overlapping migratory barren-ground caribou (*R.t.

groenlandicus*) are known as the tundra/taiga ecotype, as they undertake long distance

migrations with barren-ground caribou, their primary food source (Kuyt 1972, Williams

1990), to and from their summer grounds in the tundra and wintering areas in the taiga

(Musiani et al. 2007). Tundra/taiga wolves maintain territories only during the denning

period (Carmichael et al. 2007), but can travel long distances in search of food (Frame et al. 2004). Annual ranges of tundra/taiga wolves can average $\leq 63,058$ km^2 (Walton et al. 2001).

Many suggest that both wolf ecotypes occur in northern Manitoba (Parker 1973, Heard and Calef 1986, Heard and Williams 1992). Some wolves from the taiga of northern Manitoba, inhabiting ranges that overlap the winter range of the Qamanirjuaq barren-ground caribou herd, have been observed migrating with the herd to their calving and calf-rearing grounds in the Northwest Territories (now Nunavut) in spring (Parker 1973); however, identifying wolf ecotypes in Manitoba has not been genetically explored.

CARIBOU IN NORTHERN MANITOBA

Woodland and barren-ground are two known subspecies of caribou found in Manitoba. The Province of Manitoba manages for boreal woodland caribou, a forest-dwelling ecotype, because they are listed as threatened under the Species at Risk Act.

Boreal woodland caribou inhabit the forest year-round and disperse after winter to calve in isolation (Courtois et al. 2003, Abraham et al. 2012). They are considered sedentary because the short distance travelled between winter and summer ranges are usually less than 50 km (Brown 2001, Metsaranta and Mallory 2007, Courtois et al. 2003).

During the calving period, barren-ground caribou cows move en masse north of the tree line to reduce predation risk (Bergerud 1988; 1996). Qamanirjuaq barren-ground caribou range west of Hudson Bay, covering approximately 282,308 km^2 (Parker 1973). The herd spends May to September in Nunavut during the calving and calf-rearing period, and migrate into the taiga and boreal forest of northern Manitoba (and occasionally

northeastern Saskatchewan), where they remain until spring (Parker 1973). As of 2010, the herd is estimated at ≤349,000 individuals (Campbell et al. 2010).

Two coastal caribou populations, Pen Island (*Rangifer tarandus* ssp.) and Cape Churchill (*Rangifer tarandus* ssp.), are not included under the current threatened listing for boreal woodland caribou as they have not undergone genetic analyses. Referred to as forest-tundra ecotypes, these herds traditionally migrate northeast to the Hudson Bay coast, and aggregate during the calving and calf-rearing periods, then return to their wintering grounds in the boreal forest (Abrahams and Thompson 1998). A formal population estimate of the Cape Churchill herd is not available, but informal observations estimate the herd population at ≤3,500 individuals (V. Trim, Manitoba Conservation and Water Stewardship, personal communication).

The summer range of the Pen Island caribou herd has traditionally occurred between the Hayes River, Manitoba and Cape Henrietta Maria, Ontario, with most individuals congregated at the Pen Islands near the Manitoba–Ontario border (Abrahams and Thompson 1998). Recent surveys suggest that a change in calving ground use has occurred; some individuals move eastward to congregate near Cape Henrietta Maria, and others occupy areas further inland (Abraham et al. 2012). Caribou occupying areas along the Hudson Bay coast during the calf-rearing period are ≥3,000 animals, with limited individuals observed near the Pen Islands (Abraham et al. 2012).

BOREAL WOODLAND CARIBOU, MOOSE, AND WOLVES: APPARENTLY COMPETING

Determining the impact of wolf predation on caribou survival is a complex problem for wildlife managers when attempting to address caribou conservation strategies. Wolf

predation is considered the main factor limiting boreal woodland caribou populations (Bergerud 1988, Seip 1992, Ballard et al. 1997, Rettie and Messier 1998), yet boreal woodland caribou have coexisted with wolves for thousands of years, and in the absence of human disturbance, wolves and caribou are able to coexist (McLoughlin et al. 2003, Weclaw and Hudson 2004). Furthermore, low boreal woodland caribou densities found throughout the boreal forest are not able to support wolves in the absence of alternate ungulate prey (Rettie and Messier 1998). Consequently, caribou predation risk may be advanced by anthropogenic disturbances that often create habitat better suited for other ungulates such as moose or deer, which facilitates an influx of predators; thus identifying direct impacts of predation is difficult (James and Stuart-Smith 2000, Kuzyk et al. 2004, Seip 2008,Latham et al. 2011*b*).

Boreal woodland caribou space themselves away from each other, other prey species, and wolves to reduce their predation risk (Bergerud and Page 1987, Stuart-Smith 1997, James et al. 2004, Gustine et al. 2006). Boreal woodland caribou generally isolate themselves from moose by using mature coniferous forest habitat (Seip 1992, Cumming et al. 1996, Rettie and Messier 2000, James et al. 2004, McLoughlin et al. 2003) comprised of jack pine (*Pinus banksiana*), tamarack (*Larix laricina*) and black spruce (*Picea mariana)* bogs, peatlands, and generally avoid deciduous stands (Stardom 1977, Darby and Pruitt Jr. 1984, Hirai 1998, Martinez 1998, Brown 2001). Alternatively, moose select areas of early seral growth, with young stands of trembling aspen (*Populus tremuloides*) and jack pine (Bryant 1955). Areas with the greatest moose densities in northern Manitoba were young mixed wood deciduous habitat (Elliot 1988).

Moose and boreal woodland caribou generally do not compete for resources, yet they compete for survival because they share a common predator (Bergerud and Ballard

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1988, Seip 1992, Cumming et al. 1996, Weclaw and Hudson 2004, Wittmer et al 2005). This type of competition, referred to as 'asymmetrical apparent competition', occurs when boreal woodland caribou are a secondary prey for wolves and the numerical response of wolves increases as primary prey (e.g. moose or deer) density increases. Wolves are sustained on the primary prey species, regardless of the decline in boreal woodland caribou because wolf densities are not influenced by caribou densities; therefore, caribou mortality increases as the number of caribou decreases (Seip 1991, DeCesare et al. 2009, Latham et al. 2011*b*). Boreal woodland caribou are a secondary prey species in Manitoba because their low densities cannot solely sustain wolves (COSEWIC 2002).

Two prevailing theories that facilitate asymmetrical apparent competition among wolves and caribou, are forestry practices and anthropogenic linear features (e.g. roads, seismic lines, pipelines, and transmission line right-of-ways) (James and Stuart-Smith 2000, Kuzyk et al. 2004, Seip 2008, Latham et al. 2011*a*). Northern Manitoba supports a resource-based economy dependent on mining exploration, forestry, and hydro development which can have deleterious effects on caribou populations, which avoid industry-related disturbances (Weir et al. 2007, Courbin et al. 2009). Forestry practices create young seral habitat, mixed deciduous forests, and areas of clearcut that are frequently occupied by wolves and moose (Pulliainen 1982, Kuzyk et al. 2004, Courbin et al. 2009, Bowman et al. 2010, Gurarie et al. 2011).

Anthropogenic linear features are avoided by caribou and can act as partial barriers to their movement (Dyer et al. 2001, Dyer et al. 2002, Courbin et al. 2009, Bowman et al. 2010). Wolves do not randomly use landscapes; movements are influenced by the presence of linear corridors depending on the type of feature and season (Ciucci et

al. 2003, Kuzyk et al. 2004, Latham et al. 2011*a*). Roads are often used by wolves as efficient travel routes potentially allowing better access to prey (James et al. 2004). Ciucci et al. (2003) and Gurarie et al. (2011) found that wolves avoided heavily-used roads and selected low use linear features for travel. Encounter rates between boreal woodland caribou and wolves increases when caribou are in close proximity to linear features, suggesting an increased risk of predation for caribou (James and Stuart-Smith 2000, Latham et al. 2011*a*, Whittington et al. 2011). Thus, attempting to identify wolf predation as a proximal cause of boreal woodland caribou mortality, and finding solutions to mitigate the effects of industrial development is a challenging matter.

STUDY OBJECTIVES

Understanding the foraging ecology of wolves is crucial when formulating adaptive management plans for boreal woodland caribou. The objective of this study was to investigate the summer diet of wolves from across northern Manitoba, using stable isotopes analyses.

In Chapter 2, I establish a baseline dataset of stable isotope ratios from different caribou ecotypes found in northern Manitoba.

In Chapter 3, I reconstruct the summer diet of wolves and examine the potential implications on boreal woodland caribou.

In Chapter 4, I summarize the results from Chapter two and three, and discuss the knowledge gaps that should be addressed in future research to improve caribou conservation and management decision making in Manitoba.

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CHAPTER 2: STABLE ISOTOPES RATIOS OF CARIBOU IN NORTHERN MANITOBA

Understanding the foraging habits of predators are important for wildlife managers involved in formulating caribou (*Rangifer tarandus*) recovery action plans. Traditional methods used to investigate predator diets, such as faecal and stomach content analyses, require the researcher to identify undigested remains; however, in multi-ungulate systems where more than one caribou ecotype occur, this can be difficult when their remains appear similar. An alternative to this problem is using the carbon ($^{13}C/^{12}C$; $\delta^{13}C$) and nitrogen($^{15}N/^{14}N$; $\delta^{15}N$) stable isotope ratios of caribou tissues, which can allow ecologists to differentiate between similar prey in predator diets, ultimately allowing for more informed decision making when compiling management plans.

Foraging strategies of animals are reflected by the stable isotopes in their tissues (see Ben-David and Flaherty 2012), thus in caribou, stable isotopes of their tissues are a measure of the species they consume (e.g. plants). Plant carbon and nitrogen stable isotopes are related to their physiology and environment (Broadmeadow et al. 1992, Heaton 1999, Dawson et al. 2002, Bobbink et al. 2010).

Three ecotypes of caribou are found northern Manitoba, permitting an opportunity to examine isotopic differences between caribou populations living in different biomes. The objective of this chapter is to establish a baseline dataset of stable isotope ratios of northern Manitoba caribou ecotypes that can be used by wildlife managers in future predator or ungulate foraging ecology investigations.

STUDY AREA

The study area extends from the northeastern edge of the Northern Arctic ecozone in Nunavut through the Southern Arctic ecozone crossing the Taiga Shield of Manitoba and into the Boreal Shield and Hudson Plain ecozones. The Northern Arctic ecozone is characterized by an absence of trees with a nearly continuous cover of tundra vegetation consisting of dwarf shrubs, sedges (*Carex* spp.), lichen, and heath (*Vaccinium* spp.) including willows (*Salix* spp.), dwarf birch (*Betula nana*), Labrador tea (*Ledum decumbens*), alder (*Alnus crispa*), and moss (*Sphagnum* spp.) (Beckel 1958, Thompson and Klassen 1980, Campbell et al. 2010).

In the taiga of northern Manitoba, uplands and lowlands are dominated by black spruce (*Picea mariana*), jack pine (*Pinus banksiana*), trembling aspen, and birch (*Betula papyrifera*) which gradually transition from the northwest into stunted black spruce forest and tundra in the Coastal Hudson Bay Lowlands (Elliott 1988). Lower canopy species include dwarf birch, willows, sedges (*Carex* spp. and *Eriophorum* spp.), fruticose lichens and moss (Campbell et al. 2010).

The Cape Churchill coastal area is characterized by willows, alpine bearberry (*Arctosstaphylos alpine*), alpine blueberry (*Vaccinium uliginosum*), dwarf birch, crowberry (*Empetrum nigrum*), rock cranberry (*Vaccinium vitis-idaea*), Arctic avens (*Dryas integrifolia*), soapberry (*Shepherdia Canadensis*), Lapland bog-rosebay (*Rhododendron lapponicum*), Labrador tea (Johnson 1987, Scott 1997), graminoids, and approximately 134 species of lichens (Piercey-Normore 2005).

Dominant tree species in the Boreal Shield are black spruce, white spruce (*P. glauca*), jack pine, and tamarack (*Larix laricina*). Trembling aspen, balsam poplar, balsam fir and birch also occur in these areas (Bryant 1955, Scott 1997). Common

understory shrubs include green alder (*Alnus crispa*), speckled alder (*A. rugosa*), bog birch (*B. glandulosa*), small bog cranberry (*Oxycoccus microcarpus*), common bearberry (*A. uva-ursi*), leatherleaf (*Chamaedaphne calyculata*), northern bog laurel (*Kalmia polifolia*), Labrador tea, prickly rose (*Rosa acicularis*), wild red raspberry (*Rubus idaeus*), willows, and a variety of graminoids, lichens, and mosses (Hirai 1998).

Distribution of Ungulate Species

Qamanirjuaq caribou (*R.t. groenlandicus*; barren-ground ecotype) seasonally occur in the province, wintering in the taiga of northern Manitoba, then migrating en masse to their calving and calf-rearing grounds in the tundra of Nunavut in spring (Parker 1973; Fig. 2.1). Pen Island (*R. tarandus* ssp.) and Cape Churchill caribou herds (*R. tarandus* ssp.), both migratory forest-tundra ecotypes, winter in the boreal forest and move northeast to their respective calving and calf-rearing grounds on the tundra coast in spring (Campbell 1995, Abrahams and Thompson 1998, Abraham et al. 2012). While the Cape Churchill caribou herd congregates on the Hudson Bay coast in the summer, recent surveys suggest that a change in calving ground use has occurred for the Pen Island herd; some congregate near Cape Henrietta Maria, Ontario, and others occupy areas further inland in the boreal forest of Manitoba (Abraham et al. 2012, V. Trim, Manitoba Conservation and Water Stewardship, personal communication). Boreal woodland caribou (forest-dwelling ecotype) inhabit the boreal forest year-round.
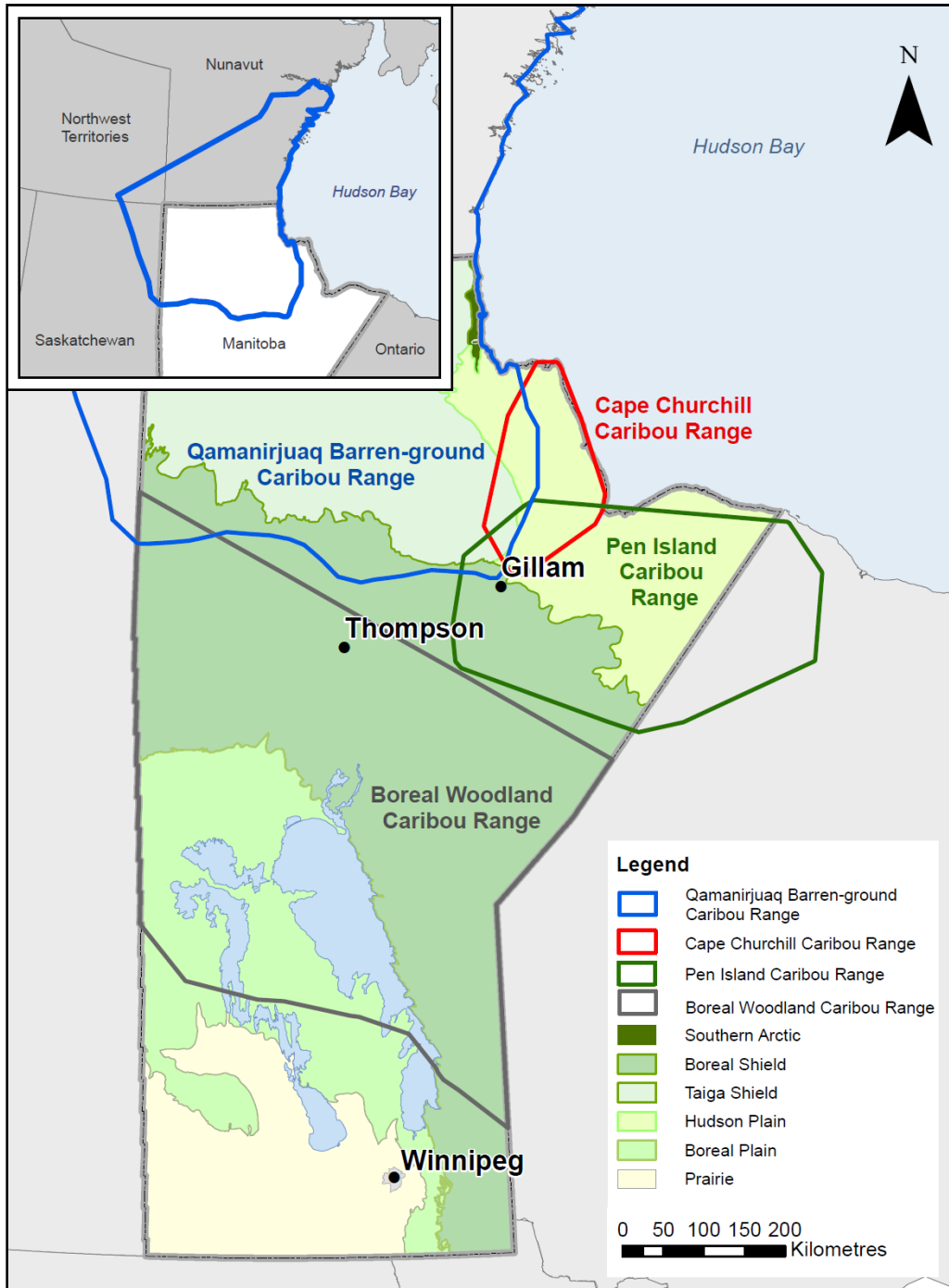
Figure 2.1. Caribou ranges in Manitoba, Canada. Qamanirjuaq barren-ground migrate into northern Manitoba in late August–early September from their calving and calf-rearing grounds in Nunavut. Ecological areas adapted from the Ecological Stratification Working Group (1996). Qamanirjuaq caribou range adapted from Parker (1973).

