

**Determining the relationships between forage use,
climate and nutritional status of barren ground
caribou, *Rangifer tarandus groenlandicus*, on
Southampton Island, Nunavut, using stable
isotopes analysis of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$**

by

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Thesis Abstract

The caribou (*Rangifer tarandus groenlandicus*) on Southampton Island, Nunavut, Canada for the years 1998-2000 and 2004, 2005, were investigated using stable isotope analysis (SIA) of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$). Spring signatures of rumen contents and muscle samples were correlated with standard biological measures of back fat and Riney kidney fat index. Caribou $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios, together with detailed rumen content analysis, show that SIA data yields a time-integrated signal reflective of spatial and temporal variation in feeding ecology and as such is capable of detecting trophic interactions. Rumen content signatures provide current indication of forage selection, while muscle tissue signatures reflect bulk summer seasonal diet and in combination with rumen signatures, can help identify potential shifts in winter diet and the potential for short-term changes in caribou condition.

$\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures for major forage species categories were also compared to variations in rumen content and muscle signatures to investigate possible changes in forage preference. The results indicate that SIA is capable of assessing the importance of seasonal habitat use with regard to seasonal food intake. Stable isotopes analysis (SIA) was also used to investigate the effects of winter snow thickness and temperature on caribou (*Rangifer tarandus*), on Southampton Island. Variations found in isotope signatures of rumen content and muscle indicated that differences in winter climate conditions might affect forage selection, and impact on animal condition.

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Finally, thanks to my family, friends, coworkers, people in Arviat and Coral Harbour, and lab mates along the way, who all contributed to this thesis coming together through their support and by putting up with me all the while. God bless you all.

Dedication

This thesis is dedicated to my beautiful daughters, Abigail Jane McLeman and Avery
Ellen McLeman.

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Chapter 1

General Introduction

1.1 Studying Caribou in the Arctic

In the Arctic, the high cost of aircraft charter and support means that wildlife monitoring is usually sporadic and infrequent. Consequently, a decline in wildlife abundance is not always easy to detect, and when it is detected, it is usually well after the fact (Gunn *et al.*, 2006). Nevertheless, in northern Canada considerable biological research on the movements of barren ground caribou, *Rangifer tarandus*, and their interactions with the environment has been completed (e.g. Adamzcewski *et al.*, 1988, 1993; Ouellet *et al.*, 1997; Ferguson *et al.*, 2001; Gunn *et al.*, 2006).

Key among completed studies, are those focusing on distribution and movement. Such studies are often limited in scope by the expense of tracking methods, the ability to monitor only a handful of animals at any given time and their general inability to determine why, or how, an animal uses a particular habitat type (Scotter, 1980; Thompson *et al.*, 1980; Messier *et al.*, 1987; White, & Garrott, 1990). Furthermore, the capture and handling of animals, necessary to the attachment of collars, may have impacts on animal welfare (Fuller, 1987; Hearn & Luttich, 1990; Pank *et al.*, 1985).

Traditional methods of studying feeding ecology such as fecal or rumen content analyses are also limited because they represent only the food most recently consumed by an animal. The “snapshot” view of feeding patterns, therefore, often does not provide adequate information on migratory species such as caribou characterized by extensive rather than intensive foraging behaviour (Kurle, 2002).

1.2 Stable Isotopes Analysis in Ecology

A temporally integrated view of animal feeding may be obtained from stable isotope analysis (SIA), a potentially cost effective and logistically simple approach to studying animal ecology in the Arctic (Peterson & Fry, 1987). One key advantage of SIA is that it is relatively easy to carry out. SIA requires only a small amount (~1-5mg) of biological material for accurate analysis of the elements important to ecological study (C, N, S, and O). Organisms more or less reflect the isotopic composition of the materials in their environments (Boner & Foerstel, 2004) and as such the isotopic composition of an animal may serve as a kind of “natural fingerprint” for the environments they inhabit. Unlike radio-telemetry, the biological material needed for SIA may be obtained from previously deceased animals, archived samples, or other sources (Ainley *et al.*, 2002; Struck *et al.*, 2002; Bearhop *et al.*, 2003).

As a consequence of the isotopic fractionation associated with many physiological processes, isotope signatures give an integrated insight into which nutrient sources a focal organism has used over its lifetime. Stable isotope techniques have proved to be useful tools for studies of resource partitioning in complex communities where other methods to quantify trophic positions have largely been ineffective (Bluthgen *et al.*, 2003). Furthermore, since distinct isotopic landscapes occur in nature, it is possible to exploit differences among them to monitor movements of individuals (Rubenstein *et al.*, 2004).

Dietary estimates based on stable isotope analysis are generally in broad agreement with other measures of diet (Gerhart *et al.*, 1996; Ainley *et al.*, 2002; Cerling *et al.*, 2003), but differences can arise. For example, “isotopic routing” occurs when tissues do not reflect the isotopic composition of the bulk diet, but the isotopic

composition of the nutrient component of the diet from which the tissue was synthesized. Thus, the composition of body protein in omnivores, for example, often reflects the isotopic composition of dietary protein (Ambrose & Norr, 1993). Differences between SIA measured tissue and diet may also arise because of differential tissue turnover rates.

In mammals, collagen, connective tissue, and muscle turnover at much slower rates than the more metabolically active tissues such as adipose tissue, liver, kidney, pancreas, and components of the digestive tract (Waterlow *et al.*, 1978), and there is also evidence to suggest that individual proteins within each tissue have characteristic turnover times that depend on tissue metabolic functions (Waterlow *et al.*, 1978). Lipids tend to be depleted in $\delta^{13}\text{C}$ relative to whole-tissue samples (DeNiro & Epstein 1977; Tieszen & Fagre, 1983), thus low $\delta^{13}\text{C}$ values would be expected for samples with high lipid content. Nevertheless, the degree of enrichment from rumen to tissue in ruminants is a reflection of the extent that forage carbon is incorporated into microbial protein and metabolites (e.g., volatile fatty acids) within rumen and then converted to tissue end-products such as amino acids (proteins), lipoprotein membranes and lipids in the animal (Metges *et al.*, 1990).

1.3 Studies using Stable Isotopes Analysis

Studies show animals 1) assimilate dietary components with varying efficiencies; 2) fractionate (change the isotope ratios) in their diet and 3) allocate nutrients in their diet differentially to specific tissues (Gannes *et al.*, 1997). The general premise of SIA studies is that the isotope compositions of the diet are recorded in animal tissues in a predictable manner (DeNiro & Epstein, 1978; Lee-Thorp & van der Merwe, 1987; Cerling & Harris, 1999). As a result, applications of SIA in ecological studies, have allowed ecologists to:

- trace the migration origin of birds (Hobson, 1999), terrestrial mammals (DeNiro & Epstein, 1978; van der Merwe *et al.*, 1990; Vogel *et al.*, 1990) and fish (Kline *et al.*, 1998);
- differentiate habitat usage and forage ecology in; marine mammals (Clementz & Koch, 2001; Das *et al.*, 2004; Schell *et al.*, 1989; Kurle, 2002), Arctic foxes, *Alopex lagopus*, (Hoekstra *et al.*, 2003; Roth, 2001), beef cattle (Boner & Foerstel, 2004), Arctic and sub-Arctic fish (Power *et al.*, 2002; Guiguer *et al.*, 2002), King eiders, *Somateria spectabilis* (Mehl *et al.*, 2004);
- reveal the composition of, or changes in, the diets of; birds, (Hobson & Clark, 1992), marsupials, *Bettong tropica*, *Isodon macrourus* (McIlwee & Johnson, 1998), marten, *Martes Americana* (Ben-David *et al.*, 1997), red foxes, *Vulpes vulpes* (Lavin *et al.*, 2003), Alaskan brown bears, *Ursus arctos* (Ben-David *et al.*, 2004), grizzly bears, *Ursus arctos horribilis* (Felicetti *et al.*, 2003), insular rodent populations (Stapp & Polis, 2003), African bovids (Cerling *et al.*, 2003; Sponheimer *et al.*, 2003), horses (Ayliffe *et al.*, 2004), Adelie penguins, *Pygoscelis adeliae* (Ainley *et al.*, 2002), Patagonian seabirds (Forero *et al.*, 2004), mule deer, *Odocoileus hemionus* (Stewart & Bowyer, 2003);
- enhance paleoecological studies (Cerling, & Harris, 1999; Zazzo *et al.*, 2000);
- show latitudinal variation of isotope signatures in plant species (Kelley, 2000; Cerling *et al.*, 2004), east-west gradients of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ in zooplankton (Dunton *et al.*, 1989, Schell *et al.*, 1998), and altitudinal distributions and movements in hummingbirds, *Phaethornis* (Hobson *et al.*, 2003);

- show stepwise enrichment along food chains, and the relationships between $\delta^{15}\text{N}$ and animal age (Minagawa & Wada, 1984; Cerling *et al.*, 2004), define trophic position in marine food webs (Jennings & Warr, 2003; Carmichaela *et al.*, 2004), and determine the trophic positions of sperm whales and jumbo squid (Ruiz-Cooley *et al.*, 2004);
- and study the ecology and movements of endangered species such as; monitor lizards, *Varanus mabitang* (Struck *et al.*, 2002), and aquatic warblers, *Acrocephalus paludicola* (Pain *et al.*, 2004);

1.4 Stable Isotopes Analysis with Caribou

Guiguer *et al.*, (2002) suggested that with more detailed sampling of forage species, it should be possible to further define the food web links within an Arctic aquatic community and to determine the extent to which carbon is recycled between trophic levels as a result of food web interactions. Feeding linkages highlighted by SIA, between forage species, herbivore tissues and onward into carnivores, would also allow food web connections in terrestrial systems to be studied in greater detail. Such knowledge will be particularly important for determining the possible consequences of human impacts on the food webs of Arctic communities.

For example, Epstein *et al.* (2004) predict changes in tundra plant community composition with climatic warming, with an increase in shrubs and a decline in mosses. Both are important forage species for caribou, and changes in their relative abundance are likely to affect caribou foraging behaviour and possibly animal condition. In addition, Weladji & Holand, (2003) suggest that if the current pattern of global warming continues, reduced body weight of caribou calves may occur in areas where winters with a high North Atlantic Oscillation (NAO) winter index are severe (such as Southampton Island).

Although occurring relatively infrequently, Edenius *et al.* (2003) found snow-bed vegetation to be the cover type most intensively used (selected) by reindeer, *Rangifer tarandus*. When foods are in short supply, access to snow-bed vegetation may strongly affect the well being of reindeer (Skogland, 1994). Snow-beds also function as refuges before snowmelt, from both insect harassment (Gaare *et al.*, 1975; Downes *et al.*, 1986; Walsh *et al.*, 1992) and high temperatures (Ion & Kershaw, 1989; Andersen & Nilsen, 1998). As a result, reindeer select areas containing snow-bed vegetation, and the scarcity of such areas may be a limiting factor in reindeer summer ranges (Edenius *et al.*, 2003).