METHODS

Stable Isotope Hair Sampling and Laboratory Procedure

Hair from boreal woodland caribou and forest-tundra caribou were plucked during a

collaring project in winter 2010 by Manitoba Conservation and Water Stewardship.

Boreal woodland caribou sampled were from the Wabowden and Wapisu herds. Caribou

replace their coat once a year, beginning late spring and continuing through fall and

winter (Drucker et al. 2010); therefore tissues sampled approximately reflect dietary

habits from the summer and late fall seasons. Qamanirjuaq barren-ground caribou isotope

values from teeth roots reflecting summer foraging habits were obtained from Drucker et

al. (2001).

A 2:1 chloroform:methanol solution (Urton and Hobson 2005, Darimont et al.

2007) removed excess oil and debris from the hair. Hairs were air dried for 24 hours then

cut with scissors into a fine powder (Roth and Hobson 2000, Roth et al. 2007). Samples

were weighed into tin capsules and loaded into a Costech EA 4010 elemental analyzer

(Costech Analytical Technologies Inc., USA) interfaced to a Delta V Plus isotope ratio

mass spectrometer (Thermo Fisher Scientific Inc., Germany) at the Stable Isotope for

Innovative Research Laboratory, University of Manitoba. Samples combusted at 1,800°C

into CO_2 an N_2 gases, which were separated based on mass and measured as ratios

expressed in delta notation (δ), in parts per thousand(‰):

$$\delta X = \left[\left(R_{sample}/R_{standard}\right) - 1\right] \times 1000$$

where X is ^{15}N or ^{13}C and R_{sample} and $R_{standard}$ correspond to the ratios of heavy to light

isotopes (^{13}C/^{12}C or ^{15}N/^{14}N) in the sample and standard respectively. The standards used

were PeeDee Belemnite for ^{13}C and atmospheric nitrogen for ^{15}N. Analytical error was estimated to be ±0.1‰ for δ^{15}N and δ^{13}C based on replicates of a lab standard.

δ^{13}C Isotope Values Corrected to 2010 Sampling Year

Qamanirjuaq barren-ground caribou stable isotope values reflect the years 1966 and 1967 (Drucker et al. 2001). To make isotopic comparisons between samples collected from different time periods, I adjusted δ^{13}C values for the decrease in atmospheric CO_2 δ^{13}C caused by fossil fuel combustion since the year 1880 (pre-industrial times) using the equation from Long et al. (2005):

$$\delta^{13}C_{atm\ =} -5.5656 - e^{[(6.0932\times10^{-5})(t-1880)(t-1880)]}$$

where δ^{13}C$_{atm}$ is the atmospheric δ^{13}C of the year of sampling. I used the year 2010 (*t*) to match the year when all other caribou hair were sampled. The correction factor for fossil fuel combustion, *f*, was then calculated using the difference between the value of δ^{13}C in the year 1880 (−6.5‰) and the δ^{13}C of the year of sampling.

$$f = -6.5 - \delta^{13}C_{atm}$$

The correction factor *f*, and the δ^{13}C of the tissue were summed to give the corrected δ^{13}C in the tissue that would have been measured in 2010:

$$\delta^{13}C_{tissue\ corrected} = \delta^{13}C_{tissue} + f$$

Conversion of Collagen Tissue Isotopic Values to Keratin Isotopic Values

Teeth and hair are composed of different proteins, collagen and keratin respectively. I corrected isotopic values of teeth to allow comparisons to be made with the stable

isotopes values of hair. Using Barnett's (1994) tissue correction factor *s* of 1.5‰ for δ^{15}N

and 1.5‰ for δ^{13}C, I converted δ^{15}N$_{teeth}$ and δ^{13}C$_{teeth}$ to δ^{15}N$_{hair}$ and δ^{13}C$_{hair}$. (Table 2.1):

$$\delta^{13}C_{bone\ collagen} - s \approx \delta^{13}C_{hair\ keratin}$$

$$\delta^{15}N_{bone\ collagen} - s \approx \delta^{15}N_{hair\ keratin}$$

Barnett (1994) derived these correction values from sampling the Porcupine and Delta

caribou herds.

Statistical Analyses of Isotopes

I used multivariate analysis of variance (MANOVA) to assess differences between

ungulates in either δ^{15}N and δ^{13}C values, and applied sequential Bonferroni adjustments

to reduce Type I errors (i.e. rejecting *Ho* when *Ho* is true) from multiple testing (Holm

1979, Rice 1989). I used Levene's test for homogeneity of variances among groups. All

statistical analyses were performed in R (Version 2.14, www.r-project.org, accessed 20

Jan 2012) and $\alpha = 0.05$ for all statistical tests.

Table 2.1. Converting Qamanirjuaq barren-ground caribou isotopic values from teeth roots (Drucker et al. 2001) to reflect isotopic values of hair (Barnett 1994). Isotope values also corrected for the depletion of δ^{13}C CO_2 in the atmosphere to reflect the yr 2010 (Long et al. 2005).

Caribou ID No.	Sampling Yr	Teeth δ^{15}N	Hair δ^{15}N $_{\text{diet corrected}}$	Teeth δ^{13}C	δ^{13}C$_{\text{atm 2010}}$	f_{2010}	Teeth δ^{13}C$_{\text{corrected to 2010}}$	Hair δ^{13}C $_{\text{diet corrected}}$
204	1966	4.2	2.7	−19.4	−8.4	1.9	−21.3	−22.8
397	1967	4.5	3.0	−19.6	−8.4	1.9	−21.5	−23.0

Table 2.2. Stable isotope differences in $\delta^{15}N_{hair}$ or $\delta^{13}C_{hair}$ values between ungulates in northern Manitoba, Canada using multivariate analysis of variance (MANOVA) and sequential Bonferroni adjustments.

	Prey		
	Qamanirjuaq Barren-ground Caribou	**Cape Churchill Caribou**	**Pen Island Caribou**
Species	P_{Holm}	P_{Holm}	P_{Holm}
Boreal Woodland Caribou[a] (*n* = 30)	<0.001	<0.001	0.019
Qamanirjuaq Barren-ground Caribou[b] (*n* = 2)		0.038	0.001
Cape Churchill Caribou (*n* = 9)			<0.001
Pen Island Caribou (*n* = 9)			

[a]Wabowden and Wapisu herds

[b]Isotope values of teeth roots (Drucker et al. 2001) reflecting summer dietary habits from 1966 and1967. Isotope values corrected to reflect hair stable isotope values (Barnett 1994) and corrected for the depletion of $\delta^{13}C$ CO_2 in the atmosphere in the yr 2010 (Long et al. 2005).

P_{Holm}: Adjusted *P*-value using the sequential Bonferroni procedure modified by Holm (1979).

RESULTS

The Wabowden and Wapisu boreal woodland caribou herds did not differ in δ^{15}N or δ^{13}C (MANOVA, Pillai's trace = 0.078, $F_{2,27}$ = 1.14, P = 0.33) values, thus both herds were pooled together as boreal woodland caribou. Each caribou ecotype had different average isotopic signatures (Table 2.2, Fig. 2.2). Boreal woodland caribou exhibited the lowest δ^{13}C value (–24.3‰) and had stable isotope values that differed from forest-tundra (Pen Island: MANOVA, Pillai's trace = 0.267, $F_{2,36}$ = 6.55, P_{Holm} = 0.019; Cape Churchill: MANOVA, Pillai's trace = 0.739, $F_{2,36}$ = 50.80, P_{Holm} <0.001) and barren-ground caribou (MANOVA, Pillai's trace = 0.718, $F_{2,29}$ = 36.94, P_{Holm} <0.001)

   Barren-ground caribou had the lowest δ^{15}N value (2.8‰) among all ungulates sampled. Boreal woodland caribou had an enriched average δ^{15}N value compared to Cape Churchill (+2.8‰) and barren-ground caribou (+3.5‰), but was lower than the Pen Island herd (–0.6‰). Differences between δ^{15}N values of Cape Churchill caribou and Pen Island caribou were also large (3.4‰).
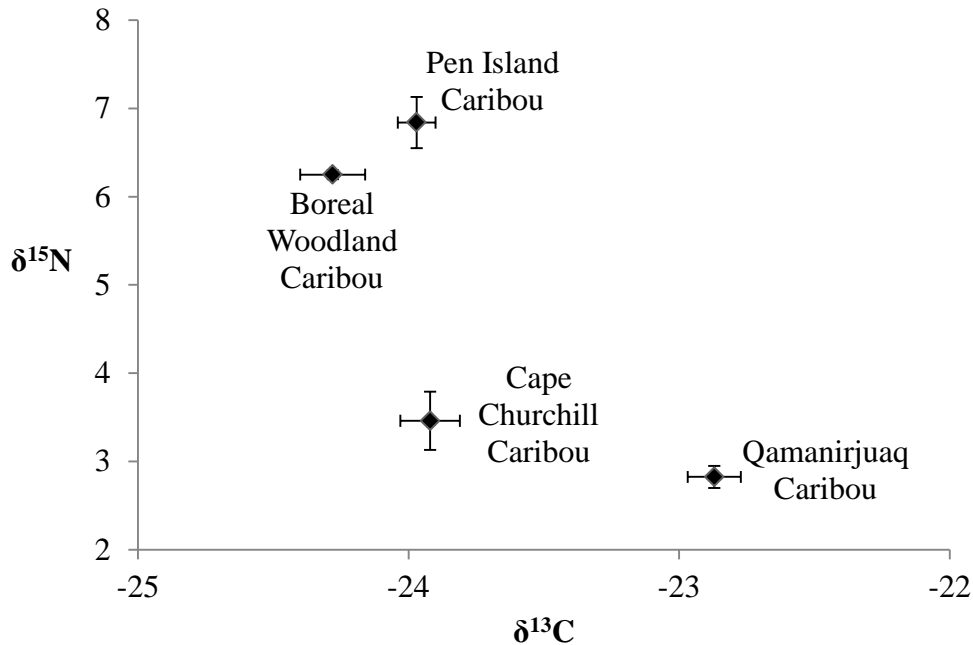
Figure 2.2. Distribution of $\bar{x}$ (±SE) $\delta^{15}N_{hair}$ and $\delta^{13}C_{hair}$ values (‰) of caribou in northern Manitoba, Canada reflecting summer–late fall diets. Isotope values of Qamanirjuaq barren-ground caribou teeth roots from Drucker et al. (2001) were corrected for hair (Barnett 1994) and for the depletion of ^{13}C CO_2 in the atmosphere in the yr 2010 (Long et al. 2005).

DISCUSSION

Isotopic Differences between Caribou Ecotypes

Recent studies (Drucker et al. 2008, Drucker et al. 2010, Meier 2010) using stable isotopes, have documented depleted $\delta^{13}C$ values in caribou populations living in closed canopy habitats (i.e. boreal forest) compared to populations in open environments (i.e. tundra), a pattern known as the 'canopy effect'. The canopy effect occurs as the concentration ^{13}C depleted CO_2 accumulates beneath the forest canopy as a result of soil respiration and litter decomposition (Vogel 1978). Combined with restricted light

conditions under the canopy, these interactions lead to changes in photosynthetic activity and stomatal conductance (Francey et al. 1985), resulting in depleted plant $\delta^{13}C$ values under a canopy than the same plant group in an open, well-ventilated environment (Vogel 1978, Brooks et al. 1997). Boreal woodland caribou in northern Manitoba did exhibit lower $\delta^{13}C$ values compared to other caribou ecotypes, where the depletion of $\delta^{13}C$ was most distinct between boreal woodland caribou and Qamanirjuaq caribou ($-1.4‰$), ecotypes with the greatest difference in canopy structure between their respective habitats. If the canopy effect does influence $\delta^{13}C$ values in the tissues of caribou from this study, this could explain differences between boreal woodland caribou and Qamanirjuaq caribou $\delta^{13}C$ values, and the similarities in $\delta^{13}C$ values between the Wabowden and Wapisu herds.

Understanding the variability observed in the $\delta^{15}N$ values of northern Manitoba caribou ecotypes is difficult due to the complexity of fluxes and pools of nitrogen. The $\delta^{15}N$ values observed among caribou ecotypes may be due to forage selection, or may highlight the potential impact of the local environment on their $\delta^{15}N$ values, independent of their diet. Soil $\delta^{15}N$ values are not directly associated with plant $\delta^{15}N$ values and plant $\delta^{15}N$ values can vary with soil age, soil parent material, topography, fire, temperature, humidity, and precipitation (Schulze et al. 1994, Amundson et al. 2003, Smithwick et al. 2005, Menge et al. 2010, review in Pardo and Nadelhofer 2010). Plant $\delta^{15}N$ values can also vary within a site due to species-specific nutritional strategies and fractionation processes (Schulze et al. 1994, Dawson et al. 2002, Pardo and Nadelhofer 2010). Despite these variables, some research has shown a general pattern of $\delta^{15}N$ in boreal forest and tundra plants and fungi that suggest the following pattern: lichens <trees <shrubs = mosses <forbs< graminoids (sedges and grasses) <fungi (Barnett 1994, Schulze et al.

1994, McLeman 2006). Additionally, Amundson et al. (2003) suggest that $\delta^{15}N$ values

are usually lower in tundra areas compared to southern boreal forest because $\delta^{15}N$ values

tend to decrease with temperature, a pattern that may offer insight on the difference

observed between boreal woodland caribou and Qamanirjuaq caribou.

Differences observed between $\delta^{15}N$ and $\delta^{13}C$ values of boreal woodland caribou

and Qamanirjuaq caribou may also be attributed to the plant communities available as

forage in their respective biomes. I had to make several assumptions when using

Qamanirjuaq barren-ground caribou $\delta^{15}N$ and $\delta^{13}C$ values from Drucker et al. (2001)

from the 1960s to make them comparable to my 2010 sampling year, including that the

range use, forage availability, and forage consumption were temporally similar; the $\delta^{15}N$

and $\delta^{13}C$ values of the samples were representative of the herd and; climatic changes

between decades were minimal and had no effect on the isotope values. Additionally,

uncertainties are inherent in using different tissues due to differences in metabolic

process.

Nonetheless, the results represent the first dataset for nitrogen and carbon stable

isotope ratios of different caribou ecotypes in northern Manitoba. High-resolution animal-

borne video cameras capable of long-term recordings with global positioning units were

successfully deployed on woodland caribou in Alberta, enabling researchers to

reconstruct diets by plant species and simultaneously identify habitat selection in the

summer (Thompson et al. 2012). The future use of such cameras with stable isotope

analyses on the plants consumed could provide detailed information to improve our

understanding of summer ungulate diets in the province, and allow us to better understand

the influence of various environmental factors on the stable isotope ratios of caribou.

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CHAPTER 3: DIET OF WOLVES IN NORTHERN MANITOBA WITH INTEREST IN BOREAL WOODLAND CARIBOU

Canada's listing of boreal woodland caribou (*Rangifer tarandus caribou*) under the Species at Risk Act sparked the development of Manitoba's recovery strategy, placing priority on the need to understand all factors impacting their survival (Manitoba Conservation 2006). Coupled with increasing development projects in Manitoba (e.g. hydro, mining, and forestry), a proactive strategy was needed to address knowledge gaps on the possible causes of woodland caribou mortality in these populations. One area requiring further investigation was to understand the diet of wolves (*Canis lupus*) within caribou ranges.

Wolves' food habits are influenced by many factors, including: prey abundance, body size, ease of prey capture, prey vulnerability, and diet variation between packs and years within study areas (Haber 1977, Holleman and Stephenson 1981, Bibikov 1982, Kunkel and Mech 1994, Ballard et al. 1997, Bergerud and Ballard 1988, Marguard-Peterson 1998, Wiebe et al. 2009, Nowak et al. 2011). Wolves prey primarily on ungulates in North America (Ballard et al. 1997, Allison 2001, Urton 2004, Milakovic and Parker 2011), with smaller mammals (e.g. beaver) and birds supplementing diets when available (Forbes and Theberge 1996, Marguard-Peterson 1998, Spaulding et al. 1998, Tremblay et al. 2001, Milakovic and Parker 2011). In multi-ungulate systems with woodland caribou, wolves are primarily sustained by moose (*Alces alces*), elk (*Cervus elaphus*), and/ or deer (*Odocoileus virginianus*) (Seip 1992, Tremblay et al. 2001, James et al. 2004, Urton 2004, Kuzyk et al. 2006, Latham et al. 2011). Woodland caribou generally comprise a small portion of the wolf diet (James et al. 2004), as their low

population densities are unable to support wolves in the absence of alternate ungulate prey (Rettie and Messier 1998).

Moose are the most abundant and widely available large prey species for wolves year-round in northern Manitoba (Bryant 1955). Three ecotypes of caribou are also available: localized herds of forest-dwelling boreal woodland caribou occurring in low numbers; Qamanirjuaq barren-ground caribou (*R. t. groenlandicus*) that are seasonally available in late fall through winter; and Pen Island and Cape Churchill forest-tundra herds (*R. tarandus* spp.) that are present throughout the year, but migrate throughout northern Manitoba from their wintering area in the boreal forest, to their respective calving grounds on or near the Hudson Bay coast.