As access to forage may be prevented, or seriously reduced, by exceptionally severe snow and ice conditions, large-scale die-offs involving both caribou and muskoxen have been observed on Arctic Islands (Miller *et al.*, 1977; Miller, 1998; Gunn & Dragon, 2002; Miller & Gunn, 2003a, b). For example, weather records revealed that snowfall on Bathurst Island was exceptionally heavy in winter and spring (Sept.-June) from 1994-1995 to 1996-1997, when a major (98%) three-year caribou die-off was recorded (Miller & Gunn, 2003b). The effects of climate variation on forage availability, therefore, may become more important at increased herd densities (Dragon, 2002). For insular herds whose numbers have increased, the forage related implications of climate change may be correspondingly significant and worthy of study.

1.5 Research Objectives

In light of the limited information on the association between forage habitat use and animal condition for Southampton Island caribou, the major aims of this research were to apply stable isotopes analysis to archival (1998-2000, 2004, 2005), muscle and rumen content (also referred to as only “rumen”) samples, obtained from standardized monitoring of the annual commercial harvest begun in 1993, to determine whether caribou $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ muscle and rumen signatures:

- 1) correlate in any predictable manner with variations in standard biological measures of animal condition (e.g., back-fat, Riney kidney fat index)
- 2) correlate with mean winter (November- March) temperatures and snow depth, as a means of establishing the possible consequences of climate variation for forage availability/use and animal condition.

Additionally, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures were obtained for major forage plant groups on Southampton Island. Together with detailed rumen analysis, the SIA results of rumen were used to determine the extent to which animal condition was influenced by climatic variation.

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Chapter 2

Southampton Island, Nunavut: Study Site and Insular Caribou Herd

2.1 Canadian Arctic Island

Southampton Island is one of the largest islands in Hudson Bay (43,000 km²), in the Canadian Territory of Nunavut (Fig. 2.1), and lies at the north end of Hudson Bay (65°20' N, 84° 40' W). The west half and southeastern part of the island (Bell Peninsula) consist of low flat limestone plains dominated by *Dryas* barrens and sedge meadows. The remainder of the island is steep to rolling Precambrian shield dominated by *Alectoria* and *Cetraria* lichens and heaths (Campbell, pers. comm., 2003). Southampton Island is completely surrounded by open water year-round, which creates a climate as harsh as that found on most of the High Arctic islands (Parker, 1975).

The snow cover period generally lasts from mid-September or early October until mid-June (Dragon, 2002), with snowmelt occurring rapidly in mid-June and the growing season lasting from July to the beginning of September. The mean daily temperature recorded at Coral Harbour (approximate population = 800) is -11°C and the annual precipitation for rain and snow is 13 cm and 113 cm respectively (Environment Canada, 2006). Coral Harbour typically records double the amount of snowfall as Baker Lake, which is located at the same latitude as Coral Harbour on the mainland (Parker, 1975). The average wind speed at Coral Harbour is 20 km/hr, and fog and low overcast conditions are often present during the snow-free months (Dragon, 2002).

2.2 Resident Caribou Herd

The caribou herd on Southampton Island originated from 48 animals introduced from Coat's Island (62°30' N, 83° 00' W) in 1967. Since introduction, the herd has grown in numbers and is now a main dietary staple of local Inuit and is subject to an annual commercial spring harvest. Caribou (*Rangifer tarandus*) and wolves (*Canis lupus*) were common on Southampton Island until the early 1900's (Parker, 1975). The extinction of wolves in the 1930's, followed by the extirpation of caribou in 1953, a direct result of over hunting (Parker, 1975), was deeply felt by the local residents of Coral Harbour.

The caribou re-introduction was initiated to supplement the diet of the local Inuit community (Manning, 1967). Post re-introduction, the local Inuit, adopted strict no hunting guidelines, in order to let the herd grow to a harvestable level (Parker, 1975). The lack of predation (wolves absent), low initial harvest rates, and abundant sources of vegetation in the summer and winter, allowed the herd to increase dramatically after re-introduction (Ouellet, 1992). Population surveys, first begun in 1978, have shown that the caribou population continues to grow rapidly (Heard & Ouellet, 1994), and currently Southampton Island's caribou population numbers approximately 20,000 animals (Campbell, pers. comm., 2006).

Based on historical population surveys of the SHI herd, Heard & Ouellet (1994) estimated the annual rate of growth to be 27.6 percent. Parker (1975) estimated the carrying capacity of Southampton Island (SI) to be in the range of 40 000 caribou, but did not visit the island in the winter to document snow conditions or the availability of critical forage lichens (Ouellet *et al.*, 1993). "As caribou on the island are restricted to

mainly windswept areas that were free of snow cover and Parker's predictions did not include habitat use based on seasonal changes in distribution of caribou (Heard & Ouellet, 1994), Ouellet *et al.*, (1993) proposed that Parker's estimate could be an overestimate of the island's carrying capacity," (*as cited in* Dragon, 2002).

Some researchers have suggested that over periods of several decades, Arctic tundra caribou (*Rangifer tarandus*) may be regulated by density-dependent forage depletion (Leader-Williams & Ricketts, 1982; Skogland, 1985). Winter range shifts could potentially delay such regulation when a population is at or near long-term maximum abundance (Ferguson *et al.*, 2001). Ouellet (1992) commented that SI caribou rely heavily on lichens for their winter diet. Considering the increases in abundance since re-introduction (Heard & Ouellet, 1994) and the history of re-introductions on other Arctic islands (Dragon, 2002), a critical issue of concern is how can the Southampton Island herd persist as the carrying capacity for this Island is approached. Study of the Southampton Island caribou herd offers an opportunity to increase our knowledge of northern ungulate population dynamics because this population has been monitored periodically since its re-introduction (Ouellet, 1992; Ouellet *et al.*, 1996) and a wealth of data is available on the herd.

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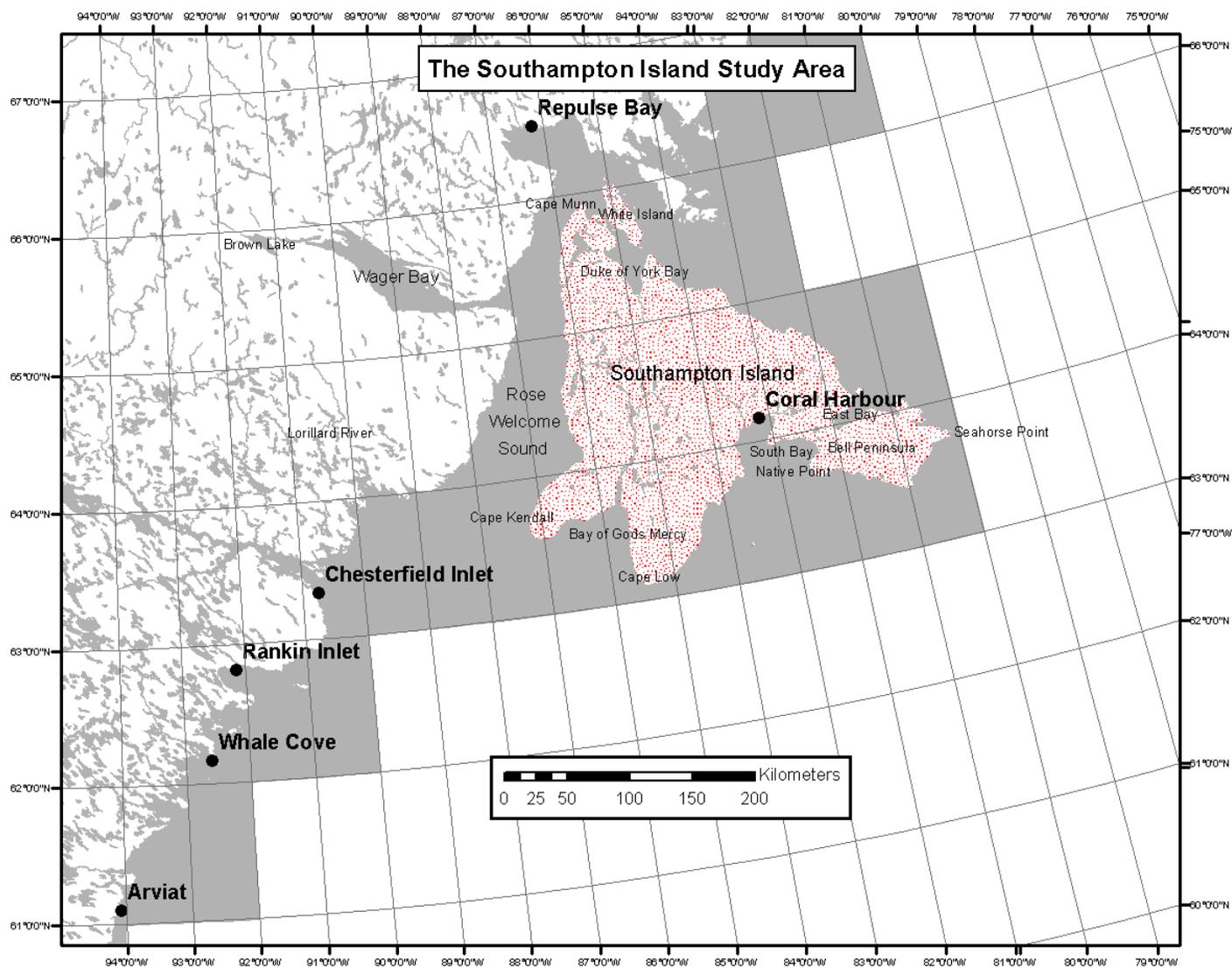


Figure 2.1: Location of study site in Nunavut, Southampton Island is located at the North-West end of Hudson Bay. *figure obtained from Campbell (2006)*

Chapter 3

Correlating $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures of Southampton Island Caribou with variations in standard biological measures

3.1 Chapter Abstract

Yearly variations in the condition of caribou (*Rangifer tarandus*) on Southampton Island, Nunavut, Canada, were investigated using stable isotope analysis (SIA) of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) of rumen and muscle tissue. Rumen analysis was used as a proxy for short-term dietary shifts. Muscle analysis was used as a proxy for long-term dietary shifts. Enrichment from rumen to muscle for mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures tested significant (all t-test p for mean differences <0.05) in all years and between reproductive groupings. Signatures of rumen and muscle were correlated with standard biological measures of condition, and dominant among them were significant correlations among the SIA signatures (muscle and rumen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) and significant correlations ($p<0.001$) between back fat and muscle $\delta^{13}\text{C}$ measures, and kidney and muscle $\delta^{15}\text{N}$ measures ($p<0.001$). Also prominent was the significant correlation ($p<0.001$) between back fat and sex. For example, muscle $\delta^{13}\text{C}$ signatures negatively correlated with back fat measures ($p<0.001$), while rumen signatures positively correlated with Riney kidney fat index ($p<0.01$), due mainly to the influence of the male samples.

Of the six plant categories sampled for SIA, lichens show the most depleted isotopic values for $\delta^{15}\text{N}$, and the least depleted $\delta^{13}\text{C}$ values. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures for major forage species categories were compared to variations in rumen and muscle signatures and indicate possible changes in forage preference between years. Results indicated that SIA is capable of assessing the levels of body condition, and can identify

annual shifts in diet and the potential short-term (rumen) and long-term (muscle) implications of dietary shifts for caribou condition.

3.2 Introduction

Herbivory has shown the potential to significantly alter plant communities (Leader-Williams *et al.*, 1987; Manseau *et al.*, 1996; Augustine & McNaughton, 1998), with density-dependent alteration of plant communities, known to have adverse effects on caribou, *Rangifer tarandus* (Skogland, 1985; Ferguson *et al.*, 2001; Boudreau & Payette, 2004). On Southampton Island density-dependent degradation of forage habitat has been documented during a period of steady population growth following the caribou's reintroduction to the island in 1968 (Ouellet, 1992; Ouellet *et al.*, 1993, 1994, 1996). Recent population surveys indicate the Southampton Island caribou population is approximately 20,000 animals (Campbell, pers. comm., 2006), below the island's estimated carrying capacity of 40,000 animals (Parker, 1975). However, this number is considered an overestimate (Heard & Ouellet, 1994), and a population of 15,000 is ideal for the Island (Campbell, pers. comm., 2006). For the Southampton Island herd, little, however, is known about the correlation between variations in herd numbers and herd forage consumption patterns, the long-term changes in animal condition as it relates to animal diet or how forage availability may affect short and long-term patterns of forage consumption.

A temporally integrated view of foraging behaviours may be obtained from stable isotope analysis (SIA), a logistically simple and potentially cost effective approach to studying caribou ecology in the Arctic (Peterson *et al.*, 1987). Sponheimer *et al.* (2003)

argued SIA was an underutilized technique for studying mammalian nutritional ecology. In particular, SIA methods do not rely on the recapture or re-sighting of previously captured individuals (Rubenstein *et al.*, 2004), and can employ archival sample information for the development of temporal trends.

SIA studies rely on the fact that the $\delta^{13}\text{C}$ ratio of forage plants is incorporated with little change into herbivore tissue, and onward up the food chain (Kelley, 2000). Differential fractionation of $\delta^{13}\text{C}$ that occurs during photosynthesis in C_4 and C_3 plants, further aids the inductive use of SIA signatures in studies of animal foraging behaviour. The nitrogen isotope ($\delta^{15}\text{N}$) of the herbivorous diet is also preferentially and predictably incorporated into consumer tissues, resulting in systematic $\delta^{15}\text{N}$ enrichment with each trophic transfer of energy (McIlwee & Johnson, 1998). In combination, SIA ratios of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ are now routinely used to trace plant energy sources in herbivores (Handley & Raven, 1992), reconstruct animal diets, trace animal movements across vegetative communities, assess physiological condition based on forage quality signatures, and determine the fate of assimilated nutrients (Tiezen *et al.*, 1983; Ayliffe *et al.*, 2004).

An understanding of forage availability and use are critical to determining the relationship between the forage base and herd nutritional status. Past studies suggest an important link between the forage base and body reserves for maintaining the health of individuals in insular herds (Leader-Williams & Ricketts, 1982; Gates *et al.*, 1986; Adamzewski *et al.*, 1988, 1993). Recent observations suggest reductions in the body reserves of Southampton Island caribou may reflect degradation of summer forage

availability and associated over-grazing as a result of density-dependent population pressures (Dragon, 2002).

The direct study of foraging behaviour, however, is difficult, with the result that most studies have been limited to intermittent monitoring of herd numbers and the measurement of animal condition, age and rumen content “snapshots” of feeding patterns. The ability of SIA, however, to obtain temporally integrated feeding signatures suggests the utility of the technique for enhancing understanding of animal ecology and facilitating the study of animals where direct observation is either difficult or expensive.

To address shortfalls in our understanding of relationships between forage and animal condition, this study used archival and recently obtained muscle and rumen samples from annual monitoring of the commercial caribou harvest on Southampton Island, Nunavut. Specifically, the study aim was to determine whether caribou muscle and rumen content $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures correlated with variations in standard biological measures of animal condition and status including: back fat and Riney kidney fat indices, reproductive status and sex.

3.3 Methods & Materials

Samples for this study were obtained from the insular herd of Southampton Island Nunavut, (65°20` N, 84° 40` W). The herd originated from 48 animals introduced from Coat’s Island (62°30` N, 83° 00` W) in 1968. Since re-introduction, the herd has grown in numbers, and is a main dietary staple of local Inuit and is subject to an annual commercial spring harvest.

The Nunavut Department of Environment (NDE) has examined the condition of caribou collected during the annual spring harvest since 1993 and collected tissue samples and biological data for the purposes of determining disease status, diet and age. Up to 400 caribou are sampled each year, with each set of tissue samples obtained for biological monitoring purposes being connected through to a unique tag number affixed to the animal carcass before processing. The recorded biological data for each sample obtained include: back fat, sex, reproductive condition, and evidence of disease and/or parasites. Samples collected included: kidneys for the calculation of Riney kidney fat index, blood for disease antigen analysis, female reproductive tracts, rumen contents (rumen) and scat for diet analysis and the lower jaw and teeth for aging (Miller, 1974). All collected samples are individually bagged, immediately frozen, and maintained at minus twenty degrees Celsius (-20°C) until processed.

For the purposes of this study, archived harvest samples for the years of 1998-2000, 2004 and 2005, were sub-sampled. Samples from these years were chosen because of the availability of complete biological data and matched jaw and rumen samples for SIA. In addition, rumen samples for all individual animals in 1998, 1999, 2004 and 2005 (n= 204) were analyzed (following standardized protocols described in Chamrad & Box, 1964, 1968) to determine the percentage of plant species present.

Fifty animals from each year (54 from 2004) were selected for analysis with the aim of including an equal number of males and females. Selection was random, but designed to be representative of the range of variability in the biological data (e.g., Riney kidney fat index) and included consideration of whether females were pregnant or not. For each selected animal, rumen and lower jaw muscle samples were sub-sampled from

archived sample materials and the associated biological data (e.g., sex, back-fat, Riney kidney fat index, female reproductive status) were recorded.

Rumen content and jaw muscle samples (~5mg) were sub-sampled using a clean scalpel and placed in sterile vials labeled with the carcass tag number. All samples were shipped frozen to the University of Waterloo, where they were placed in a drying oven at 50°C for 48 hours and ground to a fine homogenate using a ball mill grinder (model MM301, Retsch GmbH & Co., Haan, Germany). Approximately 1 mg of processed muscle and 2mg of processed rumen were weighed into tin cups using a microbalance, and submitted to the Environmental Isotope Laboratory at the University of Waterloo for SIA.

To interpret the isotopic signatures obtained from the analysis of muscle and rumen samples, plant samples were collected from random sites on Southampton Island on two separate occasions. The first set of samples were obtained from standardized quadrat samplings completed by the Canadian Wildlife Service in 2003 as part of a vegetation mapping study aimed at determining relative forage availability.

The second set of samples, were collected by NDE personnel in the vicinity of known caribou foraging areas in early summer of 2003. The second set of samples was specifically aimed at obtaining examples of known forage plants as identified in the 1998 and 1999 rumen analysis. For example, plants, known to be among the preferred forage species for insular barren-ground caribou populations, have been described by Adamczewski *et al.* (1988), Ouellet *et al.* (1994), Ferguson *et al.* (2001), and Griffith *et al.* (2001). Some of the most commonly described preferred forage species include; *Salix lanata*, *Cassiope tetragona*, *Dryas integrifolia*, *Carex scirpoidea*, *Carex membranacea*,

Carex aquatilis, *Carex bigelowii*, *Betula nana*, *Ledum palustre*, *Vaccinium vitis-idaea*,
Eriophorum angustifolium, *Eriophorum vaginatum*, *Oxytropis*, *Petasites hyperboreus*,
Polygonum bistorta, *Cetraria nivalis*, *Cetraria cucullata*, *Dactylina arctica*, *Masonhalea*
richardsonii, *Cladonia amaurocraea*, *Stereocaulon tomentoum*, *Alopecurus*,
Arctogrostis.

Of these common plant types; *Arctagrostis latifolia* (grass), *Carex aquatilis* (sedge), *Carex scirpoidea* (sedge), *Cassiope tetragona* (shrub), *Dryas integrifolia* (forb), *Eriophorum angustifolium* (sedge), *Minuartia rossii* (forb), *Pedicularis sudetica* (forb), *Salix arctica* (shrub), *Salix reticulata* (shrub), *Saxifraga hirculus* (forb), *Saxifraga oppositifolia* (forb), as well as mixed lichen and mixed mosses, were harvested, dried, bagged, and prepared at the University of Waterloo for SIA. The preparation of the samples for SIA followed procedures used for muscle and rumen sub-samples.

Plant species were grouped by forage categories (shrubs, sedges, forbs, grasses, lichens, and mosses). Species-specific SIA results were used to obtain a representative forage group mean SIA signature, which in turn was used to compare and contrast the nature of observed inter-annual and among-animal variations in muscle and rumen SIA signatures.

All SIA analyses were performed on a Micromass VG Isochrom continuous-flow isotope ratio mass spectrometer connected to a Carlo Erba elemental analyzer at the Environmental Isotope Laboratory, University of Waterloo. The International Atomic Energy Agency CH6 and N1 and N2 standards, respectively, were used to calibrate $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results. Stable isotope ratios are expressed as parts per thousand differences (‰)

between the isotope ratio of the sample and an international standard according to the formula:

$$X = [(R_{\text{sample}} - R_{\text{standard}}) / R_{\text{standard}}] \times 1000 \quad (\text{Eq. 3.1})$$

Where X is the $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ value and R= the carbon ($^{13}\text{C}/^{12}\text{C}$) or nitrogen ($^{15}\text{N}/^{14}\text{N}$) isotope ratio of the sample or the standard. All international standards are set by the convention at 0‰. Standards used to compute all values reported here included carbonate rock from the Peedee Belemnite formation (Craig, 1957) and nitrogen gas in the atmosphere (Mariotti, 1983). For the purposes of assessing machine accuracy, every eighth sample was repeat analyzed.

ANOVA was used to determine whether significant differences existed among average annual muscle and rumen, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures. ANOVA was similarly used to determine significant differences among average annual Riney kidney fat indices and back-fat measures. Differences between years and reproductive groupings (i.e. male, female, reproductive female) were established using Tukey's post hoc HSD test. Two-sample t-tests were used where comparisons between only two groups were made (1999). Pearson correlation coefficients were used to determine the significance of relationships between SIA and biological measures, with significance established using standard t-tests (Zar, 1999). Maximal type 1 error in all statistical analysis was set at $\alpha = 0.05$.

3.4 Results

Enrichment from rumen to muscle for mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures tested significant (all t-test *p* for mean differences <0.05) in all years and between reproductive groupings (Fig. 3.1). $\delta^{13}\text{C}$ enrichments ranged from a low of 1.48‰ in 2004 in males, to a

high of 3.07‰ in 1998 in pregnant females (Table 3.1). Enrichment of $\delta^{15}\text{N}$ ranged from a low of 3.59‰ in 1998 in females, to a high of 5.39‰ in 2004 in pregnant females (Table 3.1).