Applying conventional methods such as faecal and stomach content analyses to estimate the food habits of wolves in northern Manitoba is difficult because: (1) prey items differ in digestibility; (2) different prey subspecies may not be easily identified; (3) the area spans hundreds of thousands of square kilometres across different ecological zones, making it difficult to collect representative samples; (4) accessibility to conduct field work year-round is poor; and (5) the time and financial costs incurred to obtain such samples are high. Alternatively, stable isotope analyses of wolf tissues are now being used to reconstruct their diets (e.g. Urton and Hobson 2005, Stotyn 2008, Derbridge 2010, Milakovic and Parker 2011) and are able to provide a more comprehensive understanding of foraging ecology. Unlike faecal analyses that capture single meals of unknown individuals, stable isotopes can reveal long term dietary habits, including seasonal shifts in foraging (Darimont and Reimchen 2002), depending on the turnover rate of the tissue being sampled.

Stable isotope signatures of a consumer reflect the ratios of heavy to light isotopes of carbon ($^{13}C/^{12}C$; $\delta^{13}C$) and nitrogen ($^{15}N/^{14}N$; $\delta^{15}N$) of the prey species consumed and the physiological processes used to assimilate the tissue and excrete their products (Ben-David and Flaherty 2012). Guard hairs of wolves chronologically record diets for the period of growth (Darimont and Reimchen 2002). Wolves undergo one annual molt in late spring when the old coat sheds and a new short summer coat grows through the fall and winter (Kuyt 1969, Paquet and Carbyn 2003), thus hair collected in early winter can represent a record of dietary information of approximately six months (Darimont et al. 2009).

The objective of this study was to identify and evaluate the relative importance of boreal woodland caribou to the summer diet of wolves in northern Manitoba using stable isotope analysis of $\delta^{15}N$ and $\delta^{13}C$ in wolf hair.

STUDY AREA

The study area encompasses approximately 193,886 km^2 of nine northern registered trapline (RTL) districts covering the Manitoba Hudson Plain, Boreal and Taiga Shield ecological zones, with a small portion in the southwest extending slightly into the Boreal Plain ecozone (Fig. 3.1). Other predators inhabiting the study area include coyote (*Canis latrans*), lynx (*Lynx canadensis*), red fox (*Vulpes vulpes*), arctic fox (*Vulpes lagopus*), wolverine (*Gulo gulo*), black bear (*Ursus americanus*), and polar bear (*Ursus maritmus*). Human density in northern Manitoba is low. Transportation into most communities is restricted to air, train, or boat in the summer.
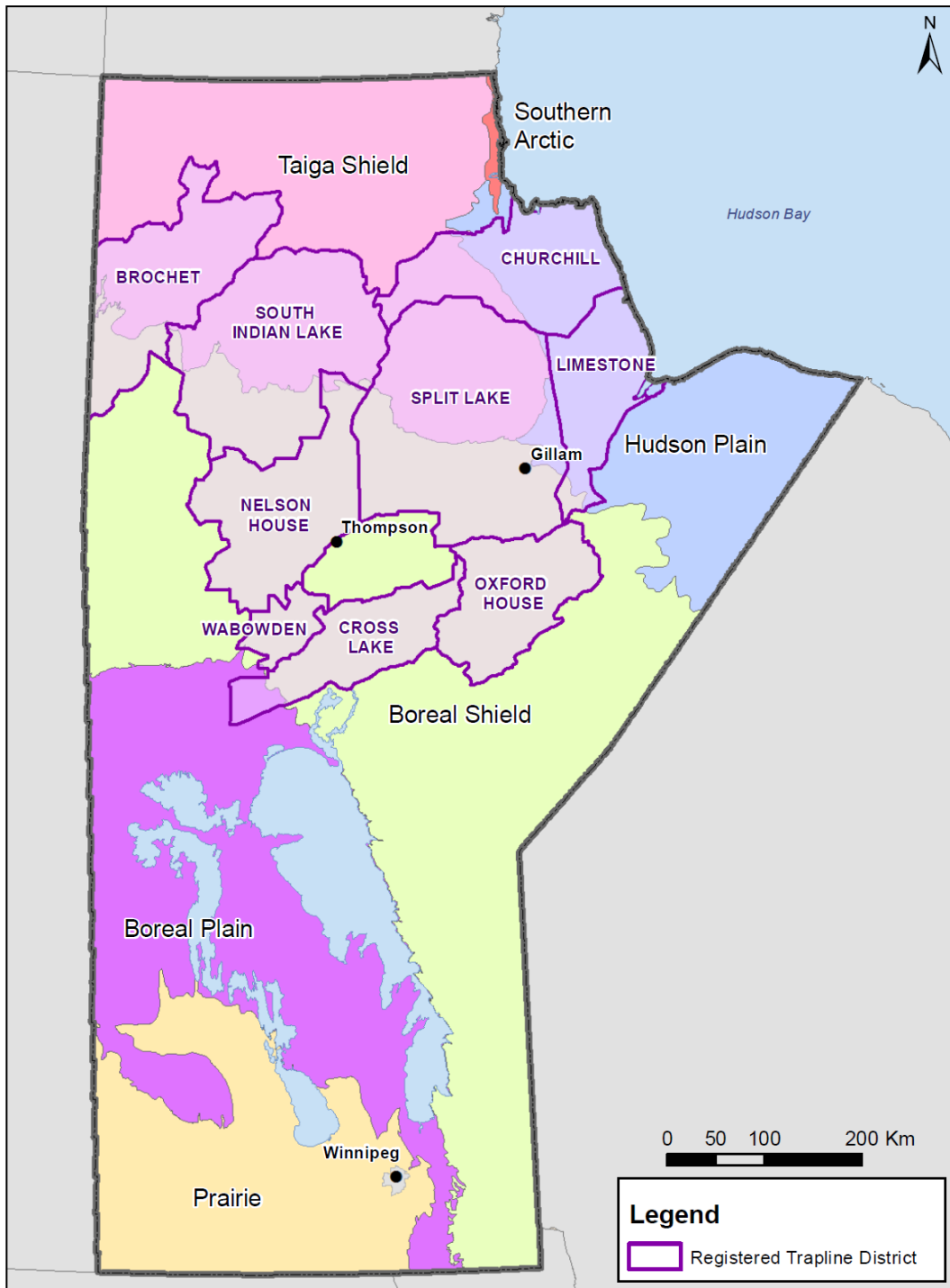
Figure 3.1. Registered trapline (RTL) districts in northern Manitoba, Canada where wolf hair samples were obtained in 2009, 2010, and 2011. Ecological zones adapted from Ecological Stratification Working Group (1996).
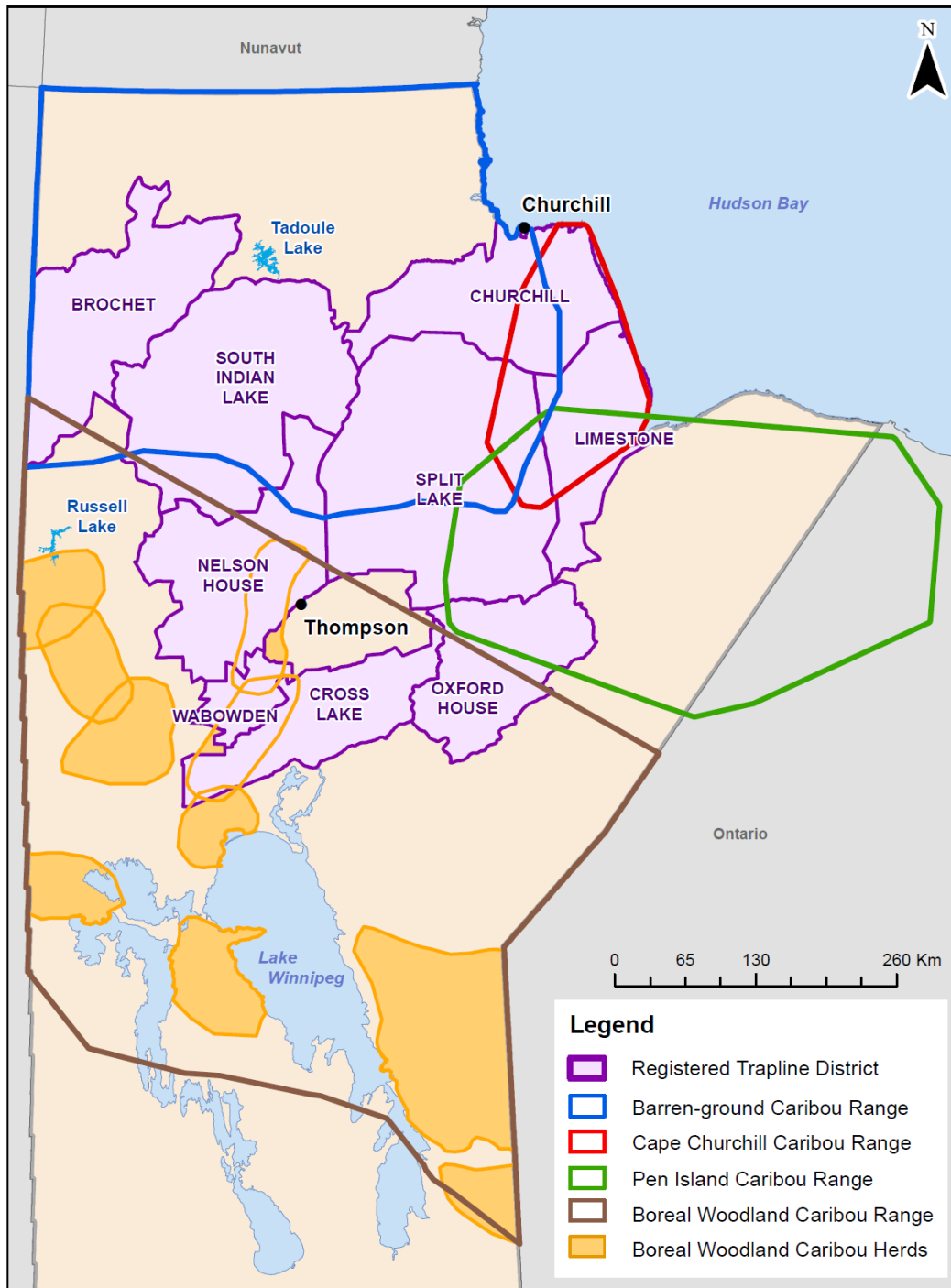
Figure 3.2. Registered trapline (RTL) districts in northern Manitoba, Canada where wolf hair samples were obtained in 2009, 2010, and 2011. Annual caribou ranges outlined (Manitoba Conservation 2006), except for Qamanirjuaq barren-ground caribou – only the winter range is shown.

METHODS

Stable Isotope Hair Sampling and Laboratory Procedure

I collected hair samples from winter-killed wolves in 2009, 2010, and 2011 from trappers

at the Fur Table (sponsored by Manitoba Conservation and Water Stewardship and the

Manitoba Trappers Association), and North American Fur Auction. The trapping season

for wolves begins in October and samples were collected in December, therefore I

recorded November as the harvest month with the RTL district from where it was

harvested. Hair retrieved was assumed to reflect dietary information from June to

November. Hair was removed near the groin and upper hind leg area thereby not

compromising pelt value.

Manitoba Conservation and Water Stewardship provided additional wolf hair

samples, as well as hair from boreal woodland caribou (Wabowden and Wapisu herds),

and Cape Churchill and Pen Island caribou herds taken during a collaring project in

winter 2010. I also collected hair from moose, snowshoe hare (*Lepus americanus*), and

beaver (*Castor canadensis*). Hair sampled from prey sources reflected the same season as

those sampled for wolves. Hair from caribou and moose share similar hair tissue turnover

rates with wolves as they replace their coat once a year, beginning late spring and

continuing until late fall (Drucker et al. 2010). I used Qamanirjuaq caribou stable isotope

values from teeth roots, reflecting summer foraging habits (Drucker et al. 2001).

A 2:1 chloroform:methanol solution (Urton and Hobson 2005, Darimont et al.

2007) was used to remove excess oil and debris from the hair which was then air dried for

24 hours. Hairs were homogenized with scissors (Roth and Hobson 2000, Roth et al.

2007) into a fine powder, and then processed at the Stable Isotope for Innovative

Research Laboratory, University of Manitoba. Samples were weighed into tin capsules

and were loaded into a Costech EA 4010 elemental analyzer (Costech Analytical

Technologies Inc., USA) interfaced to a Delta V Plus isotope ratio mass spectrometer

(Thermo Fisher Scientific Inc., Germany). Samples combusted at 1,800°C into CO_2 an N_2

gases, which were separated based on mass and measured as ratios expressed in delta

notation (δ), in parts per thousand(‰):

$$\delta X = \left[\left(R_{sample}/R_{standard}\right) - 1\right] \times 1000$$

where X is ^{15}N or ^{13}C and R_{sample} and $R_{standard}$ correspond to the ratios of heavy to light

isotopes ($^{13}C/^{12}C$ or $^{15}N/^{14}N$) in the sample and standard respectively. The standards used

were PeeDee Belemnite for ^{13}C and atmospheric nitrogen for ^{15}N. Analytical error was

estimated to be ±0.1‰ for $\delta^{15}N$ and $\delta^{13}C$ based on replicates of lab standards.

$\delta^{13}C$ Isotope Values Corrected to 2010 Sampling Year

To make isotopic comparisons between samples collected from different time periods, I

corrected Qamanirjuaq caribou samples from Drucker et al. (2001) obtained in 1966 and

1967, for the decrease in atmospheric CO_2 $\delta^{13}C$ values caused by fossil fuel combustion

since the year 1880 (pre-industrial times) using the equation from Long et al. (2005):

$$\delta^{13}C_{atm} = -5.5656 - e^{\left[(6.0932 \times 10^{-5})(t-1880)(t-1880)\right]}$$

where $\delta^{13}C_{atm}$ is the atmospheric $\delta^{13}C$ of the year of sampling (t). I selected the year 2010

(t) to match the year when all other caribou hair were sampled. A correction factor, f, was

then calculated using the difference between the value of atmospheric $\delta^{13}C$ in the year

1880 (-6.5‰) and the year of sampling.

$$f = -6.5 - \delta^{13}C_{atm}$$

I summed the correction factor f, and the $\delta^{13}C$ of the tissue to get the corrected $\delta^{13}C$ in the tissue that would have been measured in the year 2010:

$$\delta^{13}C_{tissue\ corrected} = \delta^{13}C_{tissue} + f$$

Conversion of Collagen Tissue Isotopic Values to Keratin Isotopic Values

Stable isotope values of teeth and hair cannot be directly compared with each other due to the different fractionation rates of the proteins they are comprised of. Hooves, hair, fingernails, and feathers are comparable without correction because they are measured in keratin. Likewise, ligament and bone material are made of the protein collagen, thus, correction are not needed for making comparisons between their stable isotope values (Meier 2010). I adjusted $\delta^{15}N_{teeth}$ and $\delta^{13}C_{teeth}$ values into $\delta^{15}N_{hair}$ and $\delta^{13}C_{hair}$ using Barnett's (1994) tissue correction factor s of 1.5‰ for $\delta^{15}N$ and 1.5‰ for $\delta^{13}C$ (see Table 2.1):

$$\delta^{13}C_{bone\ collagen} - s \approx \delta^{13}C_{hair\ keratin}$$
$$\delta^{15}N_{bone\ collagen} - s \approx \delta^{15}N_{hair\ keratin}$$

Barnett (1994) derived these values from sampling the Porcupine and Delta caribou herds.

Statistical Analyses of Stable Isotope Ratios

I used multivariate analysis of variance (MANOVA) to assess differences among prey in $\delta^{15}N$ or $\delta^{13}C$ values, and applied sequential Bonferroni adjustments (Holm 1979, Rice 1989) at the 0.05 significance level. I used Levene's test to examine equality of group

variances. All statistical analyses were performed in R (Version 2.14, www.r-project.org, accessed 20 Jan 2012).

Dietary mixing models convert the isotopic ratios of consumers and their food items to estimates of relative prey consumption (Ben-David and Flaherty 2012). I used the SIAR (Stable Isotope Analysis in R) software package described by Parnell et al. (2010) to estimate the proportions of prey in the diet of wolves. This mixing model uses Bayesian inference via a Markov chain Monte Carlo algorithm to provide potential dietary solutions. Unlike earlier models, SIAR can incorporate prior information and sources of variability by including the standard deviations (SD) of the food sources and trophic discrimination values (Δ; also known as 'trophic enrichment factors'), which are the change in stable isotope ratios (‰) as they are incorporated from prey into the consumers' tissue. Each prey input into the model is independent, but SIAR requires that the proportion of each food source sum to unity (Parnell et al. 2010).

As wolves primarily assimilate muscle tissue instead of hair, I considered how the trophic discrimination values used could alter the SIAR model output. Tieszen and Boutton (1988) found little difference in muscle and hair $\Delta^{13}C$ discrimination values in ungulates. Differences in $\Delta^{15}N$ have not been reported but the variation may be negligible (e.g. Roth and Hobson 2000). Therefore, I assumed that there was no difference in the signatures between prey hair and the muscle tissue that wolves consumed.