Mean muscle $\delta^{13}\text{C}$ signatures ranged from -21.73‰ in 1999 to -23.17‰ in 2004, with muscle $\delta^{15}\text{N}$ ranging between 3.84‰ in 2004 to 4.29‰ in 1999. Mean rumen $\delta^{13}\text{C}$ ranged from -24.57‰ in 1999 to -25.36‰ in 2005, with rumen $\delta^{15}\text{N}$ ranging between -1.28‰ in 2005 to 0.20‰ in 1998 (Table 3.2).

The muscle and rumen $\delta^{13}\text{C}$ signatures did not differ significantly (Tukey's HSD $p>0.05$) among the sexes or depending on reproductive status (pregnant or non-pregnant) in any year. With the exceptions of 2000, where a significant difference was found between males and pregnant females muscle $\delta^{13}\text{C}$ (Tukey's HSD $p<0.05$), 1998 where there was a significant difference between males and pregnant female rumen $\delta^{13}\text{C}$ (Tukey's HSD $p<0.05$), and in 2005 where females and pregnant females differed in rumen $\delta^{13}\text{C}$ (Tukey's HSD $p<0.05$) (*see* Table 3.3). Rumen $\delta^{15}\text{N}$ values did not differ significantly among the sexes or depending on reproductive status in any year (Tukey's HSD $p>0.05$), with the exception of 2005 where there was a significant difference between males and all females (Tukey's HSD $p<0.05$).

Sex-specific differences in back fat were more prevalent than sex-specific differences in SIA signatures, with males differing significantly (Tukey's HSD $p<0.05$) from either females or pregnant females in 1998 and 2000 and pregnant females differing significantly (Tukey's HSD $p<0.05$) from either males or females in 2005 (Table 3.3). A similar pattern was observed in the kidney data, with males differing significantly

(Tukey's HSD $p < 0.05$) from all female groupings in 1998 and from pregnant females alone in 2004 and 2005.

Isotopic results were correlated to biological condition measures for samples broken into males, non-pregnant females, and pregnant females. For males, mean values were correlated with back fat and muscle $\delta^{13}\text{C}$ (Table 3.4) with significant ($p < 0.05$) negative correlations. Significant ($p < 0.05$) positive correlations were seen between male values from the Riney Kidney Fat Index (RKFI) and muscle $\delta^{15}\text{N}$, RKFI and rumen $\delta^{13}\text{C}$, RKFI and rumen $\delta^{15}\text{N}$ and between muscle $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, rumen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, and rumen $\delta^{15}\text{N}$ and muscle $\delta^{15}\text{N}$.

There was a significant positive correlation ($p < 0.05$) between RKFI and back fat for females, however unlike the males, no other measures were significantly correlated (Table 3.4). Significant negative correlations ($p < 0.05$) for pregnant females were seen between back fat and muscle $\delta^{13}\text{C}$, and between muscle $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. Positive correlations ($p < 0.05$) were seen between back fat and muscle $\delta^{15}\text{N}$, and between RKFI and muscle $\delta^{15}\text{N}$, for pregnant females. When yearly means were correlated (without being broken into sex or reproductive status groupings), there was only a significant correlation ($p < 0.05$) between rumen $\delta^{13}\text{C}$ and rumen $\delta^{15}\text{N}$. In contrast, aggregation of the data to include all animals from all years yielded a complex pattern of significant correlations among the measured variables (Table 3.5). Dominant among them were significant correlations among the SIA signatures (muscle and rumen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) and significant correlations ($p < 0.001$) between back fat and muscle $\delta^{13}\text{C}$ measures, and kidney and muscle $\delta^{15}\text{N}$ measures ($p < 0.001$). Also prominent was the significant correlation ($p < 0.001$) between back fat and sex.

Of the six plant categories sampled for SIA (Fig. 3.2), lichens show the most depleted isotopic values for $\delta^{15}\text{N}$, followed by shrubs, mosses, and finally forbs, grasses and sedges respectively. For $\delta^{13}\text{C}$ values, shrubs displayed the most depleted values, followed by sedges, forbs, grasses then mosses and finally lichens (Fig. 3.2). Figures 3.3 and 3.4 compare the mean forage signatures to signatures of the caribou, with rumen $\delta^{15}\text{N}$ signatures similar to those for mosses, and rumen $\delta^{13}\text{C}$ signatures similar to those for grasses. The mean percentage of forage groupings found in the rumen for 1998, 1999, 2004 and 2005, can be seen in Figure 3.5, with lichens, grasses, and mosses composing the bulk of the diet in all years. Years with generally higher condition measures, such as 2004 and 1999 (Table 3.3), are also years where there is a higher percentage of grasses in the rumen, and lower percentage of mosses (Fig. 3.5).

3.5 Discussion

Caribou muscle and rumen content $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures correlated with variations in standard biological measures of animal condition and status in a variety of ways. For example, as male caribou muscle $\delta^{13}\text{C}$ signatures increase, measures of back-fat decrease and RKFI increases, while an opposite trend occurs in females. RKFI was strongly positively correlated with muscle $\delta^{15}\text{N}$ in both males and pregnant females, while back-fat measures were strongly negatively correlated with muscle $\delta^{13}\text{C}$ in both males and pregnant females. There were no relationships between isotope signatures and condition measures in non-pregnant females. Additionally our findings show differences among animals in terms of forage use that are predictive of observed variability in animal condition measures.

Variability in the rumen to muscle enrichment was observed between years, and may be related to variation in the differences in short-term dietary choices (as reflected in the rumen signatures) and long-term dietary choices (indicated in the muscle signatures), since forage species are unique in their isotopic signatures. The depletion of $\delta^{15}\text{N}$ in rumen samples appears indicative of greater consumption of moss and lichen species, for example in 2005 moss plus lichen consumption accounted for approximately 68% of average rumen contents, whereas in 1998 moss and lichens accounted for only 61% of average rumen contents (Fig. 3.5).

The depletion of $\delta^{15}\text{N}$ is not reflected in muscle signatures (Table 3.2), and may be related to proximate environmental factors such as temperature and snow depth. In colder temperatures, caribou metabolize their energy reserves more quickly, whereas more energy is needed to burrow through snow in search of forage when snow and ice conditions worsen. Short-term dietary choices reflected by the rumen signatures suggest that foraging of species less depleted in $\delta^{13}\text{C}$ (e.g. lichens, moss) correlate to increased RKF I measures.

In addition, we found that rumen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures correlate to muscle $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures, and thus future inferences on condition may be made from knowing either rumen or muscle signatures. Together, variations in mean signatures may be used to make assumptions of overall herd condition, and subsequently the selection of forage species on Southampton Island.

A limited number of studies using S.I.A. have been completed to date on barren ground caribou (Barnett *et al.*, 2001; Griffith *et al.*, 2001). Seasonal records of forage utilization by caribou have been provided for the Porcupine herd (Barnett *et al.*, 2001),

while body protein mobilization by nursing caribou has been described for the Bathurst herd (Griffith *et al.*, 2001). Griffith *et al.*, (2001) found antler core and periosteum isotope values varied seasonally for the Bathurst herd, though results suggested consistency in a diet of predominantly vascular plants throughout antler development until post-calving, when a diet shift towards grass-like plants occurs.

Barnett *et al.*, (2001) investigated seasonal variation in the diet of caribou in Arctic Alaska, by comparing seasonal variations in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of Porcupine herd caribou tissues with vegetation signatures. They found that during winter, hoof $\delta^{13}\text{C}$ values increased and $\delta^{15}\text{N}$ values decreased compared to summer and autumn values in response to feeding on lichens. Findings here supported Barnett *et al.* (2001), showing inter-annual variations in muscle and rumen signatures of the SI herd in response to consumption of lichens.

Barnett *et al.*, (2001) found hoof $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios closely tracked the large changes in rumen isotope ratios seasonally, but muscle variations were much less pronounced. Our study found that muscle $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios correlated significantly with rumen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios (Table 3.5). When separated by reproductive status, muscle $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios correlated closely with rumen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios, though only significantly in male $\delta^{15}\text{N}$ ($p < 0.05$). In comparison, these results suggest independent caribou herds may select forage areas differently, perhaps based upon forage availability as well as environmental factors.

Porcupine herd rumen $\delta^{13}\text{C}$ ranged between -27.9 to -25.4‰ , with no significant differences between 1987 and 1988 (Barnett *et al.*, 2001). While the SI herd mean rumen $\delta^{13}\text{C}$ ranged between -25.4 to -24.6‰ in the 5 years studied, significant differences

between sexes found for rumen $\delta^{13}\text{C}$ in the present study was apparent in only two of the sample years, 1998 and 2005. Suggesting that while variability is low it can occur, as environmental factors in those years possibly influenced the foraging behaviour of the herd.

Barnett *et al.* (2001), found mean muscle $\delta^{15}\text{N}$ values from March, June and September averaged 3.0‰ with samples collected during Nov 1987, being slightly lower with a mean of 2.4‰ (range 1.7 to 3.1‰.) The monthly differences were attributed to differences in dietary sources and the slow rate of protein turnover as proposed by Gerhart *et al.* (1996). Compared to the Porcupine herd, the Southampton Island herd muscle $\delta^{13}\text{C}$ signatures ranged from -21.73 to -23.17‰, with muscle $\delta^{15}\text{N}$ ranging from 3.84 to 4.29‰ (Fig. 3.3). Isotope signatures differed significantly between most years, but not between sexes within any given year. The high $\delta^{13}\text{C}$ values of mosses and lichens could be the source of the higher rumen $\delta^{13}\text{C}$ in our study, supported by $\delta^{15}\text{N}$ values in rumen contents below 0 ‰, and the depleted $\delta^{15}\text{N}$ means for mosses and lichens. If the SI herd follows the same foraging patterns as described for the Bathurst and Porcupine herds, then the $\delta^{13}\text{C}$ means would be predictably higher, and $\delta^{15}\text{N}$ means lower than other times of the year, due to feeding on lichens.

The differing ranges of rumen $\delta^{15}\text{N}$ between the Porcupine herd (Barnett *et al.*, 2001), and ranges recorded for the present study of Southampton Island caribou, may suggest differences in; forage selection between herds or biogeochemistry of plant signatures. Differences in forage selection could be related but not limited to nutritional stress, and/or regional variation, as plant signatures are known to vary geographically (Cerling *et al.*, 2004; Kelly, 2000). The differences between the rumen and muscle

signatures in the present study of SI caribou suggest seasonal variation in forage preference largely due to a lag in muscle signature assimilation, and the fact that rumen samples reflect only early spring data an artifact of the standardized dates of the harvest (Figs. 3.3 & 3.4). The observed differences between rumen and muscle signatures, is reflected by signatures of plant groups, more typically consumed in the summer, fall or early winter.

Enrichment of carbon from rumen to muscle ranged from 1.43% in males of 2000, to 3.07% in pregnant females in 2004. Whereas Barnett *et al.* (2001) found a mean enrichment of carbon from rumen to muscle of 3.6‰. These differences in the enrichment may be due to: high lipid content in the muscle samples (DeNiro & Epstein, 1978, Tieszen *et al.*, 1983), temporal or spatial variation of the samples, or possibly indicate differences in condition, dependent upon reproductive status of an individual animal.

The results from this study on caribou $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios shows that SIA data yields a signal reflective of spatial and temporal variation in feeding ecology and as such is capable of detecting trophic interactions that may otherwise be unobservable from temporally limited rumen content analysis. Since the use of gut content analysis has a number of drawbacks: it provides only a “snapshot” of an individual’s recent feeding history, and can underestimate the relative importance of quickly digestible dietary items. In addition, muscle $\delta^{15}\text{N}$ provides an integrated picture of the long-term feeding habits which is less influenced by temporal variation in diet and allows the trophic status of animals which have empty stomachs to be determined (Grey, 2001; Guiger *et al.*, 2002; Adams *et al.*, 2003). Since the rate at which isotopic signatures change over time vary

between tissues it is possible to examine the long-term consistency of diet choice by examining $\delta^{15}\text{N}$ of different tissues (Kelly, 2000). SIA, together with detailed rumen analysis, provides greater information on these interactions. Rumen signatures can provide current indication of forage selection, while muscle tissue reflects bulk seasonal diet and when combined with rumen signatures can identify annual shifts in diet.

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Table 3.1: Mean Southampton Island caribou flesh isotopic enrichment from rumen (‰), separated by year and sex within a given year.

Year	Sex	Sample size n=	$\delta^{13}\text{C}$ Enrichment (%)	$\delta^{15}\text{N}$ Enrichment (%)
1998	Male	18	2.81	3.98
	Female	21	2.65	3.59
	Pregnant female	11	3.07	3.63
1999	Male	31	2.91	4.61
	Female	19	2.74	4.50
2000	Male	25	2.59	4.49
	Female	19	2.13	4.00
	Pregnant female	6	1.77	4.54
2004	Male	30	1.48	4.77
	Female	19	1.63	4.71
	Pregnant female	5	2.33	5.39
2005	Male	25	3.01	5.33
	Female	9	2.60	4.90
	Pregnant female	16	2.71	5.25

Table 3.2: Mean ($\% \pm$ standard deviation) isotopic signatures for rumen and muscle samples of Southampton Island caribou separated by year and sex (Female indicates non-pregnant females). Years with means not significantly different from one another (Tukey's $p > 0.05$) are marked with a common superscript. NA indicates years for which tissue samples for pregnant females were not included in the sampling regime.

	Year	Both Sexes (mean \pm std dev)	Male (mean \pm std dev)	Female (mean \pm std dev)	Pregnant Females (mean \pm std dev)
Rumen $\delta^{13}\text{C}$	1998	-24.67 ± 0.32 ^{AB}	-24.52 ± 0.36 ^A	-24.70 ± 0.27 ^A	-24.86 ± 0.25 ^A
	1999	-24.57 ± 0.41 ^A	-24.46 ± 0.43 ^A	-24.74 ± 0.32 ^A	NA
	2000	-24.85 ± 0.40 ^B	-24.88 ± 1.09 ^{AB}	-22.77 ± 0.51 ^{AB}	-25.00 ± 0.36 ^A
	2004	-24.78 ± 0.30 ^{AB}	-24.78 ± 0.30 ^A	-24.75 ± 0.35 ^{AB}	-24.85 ± 0.15 ^A
	2005	-25.36 ± 0.40 ^C	-25.28 ± 0.34 ^B	-25.17 ± 0.37 ^B	-25.57 ± 0.42 ^B
Rumen $\delta^{15}\text{N}$	1998	0.20 ± 0.42 ^A	0.18 ± 0.48 ^A	0.21 ± 0.25 ^A	0.21 ± 0.59 ^A
	1999	-0.28 ± 0.37 ^B	-0.24 ± 0.36 ^B	-0.33 ± 0.40 ^B	NA
	2000	-0.09 ± 0.36 ^B	-0.29 ± 0.53 ^B	0.10 ± 0.30 ^A	0.14 ± 0.35 ^A
	2004	-1.02 ± 0.31 ^C	-1.02 ± 0.31 ^C	-0.87 ± 0.28 ^C	-0.97 ± 0.08 ^B
	2005	-1.28 ± 0.43 ^D	-1.55 ± 0.26 ^D	-0.87 ± 0.40 ^C	-1.09 ± 0.38 ^C
Muscle $\delta^{13}\text{C}$	1998	-21.85 ± 0.49 ^A	-21.66 ± 0.50 ^A	-22.05 ± 0.52 ^A	-21.79 ± 0.19 ^A
	1999	-21.73 ± 0.66 ^A	-21.56 ± 0.52 ^A	-22.00 ± 0.77 ^A	NA
	2000	-22.54 ± 0.75 ^B	-22.28 ± 0.56 ^B	-22.64 ± 0.71 ^{AB}	-23.23 ± 1.08 ^B
	2004	-23.17 ± 1.01 ^C	-23.30 ± 1.11 ^C	-23.12 ± 0.93 ^B	-22.52 ± 0.36 ^{AB}
	2005	-22.52 ± 0.77 ^B	-22.27 ± 0.57 ^B	-22.57 ± 0.76 ^{AB}	-22.86 ± 0.94 ^B
Muscle $\delta^{15}\text{N}$	1998	3.94 ± 0.57 ^{AB}	4.16 ± 0.71 ^{1AB}	3.80 ± 0.44 ^A	3.84 ± 0.43 ^A
	1999	4.29 ± 0.59 ^C	4.35 ± 0.62 ^A	4.17 ± 0.55 ^A	NA
	2000	4.22 ± 0.68 ^{BC}	4.20 ± 0.74 ^{AB}	4.10 ± 0.57 ^A	4.68 ± 0.61 ^A
	2004	3.84 ± 0.70 ^A	3.74 ± 0.68 ^B	3.84 ± 0.74 ^A	4.42 ± 0.47 ^B
	2005	3.95 ± 0.59 ^{ABC}	3.78 ± 0.39 ^B	4.03 ± 1.12 ^A	4.16 ± 0.34 ^B

Table 3.3: Mean ($\% \pm$ standard deviation) isotopic signatures for analyzed rumen and muscle samples of Southampton Island caribou separated by year and sex (Female = non-pregnant females, Pregnant = pregnant females). Within year sex/reproductive status means not significantly different from one another (Tukey's $p > 0.05$) are marked with a common superscript. NA indicates years for which tissue samples for pregnant females were not included in the sampling regime. Back fat denotes mean animal back fat measurements (cm), and Kidney denotes mean animal Riney kidney fat index measures (g).

		Muscle $\delta^{13}\text{C}$ (mean \pm std dev)	Muscle $\delta^{15}\text{N}$ (mean \pm std dev)	Rumen $\delta^{13}\text{C}$ (mean \pm std dev)	Rumen $\delta^{15}\text{N}$ (mean \pm std dev)	Back fat (mean \pm std dev)	Kidney (mean \pm std dev)
1998	Male	-21.66 \pm 0.50 ^A	4.16 \pm 0.71 ^A	-24.52 \pm 0.36 ^A	0.18 \pm 0.48 ^A	0.12 \pm 0.26 ^A	126.42 \pm 39.86 ^A
	Female	-22.05 \pm 0.52 ^A	3.80 \pm 0.44 ^A	-24.70 \pm 0.27 ^{A, B}	0.21 \pm 0.25 ^A	0.92 \pm 0.58 ^B	95.07 \pm 26.79 ^B
	Pregnant	-21.79 \pm 0.19 ^A	3.84 \pm 0.43 ^A	-24.86 \pm 0.25 ^B	0.21 \pm 0.59 ^A	0.85 \pm 0.83 ^B	89.28 \pm 18.39 ^B
1999	Male	-21.56 \pm 0.52 ^A	4.35 \pm 0.62 ^A	-24.46 \pm 0.43 ^A	-0.24 \pm 0.36 ^A	0.29 \pm 0.49 ^A	145.97 \pm 34.97 ^A
	Female	-22.00 \pm 0.77 ^A	4.17 \pm 0.55 ^A	-24.74 \pm 0.32 ^A	-0.33 \pm 0.40 ^A	1.38 \pm 0.69 ^A	106.40 \pm 26.83 ^A
	Pregnant	NA	NA	NA	NA	NA	NA
2000	Male	-22.28 \pm 0.56 ^A	4.20 \pm 0.74 ^A	-24.88 \pm 1.09 ^A	-0.29 \pm 0.53 ^A	0.58 \pm 0.48 ^A	114.67 \pm 39.89 ^A
	Female	-22.64 \pm 0.71 ^{A, B}	4.10 \pm 0.57 ^A	-24.77 \pm 0.51 ^A	0.10 \pm 0.30 ^A	2.12 \pm 0.57 ^B	150.09 \pm 41.75 ^A
	Pregnant	-23.23 \pm 1.08 ^B	4.68 \pm 0.61 ^A	-25.00 \pm 0.36 ^A	0.14 \pm 0.35 ^A	2.35 \pm 0.96 ^B	146.60 \pm 40.25 ^A
2004	Male	-23.30 \pm 1.11 ^A	3.74 \pm 0.68 ^A	-24.78 \pm 0.30 ^A	-1.02 \pm 0.31 ^A	0.74 \pm 0.52 ^A	107.84 \pm 30.49 ^A
	Female	-23.12 \pm 0.93 ^A	3.84 \pm 0.74 ^A	-24.75 \pm 0.35 ^A	-0.87 \pm 0.28 ^A	1.27 \pm 0.80 ^A	131.09 \pm 36.50 ^{A, B}
	Pregnant	-22.52 \pm 0.36 ^A	4.42 \pm 0.47 ^A	-24.85 \pm 0.15 ^A	-0.97 \pm 0.08 ^A	1.10 \pm 1.03 ^A	152.64 \pm 53.70 ^B
2005	Male	-22.27 \pm 0.76 ^A	3.78 \pm 0.39 ^A	-25.28 \pm 0.34 ^{A, B}	-1.55 \pm 0.26 ^A	0.33 \pm 0.40 ^A	97.99 \pm 21.31 ^{A, B}
	Female	-22.57 \pm 0.68 ^A	4.03 \pm 1.12 ^A	-25.17 \pm 0.37 ^B	-0.87 \pm 0.40 ^B	0.71 \pm 0.44 ^A	83.70 \pm 15.56 ^A
	Pregnant	-22.86 \pm 0.94 ^A	4.16 \pm 0.34 ^A	-25.57 \pm 0.42 ^A	-1.09 \pm 0.38 ^B	1.26 \pm 0.68 ^B	107.10 \pm 21.77 ^B

Table 3.4. Pearson correlation coefficients for all years separated by reproductive status.

Correlations significant at the $\alpha= 0.1$, or 0.05, respectively, are marked with single, or double asterisk (*). Back fat denotes mean animal back fat measurements (cm), and Kidney denotes mean animal Riney kidney fat index measures (g).