I also assumed that the differences between neonate and maternal prey isotopic signatures were minor. During the first 70 days after birth, $\delta^{15}N$ values of a caribou calf and mother differ by 1.9 ± 0.1‰ and decrease to 0.6 ± 0.1‰ at 98 days while their $\delta^{13}C$ values do not differ during the first three months after lactation (Jenkins et al. 2001).

Moose calves do not differ in δ^{15}N or δ^{13}C values from their mothers (Jenkins et al. 2001).

Stable isotope dietary studies on wolves have used discrimination factors for red foxes (e.g. Urton and Hobson 2005, Darimont et al. 2009, Derbridge 2010, Milakovic and Parker 2011, Steenweg 2011) from Roth and Hobson (2000) as no work to date has been conducted for wolves. Thus, I used trophic discrimination values from red foxes: 3.4‰ (±SD 0.3‰) for Δ^{15}N and 2.6‰ (±SD 0.2‰) for Δ^{13}C for hair (Roth and Hobson 2000).

Table 3.1. Prey availability by registered trapline (RTL) district in northern Manitoba, Canada (Bryant 1955, D. Hedman, personal communication).

RTL District	Prey					
	Moose	Beaver	Boreal Woodland Caribou	Qamanirjuaq Barren-ground Caribou	Cape Churchill Caribou	Pen Island Caribou
Brochet	✓	✓	✓	✓		
South Indian Lake	✓	✓	✓	✓		
Nelson House	✓	✓	✓	✓		
Wabowden	✓	✓	✓			
Cross Lake	✓	✓	✓			✓
Oxford House	✓	✓	✓			✓
Split Lake	✓	✓		✓	✓	✓
Churchill	✓	✓		✓	✓	✓
Limestone	✓	✓		✓	✓	✓

To refine the SIAR model's dietary estimates, I obtained prior information on prey availability by RTL district from Bryant (1955), anecdotal reports (D. Hedman, personal communication), and unpublished government reports. Boreal woodland caribou were included as possible prey for wolves sampled in Brochet and South Indian Lake RTL districts because the northern range of boreal woodland caribou is approximately ≤150 km and ≤100 km from Brochet and South Indian Lake RTL districts, respectively (D. Hedman, personal communication, Fig. 3.2). Small sample sizes were combined if trapline districts occupied a common ecological zone and had access to the same potential prey (Fig. 3.1; Table 3.1).

RESULTS

Statistical Analyses of Isotopic Signatures

I found no differences between Wabowden ($n = 10$) and Wapisu ($n = 20$) herds in δ^{15}N or δ^{13}C values (MANOVA, Pillai's trace = 0.078, $F_{2,27} = 1.14$, $P = 0.33$) and therefore, I pooled the herds together as boreal woodland caribou. I found differences in δ^{15}N and δ^{13}C values between each caribou ecotype (Table 3.2). I found no differences in δ^{15}N or δ^{13}C values between Qamanirjuaq caribou ($n = 2$), moose ($n = 4$), and snowshoe hare ($n = 2$), although snowshoe hare and moose were more depleted in δ^{13}C than Qamanirjuaq caribou by 5.1‰ and 3.2‰ respectively (Fig. 3.3).
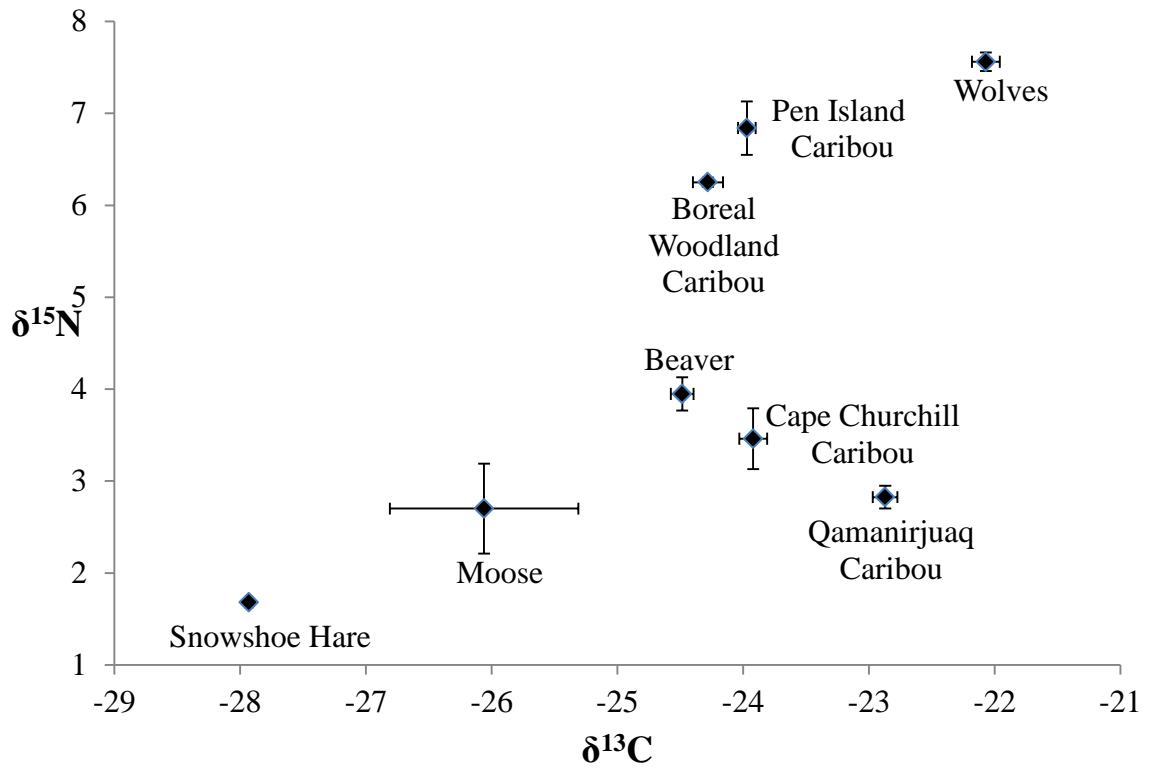
Figure 3.3. Distribution of $\bar{x}$ ($\pm$ SE) $\delta^{13}C_{hair}$ and $\delta^{15}N_{hair}$ values (‰) of wolves ($n = 79$) and prey in northern Manitoba, Canada. Teeth root stable isotope ratios for Qamanirjuaq caribou (Drucker et al. 2001) were corrected to reflect stable isotopes values of hair (Barnett 1994) and corrected for the depletion of $\delta^{13}C$ CO_2 in the atmosphere in the yr 2010 (Long et al. 2005).

Table 3.2. Stable isotope differences in $\delta^{15}N_{hair}$ or $\delta^{13}C_{hair}$ values between prey in northern Manitoba, Canada using multivariate analysis of variance (MANOVA) and sequential Bonferroni adjustments.

	Prey					
	Beaver	**Snowshoe Hare**	**Boreal Woodland Caribou**	**Qamanirjuaq Barren-ground Caribou**	**Cape Churchill Caribou**	**Pen Island Caribou**
Species	P_{Holm}	P_{Holm}	P_{Holm}	P_{Holm}	P_{Holm}	P_{Holm}
Moose (n = 4)	0.001	0.218	<0.001	0.145	0.004	0.001
Beaver (n = 38)		<0.001	<0.001	0.001	0.019	<0.001
Snowshoe Hare (n = 2)			<0.001	0.049	<0.001	<0.001
Boreal Woodland Caribou (n = 30)				<0.001	<0.001	0.019
Qamanirjuaq Barren-ground Caribou[a] (n = 2)					0.038	0.001
Cape Churchill Caribou (n = 9)						<0.001
Pen Island Caribou (n = 9)						

[a]Isotope values of teeth roots reflecting summer dietary habits in 1966 and 1967 (Drucker et al. 2001) corrected to reflect hair stable isotope values (Barnett 1994) and for the depletion of $\delta^{13}C$ CO_2 in the atmosphere in 2010 sampling yr (Long et al. 2005).

P_{Holm}: Adjusted P-value using the sequential Bonferroni procedure modified by Holm (1979).

Table 3.3. 95% Credible interval (CI) dietary estimates for wolves (*n* = 79) from northern Manitoba, Canada by registered trapline (RTL) district reflecting summer–late fall foraging (combined 2009, 2010, and 2011 yrs).

	Prey Sources											
	Moose		Beaver		Boreal Woodland Caribou		Qamanirjuaq Barren-ground Caribou		Cape Churchill Caribou		Pen Island Caribou	
RTL	CI	Mode	CI	Mode	CI	Mode	CI	Mode	CI	Mode	CI	Mode
Brochet (*n* = 18)	0−14	1%	0−44	4%	31−60	46%	11–46	29%	...	...	...	...
South Indian Lake (*n* = 10)	0−33	5%	0−51	30%	18−57	38%	0–41	24%	...	...	...	...
Nelson House (*n* = 14)	44−75	61%	0−39	11%	1−31	16%	0–14	1%	...	...	...	...
Wabowden (*n* = 15)	33−57	47%	2−45	22%	15−47	31%	...	...	...	...	...	...
Cross Lake-Oxford House (*n* = 3)	16−67	39%	0−49	28%	0−39	7%	...	...	...	...	0− 35	5%
Split Lake (*n* = 12)	23−64	45%	0−41	4%	...	...	0−19	1%	0−32	3%	1−30	17%
Churchill-Limestone (*n* = 7)	1−31	16%	0−40	25%	...	...	0−30	13%	0−37	20%	15−42	29%

The lack of statistical difference is attributed to the small sample size which reduced the power of the test and did not allow for a genuine opportunity to reject the null. As a result, I calculated 95% confidence intervals for $\delta^{15}N$ and $\delta^{13}C$ values of Qamanirjuaq caribou, moose, and snowshoe hare in R. All 95% confidence intervals overlapped except $\delta^{13}C$ values of Qamanirjuaq caribou (-24.14, -21.59) and moose (-27.62, -24.50), which I then included in the analysis. Overlap between stable isotope ratios of snowshoe hare and moose may also be explained by their similar browsing habits (Boer 2007). I pooled wolves from Cross Lake ($n = 2$) and Oxford House ($n = 1$) (hereafter Cross Lake-Oxford House) and Churchill ($n = 2$) and Limestone ($n = 5$) (hereafter Churchill-Limestone) RTL districts.

Dietary Habits of Wolves

The proportion of boreal woodland caribou consumed by wolves varied between RTL districts (Table 3.3). Boreal woodland caribou were primary prey for wolves from Brochet and South Indian Lake, whereas moose contributed the least to the diet of wolves in these two RTL districts, and among all areas sampled. Qamanirjuaq caribou were secondary prey in Brochet followed by beaver, whereas in South Indian Lake, beaver were secondary prey followed by Qamanirjuaq caribou.

Wolves primarily consumed moose in Nelson House, Split Lake, Wabowden, and Cross Lake-Oxford House RTL districts (Table 3.3). Caribou (all ecotypes combined) were a secondary prey species. Woodland caribou and beaver were secondary prey in Nelson House RTL district, but beaver was consumed more than woodland caribou in Cross Lake-Oxford House. Woodland caribou were secondary prey in Wabowden RTL district where other caribou ecotypes were unavailable. In Split Lake, where woodland

caribou were unavailable, moose and other caribou ecotypes (Cape Churchill, Pen Island, and Qamanirjuaq) comprised ~78% of the diet with beaver comprising the remainder.

Summer diets of wolves from Churchill-Limestone were sustained primarily by caribou (Table 3.3). Pen Island caribou contributed the greatest to the diet followed by beaver, Cape Churchill caribou, moose, and Qamanirjuaq caribou.

DISCUSSION

In the 1950s, boreal woodland caribou were absent in Brochet and South Indian Lake RTL districts (Bryant 1955), and their presence in these areas today are considered rare (D. Hedman, personal communication). When Qamanirjuaq caribou migrate out of the province in spring, moose are the most abundant prey available to wolves in Brochet and South Indian Lake RTL districts. Although there were exceptions in Brochet and South Indian Lake RTL districts where some individual wolves primarily fed on moose (i.e. W10-009 and W11-012; Appendix B), woodland caribou contributed the most to the diet.

Predators should respond to prey by occupying areas of high prey density to maximize encounter rates (Bergman et al. 2006). Keith (1983) and Fuller (1989) found that an increase in prey – most importantly moose – was associated with an increase in wolves; however, Mech and Peterson (2003) caution that prey abundance may not be linked to food supply especially in complex, multi-prey systems. Some studies also found low levels of wolf predation on moose in the summer, even when moose were the predominant ungulate species (Peterson 1977). Seip (1992) found that wolves in southeastern British Columbia were sustained by moose, but became a major predator of caribou in the summer when caribou, moose, and wolves occupied similar habitat. Robinson et al. (2010) also found woodland caribou predation was elevated in the

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summer when wolves showed similar habitat selection. Furthermore, wolves in Alaska did not respond to changes in ungulate density and continued to prey on caribou when moose were twice as abundant (Dale et al. 1994).

Some wolf territories (defended home ranges) are large. Mech et al. (1998) reported a wolf pack of 10 inhabiting a 4,335 km^2 territory in Alaska (51 locations year-round). Wolves are known to cover large distances in search of food (Frame et al. 2004); however, wolf movements in the spring and summer are limited to their den and rendezvous sites as adults must hunt and return food to the pups (Jedrzejewski et al. 2001, Eriksen et al. 2011). Jędrzejewski et al. (2001) reported daily movements during the denning period to be 15 km/day in May to 19–20 km/day in June/July. Movements gradually increased to meet the growing nutritional demand of the pups (Jędrzejewski et al. 2001). Breeding females are known to undertake long foraging movements (Frame et al. 2004). Frame et al. (2004) recorded a female tundra wolf traveling segments ranging from 3–83 km in response to seasonal prey availability, covering 341 km over 14 days. If wolves were denning in Brochet and South Indian Lake RTL districts, frequent long distance hunting excursions southward would be a high energy expense. Wolf packs can kill moose at rates of one adult moose per 7–16 days in the summer (Ballard and Van Ballenberghe 2007). In such hunting excursions, the net energy gained consuming caribou instead of moose would be lower if Fuller's (1989) body size conversion of one moose equates to three caribou holds true. The large amount of boreal woodland caribou consumed in the summer suggests that hunting forays southward into woodland caribou range are not energetically feasible, but rather wolves may migrate and den within that range in response to the seasonal availability of caribou – Qamanirjuaq barren-ground

caribou in the late fall through winter, and boreal woodland caribou in the summer when Qamanirjuaq caribou are absent in the province.

Migratory wolves generally depend on migratory barren-ground caribou (Kuyt 1969, Stephenson and James 1982, Williams 1990), but can also depend on woodland caribou (Paquet and Carbyn 2003). Whether wolves are migrating within the province into boreal woodland caribou range or into the range in Saskatchewan should be investigated further. Messier (1985) found four packs undertaking extensive winter movements to exploit deer, and in one case, wolves annually embarked on a traditional pattern of movement at the onset of winter. Cowan (1947) found considerable variation in seasonal movements between packs in Banff National Park; some packs had distinct summer and winter ranges separated by considerable distances (97–113 km).

If wolf hair reflects food intake from late May through November, it appears that the late fall–early winter diet signal may have been captured by the estimate of Qamanirjuaq caribou (mode 29% and 21% of Brochet and South Indian Lake RTL districts respectively). Qamanirjuaq caribou are the most abundant ungulate available for wolves in winter, commencing with the annual migration into the province in late August – early September (J.D. Robertson, Game and Fisheries Branch, unpublished report, Bryant 1955). Stomachs of wolves from the 1950s, revealed that barren-ground caribou were the most common prey, contributing 86% of the biomass to the winter diet of wolves from these RTL districts, with moose following in importance (Appendix C). Similar findings were also confirmed by Bryant (1955).

Predictable winter aggregations of Qamanirjuaq caribou in northwest Manitoba may reduce the energy cost to wolves by accessing caribou in known locations. Wolves can select home ranges that provide predictable prey encounters over the long term, then

select for the prey that are the most profitable within those ranges (Kunkel et al. 2004). Wolves hunting within woodland caribou ranges in summer may be searching for less risky foraging opportunities (Forbes 1989) as moose can kill wolves and injure wolves (Mech and Nelson 1990, Weaver 1992). Cow moose will aggressively battle wolves to protect their calves and Mech et al. (1998) reported a cow moose defending her dead calves from wolves for days.

Alternatively, wolves may take advantage of the heightened vulnerability of barren-ground caribou bulls that are lean after the fall rut, and cows with a heavy fetus and high energy requirements in late winter and spring (Skoog 1968). Fat reserves in the Qamanirjuaq herd decline from November–April (Dauphiné 1976) likely due to the great amount of energy expended travelling to their wintering grounds (Bergerud et al. 2008). Bergman et al. (2006) found ungulate densities had a weak influence on wolf movements in Yellowstone National Park and that wolves selected areas where elk vulnerability was the greatest, demonstrating that wolves were capable of selecting for these conditions. Metz et al. (2012) found that the consumption of elk was related to seasonal prey vulnerability; consuming elk when they were in their poorest nutritional condition. Future stable isotope analyses of this system should incorporate the analysis of severed base and tip portions of wolf hair to determine the possibility of seasonal shifts in foraging. Darimont and Reimchen (2007) separately analyzed base and tip portions of wolves' hair to find that salmon were seasonally important to the diet of wolves in the fall.

In this study, some wolves (e.g. W09-030, W09-035, and W11-006; Appendix B) consumed approximately 50% Qamanirjuaq caribou, suggesting that these wolves may also be migratory, following this herd into their summer range in Nunavut. Migratory wolves associated with Qamanirjuaq caribou have been observed by Parker (1973) and

similar associations between migratory wolves and other barren-ground caribou herds have been documented in Nunavut, Northwest Territories, and Alberta (Williams 1990, Walton et al. 2001, Musiani et al. 2007). The small amount of boreal woodland caribou consumed by these wolves might reflect the late fall when wolves following Qamanirjuaq caribou into their winter range can overlap boreal woodland caribou (Courtois et al. 2003).

Alternatively, the high summer consumption of boreal woodland caribou in Brochet and South Indian Lake RTL districts may relate to biases in sampling a distinct demographic cohort. Trapped wolves sampled may be less cautious, inexperienced young individuals that select smaller, safer ungulates to hunt. Pups and yearlings comprised 71% of trapped wolves in west-central Alberta (Webb et al. 2011), and the age structure of trapped wolves in a study by Mech (2006) was heavily skewed to young animals. In contrast, McNay et al. (2008) recorded the age of wolves trapped and found that 76% of wolves were ≥3 years old. Likewise, trapped wolves may have been loners unassociated with a pack, or wolves that have undergone social dominance changes within their pack, causing them to select less dangerous, smaller ungulates. Sand et al. (2006) compared prey selection among two wolf packs in Scandinavia before and after they lost one of their breeding wolves. In one pack consisting of one adult male and one adult female wolf, 73% of their kills were moose. The pair reproduced and the female was later killed, leaving the male as the only adult in the pack. Despite the loss of the breeding female, moose continued to dominate the kills (75%) with ≤17% of the moose and eight roe deer killed on his own (Sand et al. 2006). The second pack, composed of one female and her two adult male offspring, were primarily sustained on hunting moose (94% of kills), yet the following winter when the two males had dispersed, prey selection changed as the

female killed 20% moose calves and 80% roe deer which are six to 16 times smaller than juvenile and adult moose respectively (Sand et al. 2006). Gunson (1986) found that a large wolf pack once primarily sustained on moose, switched to preying on elk once the two adults males in the pack were killed. Despite these findings, single wolves can kill adult moose (Cowan 1947, Thurber and Peterson 1993, and Mech et al. 1998).

Wolves from Nelson House, Split Lake, Wabowden, Cross Lake/Oxford House RTL districts had similar dietary habits with wolves from Alberta, British Columbia, and Québec (Seip 1992, Allison 2001, Tremblay et al. 2001, James et al. 2004) in prey systems with caribou and moose.

In the past, logging practices occurred in Wabowden and Nelson House RTL districts (Elliot 1988, Brown 2001) creating young forests better suited to moose than boreal woodland caribou (Brown 2001). Elliot (1988) found young mixed wood deciduous habitat supported greater moose densities in a moose census of northern Manitoba. Forestry practices create young seral stages in mixed deciduous forests and these clearcuts are frequently occupied by wolves and moose (Pulliainen 1982, Kuzyk et al. 2004, Courbin et al. 2009, Bowman et al. 2010, Gurarie et al. 2011). The ability of young forests to support high densities of moose, which in turn support high wolf densities, can increase wolf predation on boreal woodland caribou due to higher encounter rates. A density of 0.10 moose per km^2 can allow wolves to reach ≥ 6.5 per 1,000 km^2, which limits boreal woodland caribou numbers (see Fig. 10 in Bergerud and Elliott 1986). Wolf numbers are not impacted by caribou declines, thus high densities of moose and wolves keep woodland caribou populations at low levels and facilitate further fragmentation of woodland caribou distribution; a scenario referred to as 'asymmetrical apparent competition' (Holt 1977, Rempel et al. 1997, Kuzyk et al. 2004, Bergerud et al.

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2008, Seip 2008, DeCesare et al. 2009). Wapisu and Wabowden boreal woodland caribou herds currently appear stable or slightly increasing (D. Hedman, personal communication); however, as these herds range within the Wabowden and Nelson House RTL districts, they may be more susceptible to wolf predation as a result of forestry activities.

Beaver are an important summer food item for wolves in northern Manitoba. Similar findings were reported in west-central Manitoba, Ontario, Alberta, and British Columbia (Toews 1979, Forbes and Theberge 1996, Allison 2001, James et al. 2004, Latham et al. 2011). One individual wolf (W09-022; Appendix B) appeared to be specialized in hunting beaver, comprising ~83% of the diet (65–97%).

The low consumption of moose in Churchill-Limestone is likely reflective of a low availability of moose. Migratory caribou species were the predominant summer prey for wolves harvested in these regions; however, the low consumption of Cape Churchill caribou is attributed to the small number of samples collected ($n = 2$) from the Churchill RTL district which encompasses the summer range of this herd.

General Discussion

Wide credible intervals in dietary outputs for wolves, as observed in this study also occurred in research by Steenweg (2011) and Milakovic and Parker (2011) and several possible explanations exist. Using species-specific trophic discrimination values for the species of interest is important because mixing models like SIAR can be sensitive in the model construction (Bond and Diamond 2011). Bond and Diamond (2011) used various trophic discrimination values for marine birds to infer diets of Common Terns (*Sterna hirundo*) and found the diet estimates differed significantly. Depending on which trophic

discrimination value used, Bond and Diamond (2011) found the median estimate of krill

(*Meganyctiphanes norvegica*) in their diets varied from 10.8–90.7%. One would suspect

that the physiological differences between red foxes and wolves would result in much

different trophic discrimination values, however, until future research on wolf-specific

trophic discrimination values are obtained, the use of trophic discrimination values for red

foxes (Roth and Hobson 2000) in wolf studies will continue to be used in ongoing

research (Milakovic and Parker 2011, Derbridge et al. 2010).

The average δ^{15}N and δ^{13}C values obtained for Qamanirjuaq caribou from

Drucker et al. (2001) were derived from two samples from the 1960s. Barren-ground

caribou are generally found in aggregations in July when insect harassment is at its peak

(Heard et al. 1996). During this period, they likely consume similar forage; however,

when insect numbers decline in August, aggregations break-up (Heard et al. 1996) and

the low number of caribou sampled may not have captured the variability in their diets to

accurately represent the herd. In addition, the range use of Qamanirjuaq caribou remains

unpredictable and inconsistent between years (Heard and Calef 1986, Thompson and

Fisher 1979, Campbell 2005), thus foraging conditions and range use in the 1960s may

not have been similar during this study. Although cows return to the general area of

traditional calving grounds (Campbell 2005), their use of areas within their summer range

are influenced by factors such as weather, snow melt, plant phenology, insect harassment,

and predator avoidance (Beverly and Qamanirjuaq Caribou Management Board 2004).

Despite these sources of error, SIAR estimated the greater use of Qamanirjuaq caribou by

wolves in RTL districts with closer access to these herds on their wintering grounds; in

this study, Qamanirjuaq caribou wintered primarily near Lac Brochet and Tadoule Lake

(Fig. 3.2).

As mixing models like SIAR require prior knowledge of likely prey, using stable isotopes may not offer comparable insight into the diversity of wolf diets as frequently observed in faeces and stomachs. Prey species not incorporated into the SIAR model, particularly small mammals and birds, possibly contributed to the uncertainty in diet estimates. Using $\delta^{15}N$ and $\delta^{13}C$ also limited the ability to identify the contribution of ungulate calves in diets, at least for moose, which can be important summer prey for wolves (Sand et al. 2008, Liberg et al. 2010, Gurarie et al. 2011, Metz et al. 2012). Thus, the dietary proportions may also reflect contributions from calves, which could have enriched $\delta^{15}N$ values of wolves.

Obtaining wolf hair samples from trappers depended on many factors including weather conditions, fur prices, cost, and trapper effort. Collecting representative samples from every RTL district each year was not possible and therefore did not allow for yearly comparisons and, in pooling samples it was assumed that any dietary differences between years would be negligible. Although this may have contributed to the wide credible intervals, utilizing trapper harvests appear to be the most efficient method of collecting furbearer samples, enabling vast coverage of this remote area. Since hair samples do not require special storage, wildlife managers in northern Manitoba are encouraged to utilize trapper harvests for stable isotope analyses as a complementary method in dietary research.

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CHAPTER 4: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY AND CONCLUSIONS

The objectives of this thesis were 2-fold: 1) to establish a baseline dataset of stable isotope ratios for northern Manitoba caribou ecotypes; and 2) to use this dataset of caribou stable isotope ratios, with the stable isotope ratios of other likely wolf prey, to understand the summer foraging habits of wolves. The utility of using stable isotopes reveals the possible use of this methodology to assess foraging strategies of wolves in other complex multi-ungulate ecosystems where boreal woodland caribou occur. Understanding ecological relationships and threats to boreal woodland caribou survival are important for developing appropriate action plans for boreal woodland caribou recovery. This thesis was the first to explore the summer diets of wolves in northern Manitoba and the potential implications for boreal woodland caribou.

In Chapter 2, I compiled Manitoba's first dataset of carbon and nitrogen stable isotope ratios for caribou. Each caribou ecotype sampled displayed different stable isotope signatures which may be the result of forest-canopy structure, forage, or climatic differences between their respective summer habitats.

I documented in Chapter 3 that the proportion of boreal woodland caribou consumed by wolves in the summer varied spatially; boreal woodland caribou were the primary prey in some registered trapline (RTL) districts and secondary prey in others. Unexpectedly, boreal woodland caribou were primary prey for wolves in areas where these caribou are considered rare; this may have revealed migratory behaviour in some wolves or could have resulted from sampling biases, although not conclusive. To explore the possibility of seasonal migrations undertaken by wolves, information on wolf

movement patterns using satellite telemetry would be necessary. In the Nelson House and Wabowden RTL districts, moose were primary prey for wolves followed by boreal woodland caribou, with beaver providing important contributions. These RTL districts have been impacted by forestry practices which created logging roads and habitat better suited for moose (Brown 2001), thus these areas are a 'red flag' for wildlife managers as anthropogenic disturbances can indirectly facilitate boreal woodland caribou population declines through increased predation.

RECOMMENDATIONS

Despite being one of few large areas in North America with a diversity of large carnivores and ungulates, wildlife research in northern Manitoba is in its infancy. Wildlife research must continue if the managing authority (i.e. Manitoba) wishes to gain a better understanding of the dynamic relationships between wolves and ungulates, not only in northern Manitoba, but also other areas where predation can have implications to other ungulate populations that are severely depressed. The baseline information provided in this thesis is based on a short collection period that may not be useful in an adaptive management sense, given the dynamic relationship between wolves and their prey, but does offer fruitful areas for further investigation. It must not be presumed that the dietary habits of wolves in the summer is reflective of those in other seasons, as many prey are migratory and seasonally available (e.g. Qamanirjuaq barren-ground caribou, Cape Churchill caribou herd, Pen Island caribou herd, and beaver). Furthermore, changes in the migratory behaviour of prey, (e.g. the Pen Island caribou herd – see Abraham et al. 2012), are bound to have implications on the foraging ecology of wolves.

Few longer-term studies on wolf-prey systems have been performed; some have documented changes in wolf-prey relations over many years (Vucetich et al. 2010, Lantham et al. 2011*b*). Wolf-moose relationships have been studied for nearly 50 years on Isle Royale, where the first two decades of research were characterized by different dynamics than the two subsequent decades (Peterson et al. 1998, Wilmers et al. 2006), and the dynamics were noticeably different in five year periods (Vucetich et al. 2010). Wilmers et al. (2006) found that before 1980, wolf predation strongly influenced moose population dynamics, but after 1980, winter climate and food availability became more important to moose. Ten years after a study by James et al. (2004) in northeastern Alberta, Latham et al. (2011*b*) discovered that the diet of wolves shifted from being moose dominated to primarily deer. Higher deer densities were speculated to stimulate a numerical response of wolves, causing increased predation of woodland caribou; woodland caribou consumption increased 10-fold (Latham et al. 2011*b*). Recently, Latham et al. (2012) found that the dietary selection for beaver in the summer by wolves resulted in habitat overlap with caribou, and was reflected by heightened caribou mortalities. Such findings show the dynamic complexities in wolf-prey systems and why monitoring must be ongoing.

As the City of Thompson asserts itself as the 'Wolf Capital of Canada', developing a plan for research, education, and tourism, with the Province of Manitoba in full support (Province of Manitoba 2012), an opportunity exists for researchers to carry-out long term investigations on wolves and their prey to develop more comprehensive information and ideas. Knowledge of moose, caribou, and wolf densities, habitat utilization, and population trends are important for boreal woodland caribou recovery, yet these remain poorly understood in northern Manitoba.

Research Recommendations

Moose surveys performed by Bryant (1955) and Elliot (1988) are outdated and have not been reassessed. Moose in Brochet and South Indian Lake RTL districts may be close to reaching peak numbers 22 years after a major wildfire in 1989 (see Kelsall et al. 1977, Schwartz and Franzmann 1989, Loranger et al. 1991). Of particular interest would be to understand why moose were not primary prey for wolves in these RTL districts during summer and late fall; moose habitat selection and body condition could provide key information. Presuming the abundance of moose in these RTL districts will decrease with forest succession, continuing the stable isotope work reported in Chapter 3 will be important for monitoring changes in predator-prey relationships.

Woodland caribou are likely to use alternative habitats occupied by moose when their main habitat becomes less available (Szkorupa and Schmiegelow 2003). Boreal woodland caribou herds inhabiting RTL districts where linear corridors, forestry practices, and wildfire activity have affected the landscape, may be susceptible to competition with moose and therefore, be at a higher risk level for wolf predation. Future research on the differences between the impacts of fire, logging, and corridors (snowmobile routes, forestry roads, winter roads, transmission line corridors, etc.) on the use by wolves, caribou, and moose would enhance our understanding of this system.

Little information is available on the Kississing, Naosap, and Reed boreal woodland caribou herds inhabiting areas near Russell Lake, Manitoba (Fig. 3.2; D. Hedman, Manitoba Conservation and Water Stewardship, personal communication). The Naosap herd in particular, is of high conservation concern and unlikely to be self-sustaining, as transportation corridors, hydro electric transmission corridors, and habitat disturbance from wildfires and forestry are risk factors to be considered (Manitoba

Conversation 2006, Metsaranta and Mallory 2007, Environment Canada 2011).

Monitoring population dynamics of these caribou herds in conjunction with the satellite tracking of wolves can clarify whether wolves from Brochet and South Indian Lake RTL districts are denning in these ranges in the summer. Routinely updated wildlife survey data from each RTL district will allow researchers and stakeholders to form a baseline of what is currently on the landscape, and guide strategies to monitor changes in predator-prey abundance and distribution.

Additionally, we still do not have a grasp on the impact of Aboriginal harvests on boreal woodland caribou populations when hunting has limited the growth of some caribou populations in North America (Bergerud et al. 2008). Gathering traditional knowledge specifically focused on boreal woodland caribou can provide insightful information that can be incorporated into the recovery planning (e.g. the importance of caribou as a country food and traditional management practices) (McDonald 2010, Benson 2011).

Wolves following the winter migration of barren-ground caribou can overlap into the spatial range of territorial wolves in the boreal forest (J.D. Robertson, Game and Fisheries Branch, unpublished report, Musiani et al. 2007, Carmichael et al. 2007), but the spatial relationships among these groups are unknown and warrant further investigation. Alternatively, wolves may not undertake annual migrations (Stephenson and James 1982, Ballard et al. 1997) to the tundra if they have sufficient access to alternative prey in northern Manitoba. It would be of interest to identify the spatial interactions between migratory and resident wolves, and to understand whether migratory behaviours are occasionally abandoned in this system.

Musiani et al. (2007) identified genetic differences in wolves inhabiting northern North America corresponding to the southern limit of migratory caribou ranges, and the ecological boundary between boreal forest and tundra/taiga habitats. Such genetic research in northern Manitoba would be of interest, and must involve collaboration with wildlife officials in Nunavut for biological sampling and satellite telemetry of Qamanirjuaq barren-ground caribou and wolves.

A research opportunity may also exist for non-invasive stable isotope research on captive wolves at the Thompson Zoo. Red fox trophic discrimination values from Roth and Hobson (2000) are used to reconstruct diets of wolves, as they are the closest related species to wolves where values have been obtained. As these wolves are fed in a controlled environment, measuring trophic discrimination values from the stable isotopes of carbon and nitrogen in wolf hairs left in bedding areas could refine both past and future stable isotope dietary studies on wolves.

Since woodland caribou declines are measured by female and calf mortalities (McLoughlin et al. 2003, Bergerud et al. 2008, DeCesare et al. 2012), research should be expanded beyond the role of wolves as primary predators. Other carnivores such as wolverines, black bears, and coyotes available in northern Manitoba might play an important role in caribou predation, particularly for calves, which impacts herd productivity (Bergerud and Elliot 1986, Adams et al. 1995, Gustine et al. 2006; Bergerud et al. 2008). Wolverines were primary predators of caribou calves <14 days old in northern British Columbia (Gustine et al. 2006). Although believed to be scavenged upon, caribou and moose were main sources of food for wolverines in Alaska and British Columbia (Lofroth et al. 2007, Dalerum et al. 2009). The high mobility of black bears and coyotes in Gaspésie Conservation Park, Quebec resulted in an overlap of the area used by

female caribou during the calving period (Mosnier et al. 2008). Latham et al. (2011*a*) also found overlap in habitat use by black bears and woodland caribou during the calving season in northeastern Alberta. In Newfoundland, coyotes and black bears are the main predators of caribou calves, accounting for 45–90% of calf mortalities (Gullage et al. 2012). With wolves now being found on the Island (Canadian Broadcasting Corporation 2012), they may become an important factor. Leclerc et al. (2012) found black bears to be the primary cause of woodland caribou calf mortalities in Saguenay – Lac St. Jean, Quebec. Since stable isotopes of δ^{15}N and δ^{13}C limit the ability to identify the contribution of caribou and moose calves in the diet of wolves, future investigations using high-resolution animal-borne video cameras could shed light on the behaviour of the entire suite of predators available, or alternatively, if fitted on caribou calves, could provide confirmed causes of mortality.