	Muscle $\delta^{13}\text{C}$	Muscle $\delta^{15}\text{N}$	Rumen $\delta^{13}\text{C}$	Rumen $\delta^{15}\text{N}$	Back-fat
Males					
Muscle $\delta^{15}\text{N}$	0.7971*				
Rumen $\delta^{13}\text{C}$	0.4270	0.6971			
Rumen $\delta^{15}\text{N}$	0.6083	0.8337**	0.8431**		
Back-fat	-0.8723**	-0.4243	-0.2274	-0.3677	
Kidney	0.6896	0.8750**	0.8869**	0.7599*	-0.4075
Females					
Muscle $\delta^{15}\text{N}$	0.2625				
Rumen $\delta^{13}\text{C}$	0.1914	-0.2257			
Rumen $\delta^{15}\text{N}$	0.5839	0.0020	0.5956		
Back-fat	-0.1813	0.4399	0.4957	0.4360	
Kidney	-0.5139	0.1326	0.5101	0.2246	0.9144**
Pregnant					
Muscle $\delta^{15}\text{N}$	-0.8602**				
Rumen $\delta^{13}\text{C}$	0.4373	0.0630			
Rumen $\delta^{15}\text{N}$	0.2230	-0.0778	0.5382		
Back-fat	-0.8592**	0.8307**	-0.0965	0.3032	
Kidney	-0.6326	0.9178**	0.2888	-0.2142	0.5547
All means					
Muscle $\delta^{15}\text{N}$	0.5424				
Rumen $\delta^{13}\text{C}$	0.3800	0.4134			
Rumen $\delta^{15}\text{N}$	0.6483	0.4897	0.7546*		
Back-fat	-0.5098	0.3055	0.1326	0.1273	
Kidney	0.0113	0.7103	0.6887	0.3730	0.6200

Table 3.5. Pearson correlations coefficients for all 254 caribou studied. Correlations significant at the $\alpha= 0.05, 0.01, \text{ or } 0.001$, respectively, are marked with single, double, or triple asterisk (*). Back fat denotes mean animal back fat measurements (cm), and Kidney denotes mean animal Riney kidney fat index measures (g). For “Sex”, males were assigned a value = 1, non-pregnant females = 2, and pregnant females = 3, respectively.

	Back-fat	Muscle $\delta^{13}\text{C}$	Muscle $\delta^{15}\text{N}$	Kidney	Rumen $\delta^{13}\text{C}$	Rumen $\delta^{15}\text{N}$
Muscle $\delta^{13}\text{C}$	-0.2504***					
Muscle $\delta^{15}\text{N}$	0.0654	0.1891**				
Kidney	0.3360***	0.0781	0.3114***			
Rumen $\delta^{13}\text{C}$	-0.0286	0.1969**	0.1520*	0.1795**		
Rumen $\delta^{15}\text{N}$	0.1531*	0.2771***	0.2976***	0.2069**	0.3934***	
Sex	0.4837***	-0.1316*	0.0415	-0.0462	-0.2022**	0.1369*

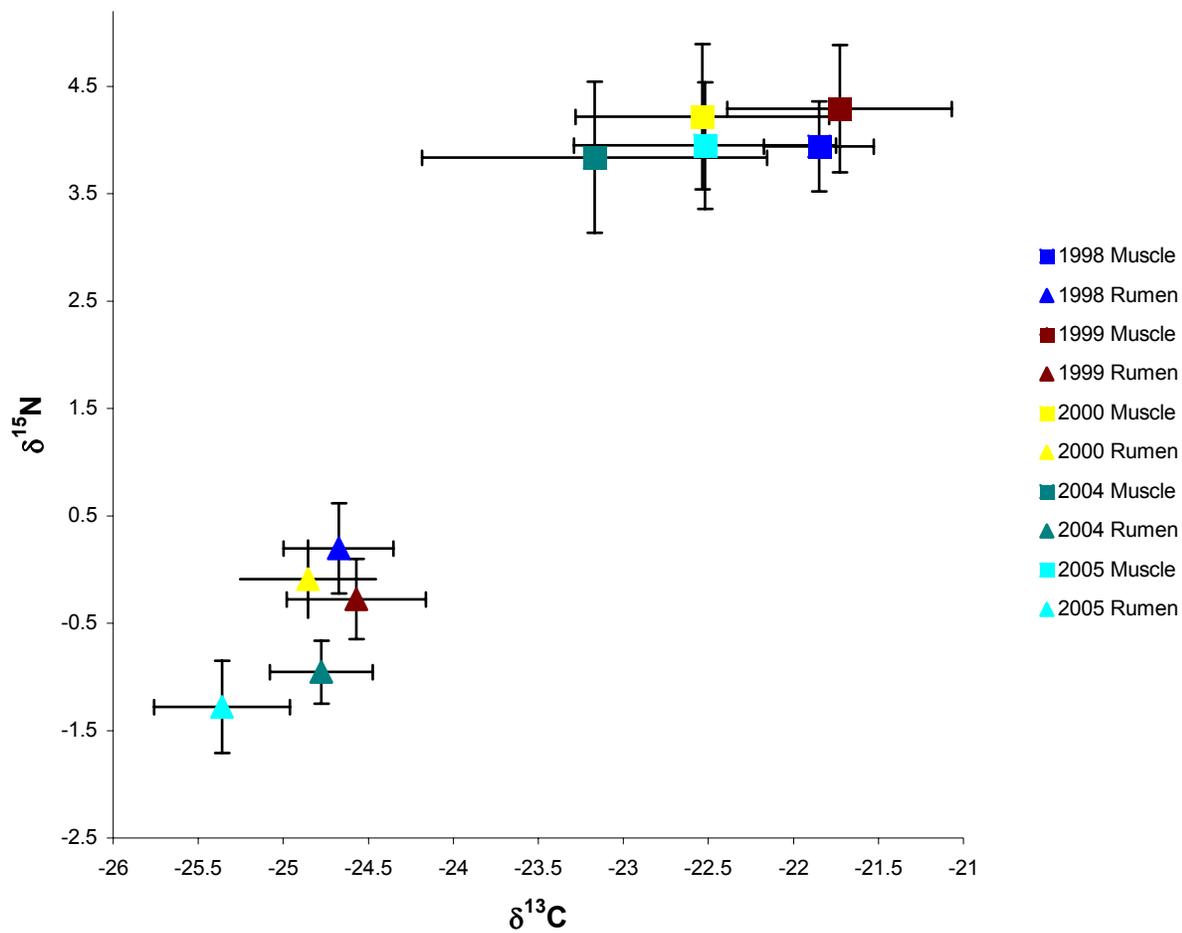


Figure 3.1: Mean (\pm standard deviation) isotopic signatures for Southhampton Island caribou rumen (triangles) and muscle (squares) samples, separated by year.

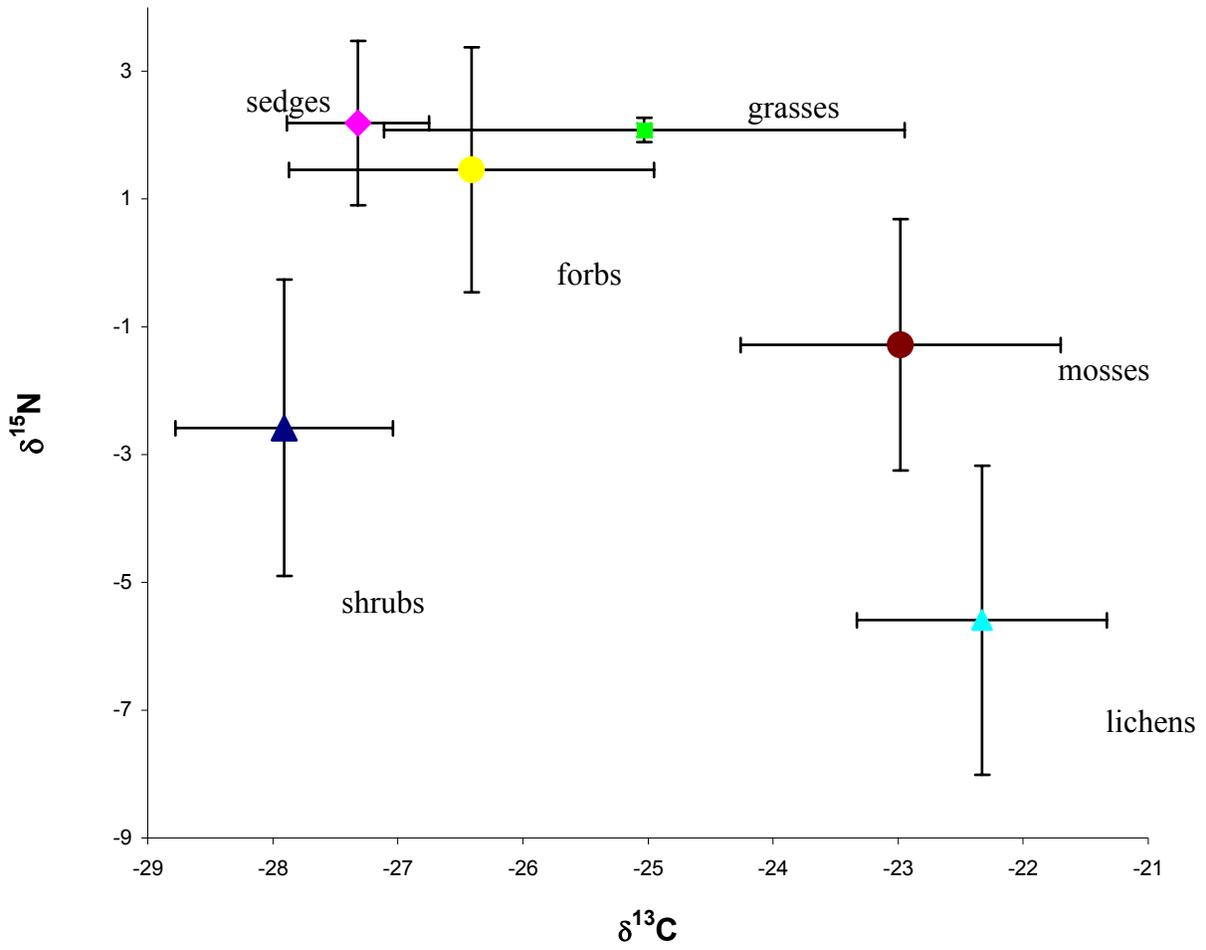


Figure 3.2: Mean (\pm standard deviation) isotopic signatures for samples of Southampton Island grouped by plant type.