White-tail deer (*Odocoileus virginianus*) were considered scarce in northern Manitoba in the 1950s (Bryant 1955) and still are today (D. Hedman, personal communication). With climate change influencing the northern advancement of species, adaptive management plans should be in place to monitor the potential influx of white-tailed deer. Like moose, white-tailed deer select similar habitats and can facilitate apparent competition with woodland caribou (Bowman et al. 2010, Latham et al. 2011*b*). In southeastern Manitoba, virtually all deer are carriers of brain worm (*Parelaphostrongylus tenuis*) – with climate change, the risk of deer, that are carriers of brain worm, advancing north is high (Wasel et al. 2003). Additionally, white-tailed deer are carriers of chronic wasting disease (CWD) and although natural transmission of CWD-infected deer to caribou has not been reported, Mitchell et al. (2012) have confirmed transmission experimentally.

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Wildlife research and management programs and policy development must involve northern Aboriginal communities, hunters, and trappers; this is critical to addressing ecological knowledge gaps for this particular region. Using local and traditional ecological knowledge as supplementary data in research can provide decades of information on population peaks and crashes, observations, and counts (Manitoba Trappers Association 2011). Manitoba must consider using compulsory hunter and trapper questionnaires for their respective trapline or game hunting areas, record observations and counts, then have this stored and examined by staff, graduate students, and researchers as funding permits. In these contemporary times, such information is important to ongoing wildlife monitoring in northern Manitoba since the region is vast, remote, and costly for Provincial staff to do this unilaterally. As wolves are highly mobile, stakeholder involvement should be multi-jurisdictional, extending to government agencies, Aboriginal communities, and the hunters and trappers in Nunavut, Saskatchewan, and Ontario. Communication must be continuous and carried-out through numerous channels such as meetings, publications, and newsletters.

Despite the existence of many ecological unknowns presented here, this study is a starting point for future investigations in northern Manitoba. Recent extirpations of caribou herds in Alberta (Hebblewhite et al. 2009) demonstrate the real urgency needed to address provincial objectives for boreal woodland caribou conservation and recovery (Manitoba Conservation 2006), particularly for northern Manitoba. Further multi-trophic level research will be essential to understanding predator-prey relationships between wolves and their prey, and the implications for boreal woodland caribou.

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Table A.1. $\delta^{15}N_{hair}$ and $\delta^{13}C_{hair}$ values (‰) of ungulates in northern Manitoba, Canada reflecting 2010 summer–late fall foraging habits. Habitats abbreviated: (BF) = Boreal forest; (CT) = Coastal tundra; (T) = Tundra; (TI) = Taiga. Qamanirjuaq barren-ground caribou values adjusted from Drucker et al. (2001).

ID No.	Common Name	Scientific Name	Location	Habitat	Yr	$\delta^{15}N$	$\delta^{13}C$
M10-001	Moose	*Alces alces*	Wabowden	BF	2010	4.4	−25.1
M10-002	Moose	*Alces alces*	South Indian Lake	BF	2010	3.0	−27.4
M10-003	Moose	*Alces alces*	South Indian Lake	BF	2010	2.7	−25.9
M10-004	Moose	*Alces alces*	South Indian Lake	BF	2010	0.7	−25.8
C10-001	Woodland Caribou	*Rangifer tarandus caribou*	Wabowden	BF	2010	6.2	−23.8
C10-002	Woodland Caribou	*Rangifer tarandus caribou*	Wabowden	BF	2010	5.3	−23.6
C10-003	Woodland Caribou	*Rangifer tarandus caribou*	Wabowden	BF	2010	6.1	−24.1
C10-004	Woodland Caribou	*Rangifer tarandus caribou*	Wabowden	BF	2010	6.6	−23.9
C10-005	Woodland Caribou	*Rangifer tarandus caribou*	Wabowden	BF	2010	6.1	−24.4
C10-006	Woodland Caribou	*Rangifer tarandus caribou*	Wabowden	BF	2010	4.9	−24.9
C10-007	Woodland Caribou	*Rangifer tarandus caribou*	Wabowden	BF	2010	5.7	−24.3
C10-008	Woodland Caribou	*Rangifer tarandus caribou*	Wabowden	BF	2010	6.5	−24.6
C10-009	Woodland Caribou	*Rangifer tarandus caribou*	Wabowden	BF	2010	6.6	−24.4
C10-010	Woodland Caribou	*Rangifer tarandus caribou*	Wabowden	BF	2010	6.0	−24.6
C10-011	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	5.7	−24.1
C10-012	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	6.8	−24.2
C10-013	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	7.5	−24.7
C10-014	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	7.6	−24.8

ID No.	Common Name	Scientific Name	Location	Habitat	Yr	δ^{13}C	δ^{15}N
C10-015	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	6.3	–24.5
C10-016	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	5.4	–24.4
C10-017	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	7.2	–24.0
C10-018	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	6.5	–24.1
C10-019	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	5.9	–24.4
C10-020	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	5.5	–24.4
C10-021	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	5.6	–23.7
C10-022	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	6.6	–24.5
C10-023	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	5.9	–24.2
C10-024	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	6.7	–24.0
C10-025	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	6.2	–24.1
C10-026	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	6.0	–24.2
C10-027	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	7.0	–24.5
C10-028	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	6.5	–24.2
C10-029	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	5.7	–24.2
C10-030	Woodland Caribou	*Rangifer tarandus caribou*	Wapisu	BF	2010	6.9	–24.5
204[a]	Barren-ground Caribou	*R. t. groenlandicus*	Qamanirjuaq, Nunavut	T/TI	2010	2.7	–22.8
397[a]	Barren-ground Caribou	*R. t. groenlandicus*	Qamanirjuaq, Nunavut	T/TI	2010	3.0	–23.0
C10-031	Forest-tundra Caribou	*R. tarandus* ssp.	Pen Island	CT/BF	2010	6.3	–24.1
C10-032	Forest-tundra Caribou	*R. tarandus* ssp.	Pen Island	CT/BF	2010	7.7	–24.3
C10-033	Forest-tundra Caribou	*R. tarandus* ssp.	Pen Island	CT/BF	2010	6.8	–23.9
C10-034	Forest-tundra Caribou	*R. tarandus* ssp.	Pen Island	CT/BF	2010	5.2	–24.2
C10-035	Forest-tundra Caribou	*R. tarandus* ssp.	Pen Island	CT/BF	2010	6.7	–23.8
C10-036	Forest-tundra Caribou	*R. tarandus* ssp.	Pen Island	CT/BF	2010	7.7	–23.7
C10-037	Forest-tundra Caribou	*R. tarandus* ssp.	Pen Island	CT/BF	2010	8.0	–23.9
C10-038	Forest-tundra Caribou	*R. tarandus* ssp.	Pen Island	CT/BF	2010	6.9	–23.8
C10-039	Forest-tundra Caribou	*R. tarandus* ssp.	Pen Island	CT/BF	2010	6.3	–24.1

ID No.	Common Name	Scientific Name	Location	Habitat	Yr	$\delta^{13}C$	$\delta^{15}N$
C10-040	Forest-tundra Caribou	*R. tarandus* ssp.	Cape Churchill	CT/BF	2010	2.8	−24.3
C10-041	Forest-tundra Caribou	*R. tarandus* ssp.	Cape Churchill	CT/BF	2010	3.9	−24.3
C10-042	Forest-tundra Caribou	*R. tarandus* ssp.	Cape Churchill	CT/BF	2010	2.9	−23.9
C10-043	Forest-tundra Caribou	*R. tarandus* ssp.	Cape Churchill	CT/BF	2010	3.3	−23.9
C10-044	Forest-tundra Caribou	*R. tarandus* ssp.	Cape Churchill	CT/BF	2010	5.6	−23.8
C10-045	Forest-tundra Caribou	*R. tarandus* ssp.	Cape Churchill	CT/BF	2010	2.7	−23.4
C10-046	Forest-tundra Caribou	*R. tarandus* ssp.	Cape Churchill	CT/BF	2010	2.8	−24.1
C10-047	Forest-tundra Caribou	*R. tarandus* ssp.	Cape Churchill	CT/BF	2010	4.4	−23.4
C10-048	Forest-tundra Caribou	*R. tarandus* ssp.	Cape Churchill	CT/BF	2010	3.0	−24.1

[a] Teeth roots reflecting the summer diet of 1966 (ID No. 204) and 1967 (ID No. 397) (Drucker et al. 2001) corrected to reflect $\delta^{15}N_{hair}$ and $\delta^{13}C_{hair}$ values (Barnett 1994) and adjusted for the depletion of $\delta^{13}C$ CO_2 in the atmosphere in the yr 2010 (Long et al. 2005).

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APPENDIX B: 95% Credible interval dietary estimates of individual wolves in northern Manitoba, Canada

Table B.1. 95% Credible interval (CI) dietary estimates of individual wolves harvested in northern Manitoba, Canada by registered trapline (RTL) district during winters 2009, 2010, and 2011. Wolves ordered by descending moose consumption. Harvest yr marked: W09-*xxx* = 2009; W10-*xxx* = 2010; and W11-*xxx* = 2011.

	Prey Sources											
	Moose		Beaver		Boreal Woodland Caribou		Qamanirjuaq Barren-ground Caribou		Cape Churchill Caribou		Pen Island Caribou	
RTL District	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)
Brochet (*n* = 18)												
W11-013	7–54	33	0–50	29	3–54	34	0–28	3	...	...	...	...
W11-007	3–45	27	0–47	27	3–49	30	1–39	27	...	...	...	...
W09-027	1–46	25	0–50	28	10–70	39	0–25	3	...	...	...	...
W09-017	0–37	16	0–46	28	6–52	32	4–46	30	...	...	...	...
W11-022	0–47	13	0–54	4	13–84	44	0–18	2	...	...	...	...
W11-018	0–58	4	0–64	3	8–92	42	0–13	1	...	...	...	...
W09-015	0–35	3	0–51	4	20–85	61	0–25	2	...	...	...	...
W11-016	0–32	3	0–50	29	13–68	39	1–40	27	...	...	...	...
W09-019	0–29	2	0–48	29	4–49	33	11–61	38	...	...	...	...
W09-025	0–30	2	0–49	29	9–59	39	6–50	33	...	...	...	...

RTL District	Moose		Beaver		Boreal Woodland Caribou		Qamanirjuaq Barren-ground Caribou		Cape Churchill Caribou		Pen Island Caribou	
	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)
Brochet (*n* = 18)												
W09-021	0−23	1	0−65	39	0−36	19	5−70	40	...	...	...	...
W09-023	0−26	1	0−54	32	3−50	34	8−61	37	...	...	...	...
W09-030	0−22	1	0−68	42	0−26	3	8−86	42	...	...	...	...
W11-005	0−26	1	0−57	34	0−39	23	11−73	43	...	...	...	...
W11-006	0−26	1	0−55	34	0−34	19	15−78	43	...	...	...	...
W11-011	0−25	1	0−62	36	1−45	29	5−62	36	...	...	...	...
W11-017	0−25	1	0−61	37	0−37	19	9−72	39	...	...	...	...
W11-018	0−24	1	0−62	36	4−62	37	1−45	28	...	...	...	...
South Indian Lake (*n* = 10)												
W10-009	35−87	59	0−45	3	0−38	4	0−17	1	...	...	...	...
W11-012	29−80	52	0−50	4	0−34	3	0−25	2	...	...	...	...
W09-034	0−39	19	0−47	27	9−61	35	1−37	23	...	...	...	...
W09-036	0−34	8	0−47	29	10−59	36	3−45	30	...	...	...	...
W09-035	0−34	6	0−50	29	0−31	12	17−77	42	...	...	...	...
W09-028	0−28	2	0−54	4	12−71	46	1−42	27	...	...	...	...
W09-037	0−29	2	0−48	30	7−54	35	10−56	36	...	...	...	...
W09-038	0−29	2	0−50	30	1−42	25	14−69	42	...	...	...	...
W09-022	0−11	1	65−97	83	0−24	2	0−17	6	...	...	...	...
W09-031	0−27	1	0−54	31	2−48	32	10−63	40	...	...	...	...

| | Prey Sources | | | | | | | | | | | |
| | Moose | | Beaver | | Boreal Woodland Caribou | | Qamanirjuaq Barren-ground Caribou | | Cape Churchill Caribou | | Pen Island Caribou | |
RTL District	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)
Nelson House (*n* = 14)												
W09-004	32−84	58	0−48	4	0−31	3	0−24	2	...	...	...	...
W09-006	31−81	55	0−49	4	0−30	3	0−27	2	...	...	...	...
W10-019	26−81	52	0−50	4	0−42	12	0−20	1	...	...	...	...
W09-009	28−80	50	0−50	4	0−36	3	0−24	2	...	...	...	...
W10-008	25−75	48	0−51	26	0−36	3	0−28	3	...	...	...	...
W09-029	24−74	47	0−51	31	0−32	3	0−32	3	...	...	...	...
W11-010	24−74	46	0−50	4	0−41	15	0−24	2	...	...	...	...
W10-010	23−73	44	0−51	31	0−30	3	0−36	5	...	...	...	...
W09-013	21−71	43	0−51	25	0−40	14	0−28	2	...	...	...	...
W09-003	21−78	41	0−51	29	0−35	4	0−35	5	...	...	...	...
W09-011	20−70	41	0−51	5	0−45	29	0−24	2	...	...	...	...
W09-008	21−69	40	0−50	29	0−40	7	0−31	3	...	...	...	...
W10-017	14−61	37	0−50	30	1−46	28	0−30	5	...	...	...	...
W10-018	0−30	2	0−50	29	12−66	42	2−44	30	...	...	...	...
Wabowden (*n* = 15)												
W10-002	24−84	49	0−58	27	0−42	14	...	...	...	...	...	...
W11-001	21−81	46	0−60	36	0−42	14	...	...	...	...	...	...
W10-003	17−77	44	0−61	36	0−44	22	...	...	...	...	...	...
W10-006	15−75	43	1−62	33	0−45	24	...	...	...	...	...	...
W11-003	14−73	43	0−62	36	0−46	29	...	...	...	...	...	...

	Prey Sources											
	Moose		Beaver		Boreal Woodland Caribou		Qamanirjuaq Barren-ground Caribou		Cape Churchill Caribou		Pen Island Caribou	
RTL District	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)
Wabowden (*n* = 15)												
W09-012	9−71	42	1−68	38	0−45	26	...	...	...	...	...	...
W010-001	12−71	40	0−63	35	1−47	28	...	...	...	...	...	...
W09-001	9−66	39	0−59	33	2−55	35	...	...	...	...	...	...
W09-020	10−67	38	0−60	34	2−53	34	...	...	...	...	...	...
W10-004	4−62	37	0−58	20	5–63	40	...	...	...	...	...	...
W11-008	2−60	36	3−74	39	0−48	26	...	...	...	...	...	...
W10-011	0−55	28	0−58	5	9−78	45	...	...	...	...	...	...
W10-007	1−50	27	0−59	36	10−73	43	...	...	...	...	...	...
W11-015	1−51	26	1−60	34	9−70	42	...	...	...	...	...	...
W09-002	0−48	23	1−61	35	10−74	42	...	...	...	...	...	...
Cross Lake/ Oxford House (*n* = 3)												
W11-009	21−68	68	0−49	29	0−39	4	...	...	...	...	0−35	3
W11-014	27−76	49	0−47	4	0−37	3	...	...	...	...	0−32	3
W09-016	15−61	36	0−50	28	0−40	15	...	...	...	...	0−37	6
Split Lake (*n* = 12)												
W09-005	34−82	58	0−41	3	...	...	0−15	1	0−22	2	0−33	4
W09-010	30−76	52	0−43	4	...	...	0−23	2	0−32	3	0−22	2
W11-002	24−69	43	0−45	4	...	...	0−25	2	0−35	3	0−25	2
W10-016	22−64	40	0−44	10	...	...	0−27	2	0−36	3	0−26	2
W09-007	20−61	38	0−44	22	...	...	0−27	2	0−36	4	0−29	3
W09-014	20−63	38	0−45	4	...	...	0−21	2	0−32	3	0−36	15

| | Moose | | Beaver | | Boreal Woodland Caribou | | Qamanirjuaq Barren-ground Caribou | | Cape Churchill Caribou | | Pen Island Caribou | |
| | | | | | | | Prey Sources | | | | | |
RTL District	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)	95% CI (%)	Mode (%)
Split Lake (*n* = 12)												
W10-014	18−60	36	0−44	25	...	...	0−32	16	0−38	23	1−38	23
W10-013	17−56	35	0−43	24	...	...	0−19	2	0−33	3	14−63	37
W10-012	11−48	29	0−41	24	...	...	6−51	31	0−39	19	3−41	26
W10-015	4−39	24	0−38	23	...	...	0−22	2	0−34	3	0−36	17
W09-018	0−39	20	0−43	4	...	...	0−32	3	0−38	17	0−26	2
W10-005	0−24	2	0−39	23	...	...	0−34	16	0−39	20	0−28	5
Churchill/Limestone (*n* = 7)												
W09-026	14−53	33	0−42	25	...	...	0−30	3	0−38	16	2−30	5
W11-004	8−47	28	0−41	23	...	...	0−24	2	0−34	4	2−44	26
W11-021	9−37	23	0−40	24	...	...	0−26	2	0−37	18	8−51	30
W09-033	1−33	17	0−38	21	...	...	1−40	25	0−40	23	1−35	21
W09-024	0−32	15	0−38	22	...	...	0–30	13	0−39	20	8−50	29
W11-020	0−28	6	0−37	21	...	...	1−38	24	0−40	23	8−48	29
W09-032	0−21	1	0−45	28	...	...	4−55	30	0−38	3	3−43	26

APPENDIX C: Stomach content analyses of winter-killed wolves in northern Manitoba, Canada in 1951 and 1952

OBJECTIVE

The study objective was to use stomach content data from wolves (*Canis lupis*) obtained from the Game and Fisheries Branch (unpublished report), to identify the relative importance of prey species to the winter diet of wolves in northern Manitoba in the 1950s.