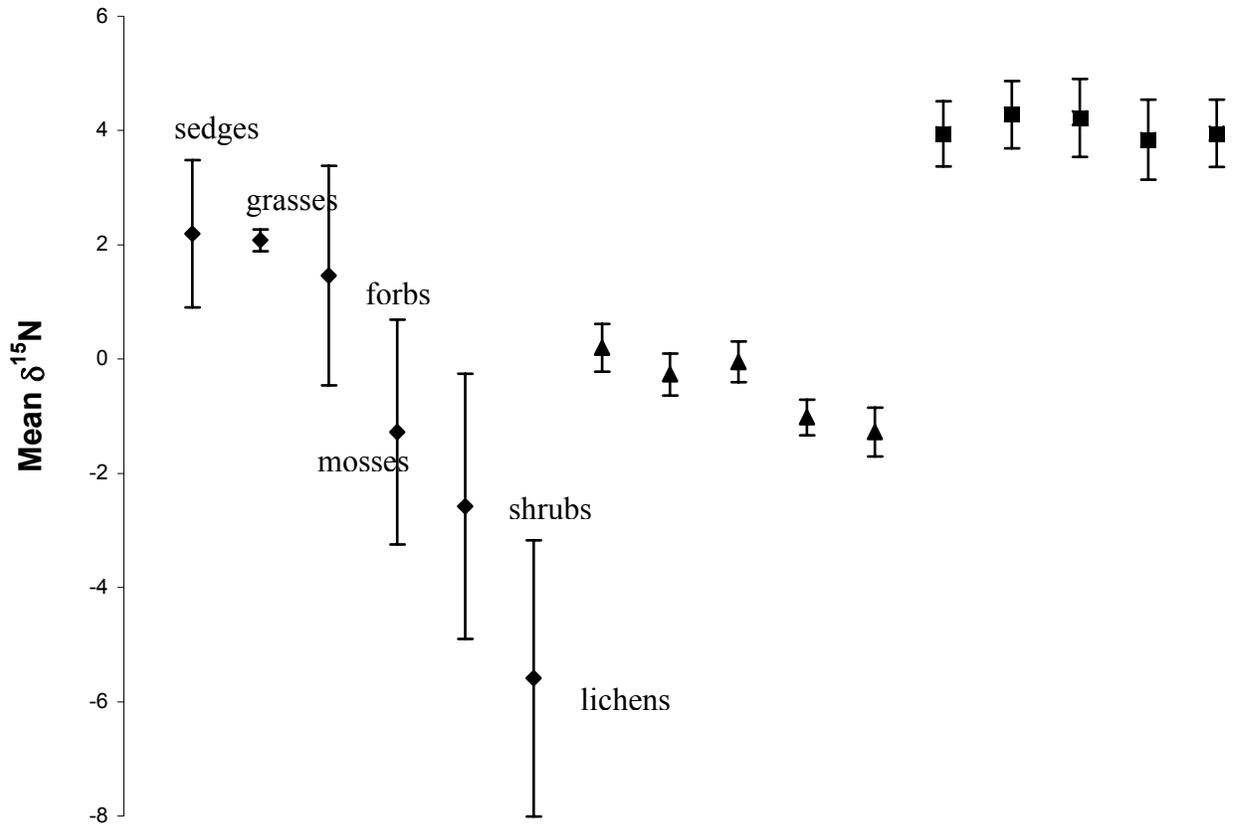


Figure 3.3 Mean (\pm standard deviation) $\delta^{15}\text{N}$ plants, rumen and muscle isotopic signatures. Plots are ordered sequentially by year, with rumen signatures plotted as triangles and muscle signatures plotted as squares.

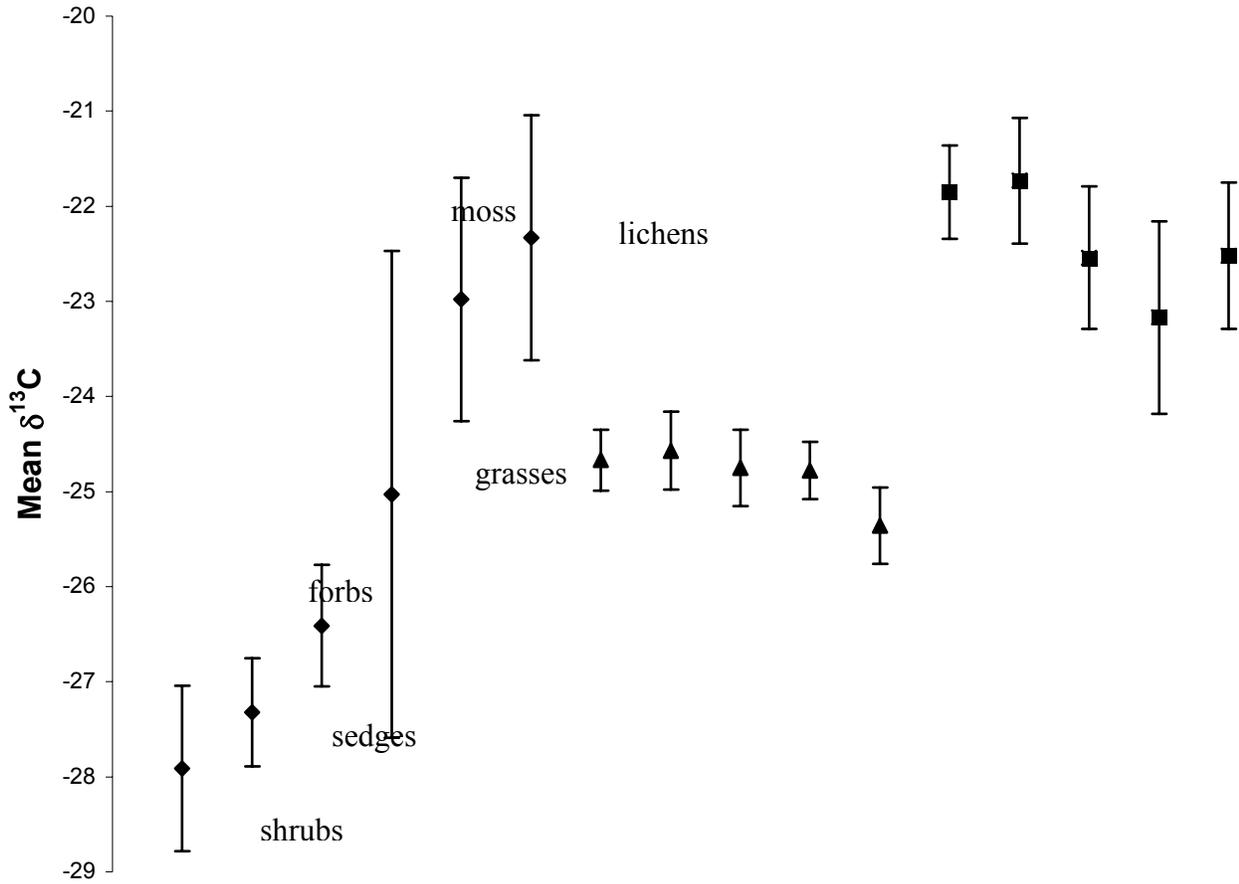


Figure 3.4: Mean (\pm standard deviation) $\delta^{13}\text{C}$ plants, rumen and muscle isotopic signatures. Plots are ordered sequentially by year, with rumen signatures plotted as triangles and muscle signatures plotted as squares.

Percentage of Forage Group in Rumen

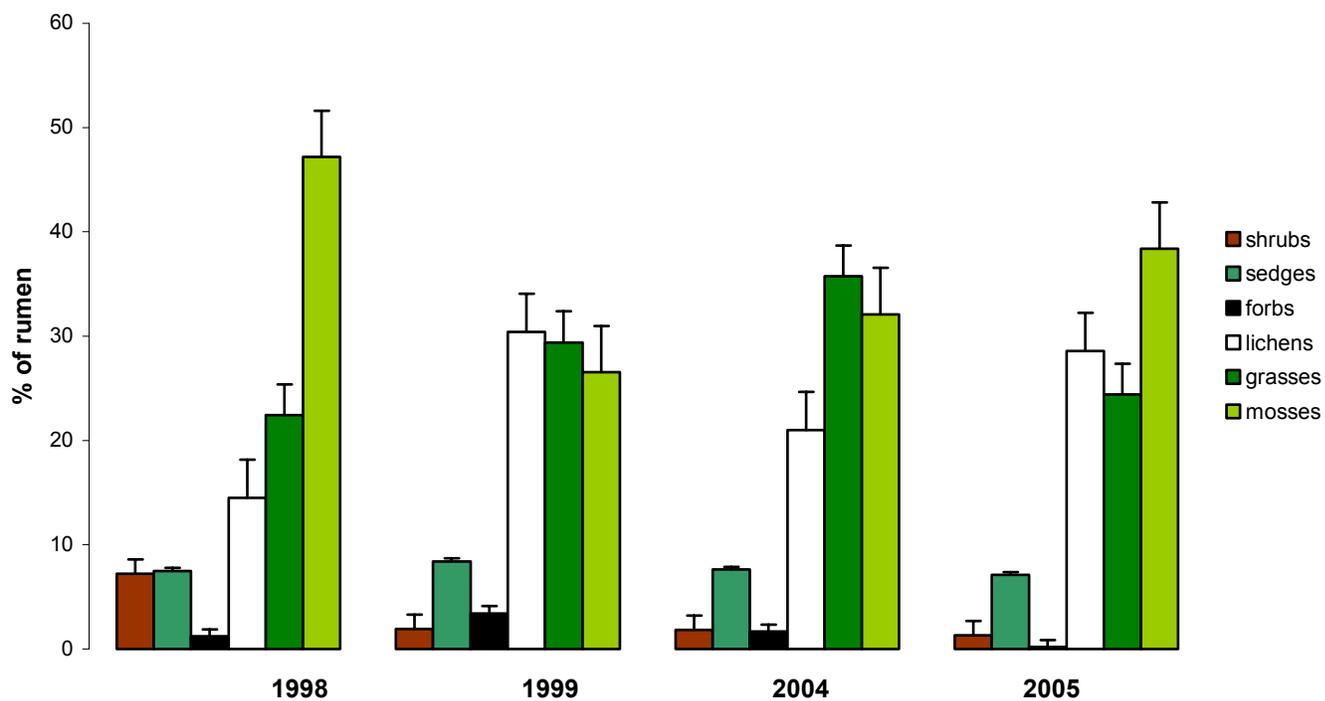


Figure 3.5: Mean annual percentage of plant groupings in rumen samples as determined from detailed rumen analysis of 50 caribou (54 in 2004).

Chapter 4

Determining the Effects of Winter Stress on the Southampton Island Caribou herd using Stable Isotopes Analysis

4.1 Abstract

Stable isotopes analysis (SIA) of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) was used to investigate the effects of winter snow thickness and temperature on caribou (*Rangifer tarandus*), on Southampton Island, Nunavut, Canada. Variations found in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ signatures of rumen contents and muscle, indicate that differences in winter conditions directly affect forage selection, which may impact animal condition. MANOVA found significant interaction effects between mean winter temperature and snow thickness on SIA signatures. Forage preference was determined using the mean rumen content analysis, and indicated that the herd is potentially at risk as their arctic environment is altered by global climate change.

4.2 Introduction

Studies of non-migratory ungulates have shown the potential for herbivory to significantly alter and/or reduce plant communities (Leader-Williams *et al.*, 1987; Augustine & McNaughton, 1998). At higher densities, caribou (*Rangifer tarandus*) forage selection can significantly reduce dominant plant species and alter the composition of plant communities visited (Ouellet *et al.*, 1993; Dragon, 2002; Boudreau & Payette, 2004). Such density-dependent resource impacts have also been found to have adverse effects on the caribou themselves, as a result of decreased juvenile survival, reduced body weights, and emigration (Leader-Williams & Ricketts, 1982; Skogland, 1985; Ferguson *et al.*, 2001).

Relationships among weather, habitat use, foraging, body reserves, and herd health have been examined for several insular caribou populations. On Coat's Island, deeper snow limited seasonal habitat use and animal forage availability, resulting in a negative shift in energy balance, and altered activity rates of female caribou (Gates *et al.*, 1986; Adamzcewski *et al.*, 1988, 1993). Leader-Williams & Ricketts (1982) demonstrated that higher South Georgia Island reindeer (*Rangifer tarandus tarandus*) body weights and fat reserves were similarly positively related to forage availability. Annual variations in temperature and precipitation also have the potential to affect the forage base by changing the relative abundance of individual species within native plant communities (Berendse & Jonasson, 1992; Chapin *et al.*, 1995), with changes in the relative abundance of preferred or high nutrient value forage species having direct consequences for animal condition.