METHOD

Strychnine poison baits targeting wolves were set in the winters of November 1951 and 1952. Frozen carcasses of poisoned wolves were retrieved in April (the following year), and stomach contents were examined in the field (J.D. Robertson, Game and Fisheries Branch, unpublished report). Targeted areas for wolf control were Brochet, South Indian Lake, Split Lake, and Churchill registered trapline (RTL) districts, essentially between the 57th and 58th parallel (J.D. Robertson, Game and Fisheries Branch, unpublished report). At the time, Qamanirjuaq barren-ground caribou (*Rangifer tarandus groenlandicus*) wintered in all of these RTL districts (J.D. Robertson, Game and Fisheries Branch, unpublished report).

Barren-ground caribou, white-tailed deer (*Odocoileus virginianus*), and fish (*Coregonus clupeaformis*) often used as bait to attract wolves (J.D. Robertson, Game and Fisheries Branch, unpublished report, Bryant 1955). To minimize potential biases associated with the bait used, white-tailed deer and fish were excluded from the analysis. The removal of white-tailed deer should not have hampered findings since white-tailed deer were considered scarce in northern Manitoba (Bryant 1955). The prevalence of barren-ground caribou in the diet from this data set should be cautioned, but

overestimations may be negligible as barren-ground caribou were the most abundant ungulate available in these areas for wolves (Bryant 1955). Moose occurred at low densities, estimated at one moose in >77 km^2 (J.D. Robertson, Game and Fisheries Branch, unpublished report; Bryant 1955). Empty stomachs were excluded from the analysis and those containing vegetation were assumed to be ingested incidentally, thus also excluded from the analysis.

Statistical Analyses

Many earlier dietary investigations using stomach contents solely reported the frequency of occurrence (FO) (Parker and Luttich 1986, Andersone and Ozolinš 2004, Steinmann et al. 2011) when FO overestimates the importance of small prey (Floyd et al. 1978, Weaver 1993). Alternatively, diet contribution in described in weight serves can serve as a better description (Stobberup et al. 2009).

To overcome the bias inherent with FO, I used the Index of Relative Importance (IRI) of prey items calculated using the formula from Pinkas el al. (1971) where the volumetric percentage is replaced with the weight percentage (Meckstroth et al. 2007, Shibuya et al. 2009, Kutt 2011), and the IRI is transformed into a percentage (Cortés 1997):

$$IRI = \%FO(\%N + \%W)$$

where $\%FO$ is the percentage of the number of occurrences of each type of prey in all stomachs sampled divided by the total number of stomachs; $\%N$ is the percentage of the total number of prey items identified per species divided by the total number of all prey items; and $\%W$ is the percentage of the total weight of prey items per prey species (number × weight) divided by the total weight of all prey items of all prey species.

The IRI is a more dependable method of interpreting the importance of prey groups in stomach contents when the weight loss of prey through digestion is unknown (Tidemann et al. 1994). The IRI integrates three single measures that when used alone, can lead to misleading interpretations (Cortés 1998). I used average adult masses of prey species from Blood et al. (1967), Wrigley (1986), Coppinger and Schneider 1995, Nowak (1999), Murray (2003), and The Cornell Lab of Ornithology (2011) to calculate the IRI.

RESULTS

Of the 71 winter-killed wolves, prey remains occurred in 63 stomachs. The remaining stomachs contained bait or vegetation and were omitted from analysis. Ungulates were the most important prey for wolves in winter (99.2%), occurring in 91.4% of stomachs (Table C.1).

Table C.1. Stomach contents of winter-killed wolves in northern Manitoba, Canada in 1951 and 1952. Expressed in frequency of occurrence (%FO), number (%N), weight (%W), and Index of Relative Importance (%IRI).

Prey	No. of Stomachs	%FO	%N	%W	IRI	%IRI
Caribou	91	71.1	65.0	54.8	8517.4	86.2
Moose	26	20.3	18.6	44.8	1286.6	13.0
Snowshoe Hare	8	6.3	5.7	0.0	36.0	0.4
Squirrel[a]	1	0.8	0.7	0.0	0.6	0.0
Mouse	1	0.8	0.7	0.0	0.6	0.0
Ptarmigan	1	0.8	0.7	0.0	0.6	0.0
Raven	2	1.6	1.4	0.0	2.2	0.0
Wolf	8	6.3	5.7	0.2	37.0	0.4
Fox[a]	1	0.8	0.7	0.0	0.6	0.0
Dog	1	0.8	0.7	0.1	0.7	0.0

[a]Squirrel: *Tamiasciurus hudsonicus*; mouse, *Zapus hudsonius*; ptarmigan, *Lagopus lagopus*; red fox, *Vulpes vulpes*

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APPENDIX D: Winter Faecal Data

Table D.1. Wolf faeces contents by registered trapline (RTL) district, Manitoba, Canada.

Faeces collected in winters 2009, 2010, and 2011; collection yr marked: WS09-xxx =

2009; WS10-xxx = 2010; and WS11-xxx = 2011.

ID No.	Yr	RTL District	Content
WS09-001	2009/2010	Churchill	Unknown
WS09-002	2009/2010	Churchill	Caribou
WS09-003	2009/2010	Nelson House	Caribou
WS09-004	2009/2010	Nelson House	Caribou
WS09-005	2009/2010	Nelson House	Caribou
WS09-006	2009/2010	Split Lake	Caribou
WS09-007	2009/2010	Split Lake	Unknown
WS09-008	2009/2010	Split Lake	Caribou
WS09-009	2009/2010	Split Lake	Caribou
WS09-010	2009/2010	Split Lake	Moose
WS09-011	2009/2010	Split Lake	Moose
WS09-012	2009/2010	Split Lake	Unknown
WS09-013	2009/2010	Split Lake	Moose
WS09-014	2009/2010	Split Lake	Caribou
WS09-015	2009/2010	Split Lake	Caribou
WS09-016	2009/2010	Split Lake	Caribou
WS09-017	2009/2010	Split Lake	Coyote
WS09-018	2009/2010	Split Lake	Unknown
WS09-019	2009/2010	Split Lake	Caribou
WS09-020	2009/2010	Split Lake	Caribou
WS09-021	2009/2010	Split Lake	Caribou
WS09-022	2009/2010	Split Lake	Caribou
WS10-001	2010/2011	Churchill	Caribou
WS10-002	2010/2011	Churchill	Caribou
WS10-003	2010/2011	Churchill	Bird
WS10-004	2010/2011	Churchill	Bird
WS10-005	2010/2011	Churchill	Bird
WS10-006	2010/2011	Nelson House	Caribou
WS10-007	2010/2011	Nelson House	Fish
WS10-008	2010/2011	Nelson House	Moose
WS10-009	2010/2011	Nelson House	Moose
WS10-010	2010/2011	Nelson House	Moose
WS10-011	2010/2011	Nelson House	Vegetation
WS10-012	2010/2011	Nelson House	Wolf Hair
WS10-013	2010/2011	Nelson House	Caribou
WS10-014	2010/2011	South Indian Lake	Moose

ID No.	Yr	RTL District	Content
WS10-015	2010/2011	South Indian Lake	Moose
WS10-016	2010/2011	Split Lake	Moose
WS10-017	2010/2011	Split Lake	Beaver
WS10-018	2010/2011	Split Lake	Caribou
WS10-019	2010/2011	Split Lake	Caribou
WS10-020	2010/2011	Split Lake	Moose
WS10-021	2010/2011	Split Lake	Caribou
WS10-022	2010/2011	Split Lake	Caribou
WS10-023	2010/2011	Split Lake	Moose
WS10-024	2010/2011	Split Lake	Beaver
WS10-025	2010/2011	Split Lake	Caribou
WS10-026	2010/2011	Split Lake	Caribou
WS10-027	2010/2011	Split Lake	Beaver
WS10-028	2010/2011	Split Lake	Garbage
WS10-029	2010/2011	Split Lake	Moose
WS10-030	2010/2011	Split Lake	Moose
WS10-031	2010/2011	Split Lake	Moose
WS10-032	2010/2011	Split Lake	Moose
WS11-001	2011/2012	Churchill	Caribou
WS11-002	2011/2012	Split Lake	Caribou
WS11-003	2011/2012	Split Lake	Moose
WS11-004	2011/2012	Split Lake	Moose
WS11-005	2011/2012	Split Lake	Moose
WS11-006	2011/2012	Split Lake	Moose
WS11-007	2011/2012	Split Lake	Caribou
WS11-008	2011/2012	Split Lake	Caribou
WS11-009	2011/2012	Split Lake	Caribou
WS11-010	2011/2012	Split Lake	Wolf Hair
WS11-011	2011/2012	Split Lake	Unknown
WS11-012	2011/2012	Thicket Portage	Soil
WS11-013	2011/2012	Wabowden	Moose
WS11-014	2011/2012	Wabowden	Moose

APPENDIX E. Stable isotope values of mammals in northern Manitoba, Canada

Table E.1. $\delta^{15}N_{hair}$ and $\delta^{13}C_{hair}$ values (‰) of individual furbearers in northern Manitoba, Canada.

ID No.	Common Name	Scientific Name	Location	Yr	$\delta^{15}N$	$\delta^{13}C$
Coy11-002	Coyote	*Canis latrans*	Cranberry Portage	2011	7.8	−24.2
Coy11-001	Coyote	*Canis latrans*	Nelson House	2011	7.8	−20.8
W09-015	Wolf	*Canis lupis*	Brochet	2009	9.2	−21.6
W09-017	Wolf	*Canis lupis*	Brochet	2009	7.7	−21.5
W09-019	Wolf	*Canis lupis*	Brochet	2009	7.7	−20.9
W09-021	Wolf	*Canis lupis*	Brochet	2009	7.5	−20.4
W09-023	Wolf	*Canis lupis*	Brochet	2009	7.8	−20.8
W09-025	Wolf	*Canis lupis*	Brochet	2009	8.1	−21.1
W09-027	Wolf	*Canis lupis*	Brochet	2009	8.7	−22.2
W09-030	Wolf	*Canis lupis*	Brochet	2009	7.1	−20.2
W11-005	Wolf	*Canis lupis*	Brochet	2011	7.4	−20.6
W11-006	Wolf	*Canis lupis*	Brochet	2011	7.2	−20.6
W11-007	Wolf	*Canis lupis*	Brochet	2011	7.6	−21.9
W11-011	Wolf	*Canis lupis*	Brochet	2011	7.8	−20.5
W11-013	Wolf	*Canis lupis*	Brochet	2011	8.0	−22.5
W11-016	Wolf	*Canis lupis*	Brochet	2011	8.5	−21.4
W11-017	Wolf	*Canis lupis*	Brochet	2011	7.5	−20.5
W11-018	Wolf	*Canis lupis*	Brochet	2011	10.2	−22.3
W11-019	Wolf	*Canis lupis*	Brochet	2011	8.6	−20.8
W11-022	Wolf	*Canis lupis*	Brochet	2011	9.4	−22.2
W09-032	Wolf	*Canis lupis*	Churchill	2009	7.8	−20.7
W09-033	Wolf	*Canis lupis*	Churchill	2009	7.2	−21.5

ID No.	Common Name	Scientific Name	Location	Yr	$\delta^{15}N$	$\delta^{13}C$
W09-016	Wolf	*Canis lupis*	Cross Lake	2009	7.3	−23.1
W11-009	Wolf	*Canis lupis*	Cross Lake	2011	7.3	−22.6
W09-024	Wolf	*Canis lupis*	Limestone	2009	8.2	−21.6
W09-026	Wolf	*Canis lupis*	Limestone	2009	6.8	−22.5
W11-004	Wolf	*Canis lupis*	Limestone	2011	8.1	−22.3
W11-020	Wolf	*Canis lupis*	Limestone	2011	8.0	−21.3
W11-021	Wolf	*Canis lupis*	Limestone	2011	8.4	−21.8
W09-003	Wolf	*Canis lupis*	Nelson House	2009	6.4	−22.8
W09-004	Wolf	*Canis lupis*	Nelson House	2009	6.5	−23.7
W09-006	Wolf	*Canis lupis*	Nelson House	2009	6.1	−23.4
W09-008	Wolf	*Canis lupis*	Nelson House	2009	6.8	−23.0
W09-009	Wolf	*Canis lupis*	Nelson House	2009	7.0	−23.5
W09-011	Wolf	*Canis lupis*	Nelson House	2009	7.8	−23.1
W09-013	Wolf	*Canis lupis*	Nelson House	2009	7.1	−23.1
W09-029	Wolf	*Canis lupis*	Nelson House	2009	6.2	−23.0
W10-008	Wolf	*Canis lupis*	Nelson House	2010	6.6	−23.2
W10-010	Wolf	*Canis lupis*	Nelson House	2010	5.9	−22.8
W10-017	Wolf	*Canis lupis*	Nelson House	2010	7.5	−22.7
W10-018	Wolf	*Canis lupis*	Nelson House	2010	8.4	−21.2
W10-019	Wolf	*Canis lupis*	Nelson House	2010	7.9	−23.6
W11-010	Wolf	*Canis lupis*	Nelson House	2011	7.4	−23.3
W11-014	Wolf	*Canis lupis*	Oxford House	2011	7.6	−23.5
W09-022	Wolf	*Canis lupis*	South Indian Lake	2009	10.3	−19.5
W09-028	Wolf	*Canis lupis*	South Indian Lake	2009	8.7	−21.1
W09-031	Wolf	*Canis lupis*	South Indian Lake	2009	7.7	−20.7
W09-034	Wolf	*Canis lupis*	South Indian Lake	2009	8.1	−21.7
W09-035	Wolf	*Canis lupis*	South Indian Lake	2009	6.7	−20.9
W09-036	Wolf	*Canis lupis*	South Indian Lake	2009	8.0	−21.4

ID No.	Common Name	Scientific Name	Location	Yr	δ^{15}N	δ^{13}C
W09-037	Wolf	*Canis lupis*	South Indian Lake	2009	7.8	−21.0
W09-038	Wolf	*Canis lupis*	South Indian Lake	2009	7.3	−20.8
W10-009	Wolf	*Canis lupis*	South Indian Lake	2010	8.2	−24.0
W11-012	Wolf	*Canis lupis*	South Indian Lake	2011	6.7	−23.5
W09-005	Wolf	*Canis lupis*	Split Lake	2009	8.6	−23.8
W09-007	Wolf	*Canis lupis*	Split Lake	2009	6.7	−22.8
W09-010	Wolf	*Canis lupis*	Split Lake	2009	6.1	−23.4
W09-014	Wolf	*Canis lupis*	Split Lake	2009	7.7	−23.0
W09-018	Wolf	*Canis lupis*	Split Lake	2009	9.2	−22.0
W10-005	Wolf	*Canis lupis*	Split Lake	2010	7.6	−20.9
W10-012	Wolf	*Canis lupis*	Split Lake	2010	6.6	−22.1
W10-013	Wolf	*Canis lupis*	Split Lake	2010	6.3	−22.5
W10-014	Wolf	*Canis lupis*	Split Lake	2010	7.6	−22.8
W10-015	Wolf	*Canis lupis*	Split Lake	2010	7.5	−21.9
W10-016	Wolf	*Canis lupis*	Split Lake	2010	6.4	−22.9
W11-002	Wolf	*Canis lupis*	Split Lake	2011	6.3	−23.1
W09-001	Wolf	*Canis lupis*	Wabowden	2009	7.8	−22.8
W09-002	Wolf	*Canis lupis*	Wabowden	2009	8.2	−22.0
W09-012	Wolf	*Canis lupis*	Wabowden	2009	6.6	−22.4
W09-020	Wolf	*Canis lupis*	Wabowden	2009	7.5	−22.7
W10-001	Wolf	*Canis lupis*	Wabowden	2010	6.8	−22.7
W10-002	Wolf	*Canis lupis*	Wabowden	2010	7.0	−23.4
W10-003	Wolf	*Canis lupis*	Wabowden	2010	6.8	−23.0
W10-004	Wolf	*Canis lupis*	Wabowden	2010	8.6	−22.8
W10-006	Wolf	*Canis lupis*	Wabowden	2010	6.8	−22.8
W10-007	Wolf	*Canis lupis*	Wabowden	2010	8.3	−22.1
W10-011	Wolf	*Canis lupis*	Wabowden	2010	9.2	−22.5

ID No.	Common Name	Scientific Name	Location	Yr	δ^{15}N	δ^{13}C
W11-001	Wolf	*Canis lupis*	Wabowden	2011	6.6	−23.2
W11-003	Wolf	*Canis lupis*	Wabowden	2011	6.9	−22.8
W11-008	Wolf	*Canis lupis*	Wabowden	2011	6.8	−21.8
W11-015	Wolf	*Canis lupis*	Wabowden	2011	8.2	−22.1
B10-015	Beaver	*Castor canadensis*	Brochet	2010	1.9	−24.9
B10-018	Beaver	*Castor canadensis*	Brochet	2010	5.0	−23.6
B10-027	Beaver	*Castor canadensis*	Brochet	2010	3.9	−25.1
B10-034	Beaver	*Castor canadensis*	Brochet	2010	4.2	−24.4
B10-020	Beaver	*Castor canadensis*	Cormorant	2010	2.4	−25.5
B10-038	Beaver	*Castor canadensis*	Cormorant	2010	4.7	−24.4
B10-005	Beaver	*Castor canadensis*	Cross Lake	2010	4.5	−24.8
B10-013	Beaver	*Castor canadensis*	Cross Lake	2010	4.3	−24.9
B10-014	Beaver	*Castor canadensis*	Cross Lake	2010	4.5	−24.9
B10-011	Beaver	*Castor canadensis*	Leaf Rapids	2010	4.3	−23.9
B10-010	Beaver	*Castor canadensis*	Norway House	2010	4.9	−25.1
B10-016	Beaver	*Castor canadensis*	Norway House	2010	2.7	−25.4
B10-017	Beaver	*Castor canadensis*	Norway House	2010	3.3	−24.8
B10-022	Beaver	*Castor canadensis*	Norway House	2010	3.9	−24.7
B10-026	Beaver	*Castor canadensis*	Norway House	2010	5.0	−23.4
B10-029	Beaver	*Castor canadensis*	Norway House	2010	4.2	−24.1
B10-031	Beaver	*Castor canadensis*	Norway House	2010	1.8	−24.6
B10-035	Beaver	*Castor canadensis*	Norway House	2010	2.5	−24.9
B10-036	Beaver	*Castor canadensis*	Norway House	2010	5.9	−22.9
B10-037	Beaver	*Castor canadensis*	Norway House	2010	2.0	−25.0
B10-039	Beaver	*Castor canadensis*	Norway House	2010	4.5	−24.0
B10-028	Beaver	*Castor canadensis*	Pukatawagan	2010	5.4	−24.7
B10-033	Beaver	*Castor canadensis*	Pukatawagan	2010	5.9	−24.2
B10-004	Beaver	*Castor canadensis*	South Indian Lake	2010	3.3	−23.9

ID No.	Common Name	Scientific Name	Location	Yr	$\delta^{15}N$	$\delta^{13}C$
B10-012	Beaver	*Castor canadensis*	South Indian Lake	2010	5.3	−23.6
B10-023	Beaver	*Castor canadensis*	South Indian Lake	2010	4.3	−24.0
B10-001	Beaver	*Castor canadensis*	Split Lake	2010	4.5	−25.1
B10-002	Beaver	*Castor canadensis*	Split Lake	2010	3.0	−24.0
B10-003	Beaver	*Castor canadensis*	Split Lake	2010	4.4	−24.8
B10-006	Beaver	*Castor canadensis*	Split Lake	2010	0.9	−23.4
B10-007	Beaver	*Castor canadensis*	Split Lake	2010	5.1	−24.9
B10-008	Beaver	*Castor canadensis*	Split Lake	2010	3.1	−24.3
B10-009	Beaver	*Castor canadensis*	Split Lake	2010	4.6	−25.2
B10-019	Beaver	*Castor canadensis*	Split Lake	2010	3.4	−24.3
B10-021	Beaver	*Castor canadensis*	Split Lake	2010	2.3	−24.4
B10-024	Beaver	*Castor canadensis*	Split Lake	2010	2.5	−24.2
B10-025	Beaver	*Castor canadensis*	Split Lake	2010	3.4	−24.4
B10-030	Beaver	*Castor canadensis*	Split Lake	2010	2.5	−20.6
B10-032	Beaver	*Castor canadensis*	Split Lake	2010	4.9	−24.7
B10-040	Beaver	*Castor canadensis*	Split Lake	2010	4.2	−24.4
Wol11-003	Wolverine	*Gulo gulo*	Brochet	2011	7.4	−21.1
Wol11-005	Wolverine	*Gulo gulo*	Brochet	2011	8.3	−22.6
Wol11-002	Wolverine	*Gulo gulo*	Limestone	2011	7.3	−22.9
Wol11-004	Wolverine	*Gulo gulo*	Limestone	2011	10.2	−22.3
Wol11-001	Wolverine	*Gulo gulo*	South Indian Lake	2011	7.7	−24.2
S11-002	Snowshoe Hare	*Lepus americanus*	Cross Lake	2011	1.7	−27.9
S11-001	Snowshoe Hare	*Lepus americanus*	Wabowden	2011	1.7	−28.0
Ott11-002	Otter	*Lontra canadensis*	Brochet	2011	12.2	−22.1
Ott11-004	Otter	*Lontra canadensis*	Brochet	2011	12.9	−24.8
Ott11-003	Otter	*Lontra canadensis*	Limestone	2011	10.2	−28.8
Ott11-005	Otter	*Lontra canadensis*	Limestone	2011	11.2	−29.5
Ott11-001	Otter	*Lontra canadensis*	Nelson House	2011	10.3	−26.0

ID No.	Common Name	Scientific Name	Location	Yr	$\delta^{15}N$	$\delta^{13}C$
Lyn11-005	Lynx	*Lynx canadensis*	Brochet	2011	7.9	−24.3
Lyn11-001	Lynx	*Lynx canadensis*	Nelson House	2011	7.2	−24.5
Lyn11-002	Lynx	*Lynx canadensis*	Nelson House	2011	7.6	−24.2
Lyn11-004	Lynx	*Lynx canadensis*	Nelson House	2011	6.4	−24.7
Lyn11-003	Lynx	*Lynx canadensis*	South Indian Lake	2011	7.2	−24.0
Mar11-006	Marten	*Martes americana*	Brochet	2011	9.5	−23.2
Mar11-007	Marten	*Martes americana*	Brochet	2011	9.9	−23.0
Mar11-009	Marten	*Martes americana*	Brochet	2011	10.4	−23.1
Mar11-010	Marten	*Martes americana*	Brochet	2011	9.6	−23.1
Mar11-011	Marten	*Martes americana*	Brochet	2011	8.9	−22.9
Mar11-001	Marten	*Martes americana*	Limestone	2011	8.9	−24.2
Mar11-002	Marten	*Martes americana*	Limestone	2011	9.3	−23.5
Mar11-003	Marten	*Martes americana*	Nelson House	2011	9.3	−23.7
Mar11-005	Marten	*Martes americana*	South Indian Lake	2011	8.9	−23.3
Mar11-004	Marten	*Martes americana*	Split Lake	2011	8.6	−24.1
Mar11-008	Marten	*Martes americana*	Split Lake	2011	8.2	−24.1
Fis11-001	Fisher	*Martes pennanti*	Flin Flon	2011	9.1	−24.6
Fis11-003	Fisher	*Martes pennanti*	Grand Rapids	2011	6.3	−24.0
Fis11-004	Fisher	*Martes pennanti*	Grand Rapids	2011	6.6	−24.6
Fis11-002	Fisher	*Martes pennanti*	South Indian Lake	2011	8.8	−24.8
E11-001	Ermine	*Mustela erminea*	Limestone	2011	9.4	−24.1
E11-002	Ermine	*Mustela erminea*	Nelson House	2011	9.9	−22.5
Min11-001	Mink	*Neovison vison*	Nelson House	2011	12.7	−26.2
Min11-002	Mink	*Neovison vison*	Nelson House	2011	8.8	−25.4
Min11-003	Mink	*Neovison vison*	Nelson House	2011	10.8	−18.2
Min11-004	Mink	*Neovison vison*	Nelson House	2011	12.7	−25.8
Min11-006	Mink	*Neovison vison*	Nelson House	2011	10.8	−23.7

ID No.	Common Name	Scientific Name	Location	Yr	$\delta^{15}N$	$\delta^{13}C$
Min11-005	Mink	*Neovison vison*	Wabowden	2011	9.0	−24.8
Mus11-001	Muskrat	*Ondatra zibethicus*	Flin Flon	2011	3.8	−22.6
Mus11-002	Muskrat	*Ondatra zibethicus*	Flin Flon	2011	2.6	−21.3
Mus11-004	Muskrat	*Ondatra zibethicus*	Oxford House	2011	2.6	−21.0
Mus11-003	Muskrat	*Ondatra zibethicus*	South Indian Lake	2011	6.4	−24.8
Sq11-001	Squirrel	*Tamiasciurus hudsonicus*	Nelson House	2011	4.1	−20.6
PB11-001	Polar Bear	*Ursus maritimus*	Churchill	2011	19.7	−17.3
AFox11-001	Arctic Fox	*Vulpes lagopus*	Brochet	2011	7.8	−23.2
AFox11-002	Arctic Fox	*Vulpes lagopus*	Split Lake	2011	7.4	−23.0
RFox11-001	Red Fox	*Vulpes vulpes*	Brochet	2011	8.6	−24.2
RFox11-002	Red Fox	*Vulpes vulpes*	Brochet	2011	8.3	−24.2
CFox11-003	Cross Fox	*Vulpes vulpes*	Limestone	2011	12.0	−24.7
CFox11-001	Cross Fox	*Vulpes vulpes*	Nelson House	2011	10.0	−22.7
CFox11-002	Cross Fox	*Vulpes vulpes*	Nelson House	2011	8.0	−23.7
CFox11-004	Cross Fox	*Vulpes vulpes*	South Indian Lake	2011	7.6	−24.1

Table E.2. Range and $\bar{x}$ ($\pm$SD) $\delta^{15}N_{hair}$ and $\delta^{13}C_{hair}$ values (‰) of mammals in northern Manitoba, Canada.

Species	n	$\delta^{15}N$ (‰)	SD_N	Range$_N$ (‰)	$\delta^{13}C$ (‰)	SD_C	Range$_C$ (%)
Moose	4	2.7	1.5	0.7 to 4.4	−26.1	1.0	−27.4 to −25.1
Coyote	2	7.8	0.0	...	−22.5	2.4	...
Wolf	79	7.6	0.9	5.9 to 10.3	−22.2	1.0	−24.0 to −19.5
Beaver	38	4.0	1.1	3.5 to 5.7	−24.4	0.8	−24.9 to −23.8
Wolverine	5	8.2	1.2	7.3 to 10.2	−22.6	1.1	−24.2 to −21.1
Snowshoe Hare	2	1.7	0.0	...	−27.9	0.0	...
Lynx	6	7.4	0.6	6.4 to 8.1	−24.3	0.2	−24.7 to −24.0
Otter	5	11.4	1.2	10.2 to 12.9	−26.3	3.0	−29.5 to −22.1
Marten	12	9.3	0.6	8.2 to 10.4	−23.4	0.5	−24.2 to −22.9
Fisher	5	8.0	1.4	6.3 to 9.1	−24.5	0.3	−24.6 to −24.0
Ermine	2	9.7	0.3	...	−23.3	1.1	...
Mink	6	10.8	1.7	8.8 to 12.7	−24.0	3.0	−26.2 to −18.2
Muskrat	4	3.9	1.8	2.6 to 6.4	−22.4	1.7	−24.8 to −21.0
Boreal Woodland Caribou	30	6.3	0.6	4.9 to 7.6	−24.3	0.3	−24.9 to −23.6
Qamanirjuaq Barren-ground Caribou[a]	2	2.8	0.1	...	−22.9	0.2	...
Cape Churchill Caribou	9	3.5	1.0	2.7 to 5.6	−23.9	0.3	−24.3 to −23.4
Pen Island Caribou	9	6.8	0.9	5.2 to 8.0	−24.0	0.2	−24.3 to −23.7
Squirrel	1	4.1	...	...	−20.6	...	...
Polar Bear	1	19.7	...	...	−17.3	...	...
Arctic Fox	2	7.6	0.3	...	−23.1	0.1	...
Red Fox	6	9.1	1.6	7.6 to 12.0	−23.9	0.7	−24.7 to −22.7

[a]Teeth roots reflecting the summer diet of 1966 (ID No. 204) and 1967 (ID No. 397) (Drucker et al. 2001) corrected to reflect $\delta^{15}N_{hair}$ and $\delta^{13}C_{hair}$ values (Barnett 1994) and adjusted for the depletion of $\delta^{13}C$ CO_2 in the atmosphere in the yr 2010 (Long et al. 2005).
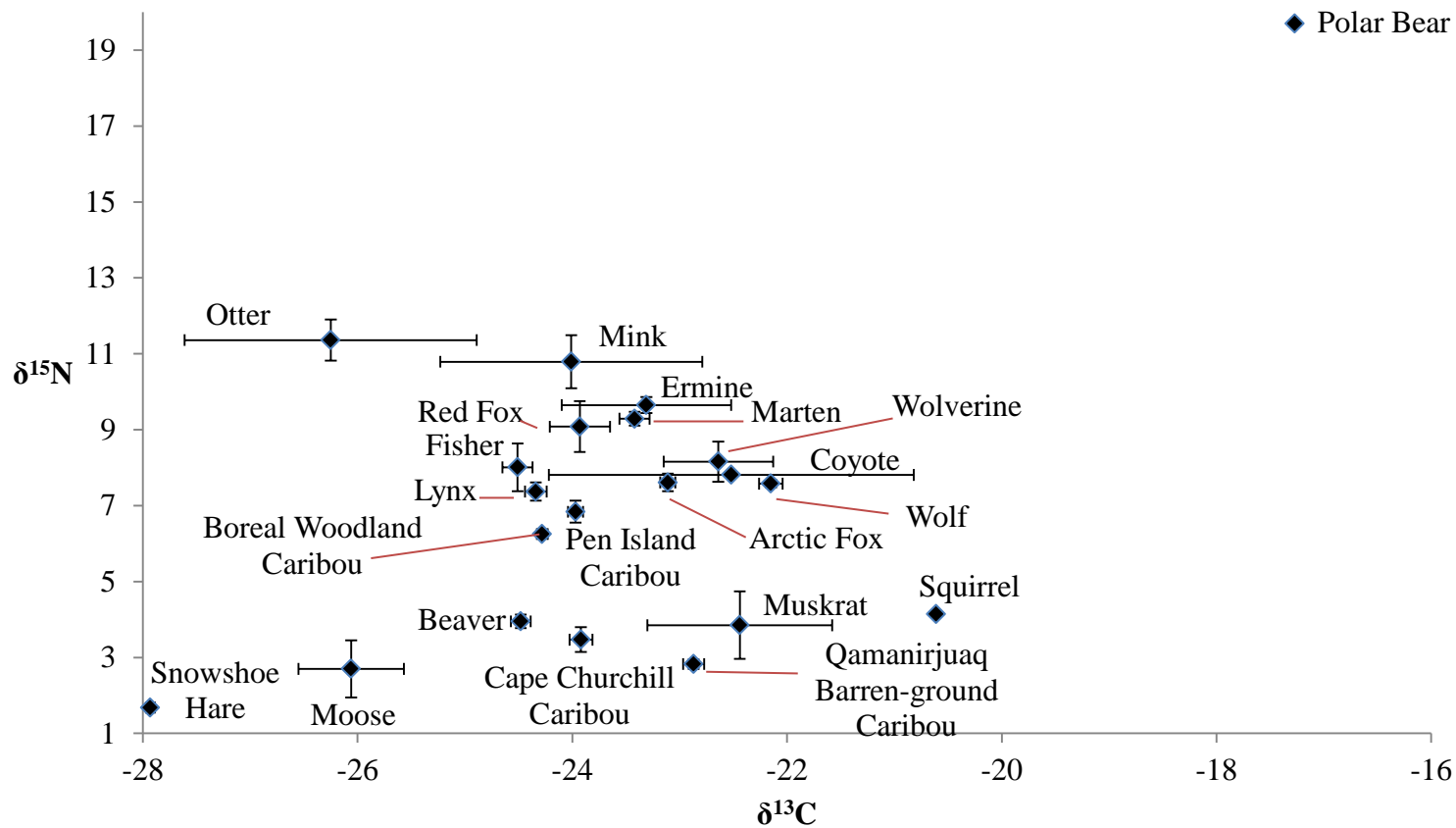
Figure E.1. Distribution of $\bar{x}$ (± SE) $\delta^{13}C_{hair}$ and $\delta^{15}N_{hair}$ values (‰) of furbearers and ungulates from northern Manitoba, Canada.

Qamanirjuaq barren-ground caribou teeth roots from Drucker et al. (2001) were corrected for hair (Barnett 1994) and for the depletion

of $\delta^{13}C$ CO_2 in the atmosphere in the yr 2010 (Long et al. 2005).

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