Climate variation therefore, has the potential to influence the population dynamics of caribou through effects on their food supply (Lenart *et al.*, 2002; Gunn *et al.*, 2006). Climate models currently predict the effects of climate change will be felt earliest in the Arctic (Lashof & Ahuja, 1990; Serreze *et al.*, 2000; Houghton *et al.*, 2001). Climate warming in particular will alter precipitation and temperature patterns critical for plant survival and growth and may also alter over-wintering conditions for caribou and/or overall forage availability (Arctic Council and International Arctic Science Committee (IASC), 2004). Of particular concern is the possibility that the effects of global warming may act at lower trophic levels to significantly alter forage composition and quality before statistically significant changes in herd dynamics or resource bases are detected through routine surveys of herd condition (Bowyer *et al.*, 1998; Lenart *et al.*, 2002).

Little is known about long-term changes in caribou condition on Southampton Island, as it relates to diet, climate, or the availability of forage. Furthermore, the divergence between short-term and long-term dietary choice as it relates to seasonal dietary resource use is not clearly understood. Stable isotopes analysis (SIA) is a potentially useful method available for assessing changes in animal condition as they relate to shifts in diet (Sponheimer, 2003). For example, SIA does not rely on the recapture or re-sighting of previously captured individuals, and is easily and widely applied (Rubenstein *et al.*, 2004). SIA is also capable of detecting trophic interactions that may otherwise be unobservable from temporally limited gut content analyses and/or feeding studies (Power *et al.*, 2002). Accordingly, SIA may be used to reconstruct animal diets when diets consist of isotopically distinct items (Hobson *et al.*, 1992, 1999; Stewart & Bowyer, 2003).

The direct and predictable incorporation of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios of plants into herbivore tissue (DeNiro & Epstein, 1978; Lee-Thorp & van der Merwe, 1987; Cerling & Harris, 1999), are key to the inductive use of SIA in dietary studies of animal ecology (McIlwee, & Johnson, 1998; Kelley, 2000). For example, feeding organisms acquire the carbon and nitrogen isotope ratios of dietary sources in direct proportion to utilization with enrichment of approximately 0.5 ‰ (Barnett *et al.*, 2001) for carbon, and 3 – 3.5 ‰, respectively (DeNiro & Epstein, 1978; 1981) for nitrogen. As a result, SIA may be used to reconstruct animal diet, trace migratory movements, detect trophic shifts, and assess herbivore physiological condition in caribou, as seen for other species (e.g., Tiezen *et al.*, 1983; Ayliffe *et al.*, 2004; Boner *et al.*, 2004).

Degradation of caribou forage habitat on Southampton Island (SI) has been documented (Ouellet, 1992; Ouellet *et al.*, 1993, 1994, 1996). Prominent among the findings are reductions in the lichen standing crop and shrub re-growth and distribution as a result of increases in caribou range use and overgrazing (Dragon, 2002). Recent findings by the Nunavut Department of the Environment report energy balance shifts and reductions in body reserves for SI caribou (Campbell, pers. comm., 2003). Together, these findings have raised concerns among local subsistence harvesters about possible declines in herd numbers and the relationship between climate and herd conditions.

In light of the limited information on the association between forage habitat use, climatic effects, and animal condition for Southampton Island caribou, the major aims of this research were to apply stable isotopes analysis to muscle and rumen samples to identify and quantify associations among the variables. Specifically, it was hypothesized that variations in winter (December- March) climate conditions (temperatures and snow

thickness) would be correlated with muscle and rumen stable isotope signatures as a result of either temperature-dependent lipid catabolization or shifts in animal forage use.

4.3 Methods & Materials

Southampton Island (43,000 km²) is located at the north end of Hudson Bay in the territory of Nunavut (65°20' N; 84°40' W). The western half and southeastern portion of the island (Bell Peninsula) consist of low flat limestone plains dominated by *Dryas* barrens and sedge meadows. The remainder of the island is steeply rolling Precambrian shield, dominated by *Alectoria* and *Cetraria* lichens and heaths. Mean annual rainfall and snowfall are 13 and 133cm, respectively (Environment Canada, 2006). Coral Harbour is the primary island settlement (approximate population = 800) and the resident caribou herd is a main staple in the diet of the local Inuit.

Seasonal temperature and snow thickness data for Coral Harbour, for the years 1998-2000, 2004 and 2005, for the winter period (November to March), were obtained from Environment Canada (Table 4.1, Fig. 4.1). Temperature (°C) represents the mean daily average for the winter period computed using Environment Canada's recorded daily average temperatures. Snow thickness represents mean measured accumulation (cm) of snow on the ground for the same period.

The Nunavut Department of the Environment (NDE) has monitored the condition of Southampton Island caribou in conjunction with the annual spring commercial harvest (since 1993). Culled animals are identified with tags attached to the head, carcass and rumen before animals are processed at the abattoir. Biological monitoring samples collected include the lower jaw, kidneys, rumen, fecal pellets, reproductive tract and

blood. Collected samples were immediately frozen and stored at -20°C . Summary biological data recorded for each animal included sex, reproductive condition, back fat thickness, and animal disease and/or parasite status.

For the years 1998, 1999, 2004 and 2005 rumen sub-samples were analyzed for dietary components (following standardized protocols described in Chamrad & Box, 1964, 1968) to determine the percentage of plant species present. Plant species found in the rumen analysis were sampled, analyzed with SIA and grouped by forage categories (shrubs, sedges, forbs, grasses, lichens, and mosses). Mean forage category results were compared to environmental conditions on an annual basis.

For the purposes of this study, archived caribou samples with supporting biological data were sub-sampled for the years 1998-2000, 2004 and 2005, from the NDE freezers in Arviat. Fifty animals from each year (54 in 2004) were selected for analysis, with selection designed to include the range of variability in back fat and Riney kidney fat index measures for both sexes. All selected samples were matched to existing jaw and rumen samples.

Sections of archived rumen samples were removed for stable isotope analysis using a clean scalpel and the sub-samples were placed in sterile vials labeled with the assigned animal identification number. Muscle samples were obtained by cutting muscle tissue from the archived lower jaws using a clean scalpel and placing the sub-sample in sterile vials similarly marked with the animal identification number. All samples were shipped frozen to the University of Waterloo, where they were placed in a drying oven at 50°C for 48 hours and subsequently ground for two minutes using a ball-mill grinder, (model MM301, Retsch GmbH & Co., Haan, Germany). Approximately 1 mg of ground

muscle tissue and 2mg of the rumen contents in homogenate were weighed using a microbalance, placed in tin cups and submitted to the Environmental Isotope Laboratory at the University of Waterloo for stable isotope analysis.

All SIA analyses were performed at the Environmental Isotope Laboratory, University of Waterloo, on a Micromass VG Isochrom continuous-flow isotope ratio mass spectrometer connected to a Carlo Erba elemental analyzer. The International Atomic Energy Agency CH6 and N1 and N2 standards, respectively, were used to determine the accuracy of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. Stable isotope ratios are expressed as parts per thousand differences (‰) between the isotope ratio of the sample and an international standard according to the formula:

$$X = [(R_{\text{sample}} - R_{\text{standard}}) / R_{\text{standard}}] \times 1000 \quad (\text{Eq. 4.1})$$

Where X is the $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ value of the sample and R= the carbon ($^{13}\text{C}/^{12}\text{C}$) or nitrogen ($^{15}\text{N}/^{14}\text{N}$) isotope ratio of the sample or the standard. All international standards are set by convention at 0‰. Standards used to compute all values reported here included carbonate rock from the Peedee Belemnite formation (Craig, 1957) and atmospheric nitrogen gas (Mariotti, 1983). Every eighth sample was repeat analyzed, for purposes of assessing machine variability.

Average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for muscle and rumen samples were compared among years for which snow thickness and mean winter temperature data were available using multivariate analysis of variance, MANOVA. Pillai's trace statistic, Wilks' lambda, Hotelling's trace and Roy's largest root were used to compare tissue stable isotope means

and to test MANOVA hypotheses. Although none of these can be described as “best”, Pillai’s trace is the most robust and desirable for general testing of common means among groups (Zar, 1999). Environmental data (temperature, snow thickness) were compared between years using a one-way analysis of variance, ANOVA, followed by a Tukey’s post hoc test to determine differences among years.

Annual muscle signatures were adjusted by theoretical caribou enrichment factors of 3.8‰ for $\delta^{13}\text{C}$, and 2.8‰ for $\delta^{15}\text{N}$ (found by Barnett *et al.*, 2001) relative to rumen signatures, to investigate possible differences between summer and winter dietary signatures. Muscle adjusted values were used to estimate summer rumen signatures under the assumption that muscle tissue signatures would reflect nutrients assimilated and incorporated into tissue during summer feeding. Rumen signatures were used to represent winter animal feeding.

All statistical analyses were performed in SPSS (version 13.0, SPSS, Chicago, Illinois, U.S.A) following procedures outlined in Zar (1999). Significance in all statistical testing was set at the $\alpha = 0.05$ level.

4.4 Results

The mean winter (November 1 to March 31) temperature and snow thickness for the 1980-2005 period on Southampton Island, respectively, were -25.9°C and 23.47cm (Fig. 4.1). The mean winter temperatures used in the five years of this study varied from a low of -28.9°C in 1998 to a high of -24.1°C in 1999 (Table 4.1), while mean snow thickness over the period, varied from a low of 11.67cm in 2000 to 39.67cm in 2005. Significant differences among mean annual winter temperatures and snow-pack condition

were found using Tukey's HSD post hoc test ($p < 0.05$). Significant differences were also found between theoretical summer and actual winter-feeding signatures (Fig. 4.2) as reflected in muscle and rumen stable isotope signatures (Tukey's HSD post hoc test $p < 0.05$).

Two-factor MANOVA, using winter temperature and snow thickness, showed significance ($p < 0.001$) for all four test-statistics for temperature and snow thickness (Table 4.2). There were significant ($p < 0.001$) interaction effects for snow thickness and winter temperature (Table 4.3) on rumen $\delta^{13}\text{C}$ and rumen $\delta^{15}\text{N}$. No significant ($p < 0.05$) interaction effects were found for muscle $\delta^{13}\text{C}$ or muscle $\delta^{15}\text{N}$. MANOVA for muscle, however, did show significant effects for snow thickness on muscle $\delta^{13}\text{C}$ and winter temperature on muscle $\delta^{13}\text{C}$ and muscle $\delta^{15}\text{N}$ (Table 4.3). Figure 4.3 plots the estimated marginal means for each response variable (e.g. rumen $\delta^{13}\text{C}$) against temperature for above and below average snow thickness years.

Mosses, grasses, and lichens composed the bulk of the forage species chosen in all four years where detailed rumen content data were available (Fig. 4.4). The mean percentage of grasses in the rumen was lowest in 1998 and 2005, years with above average snow accumulation and below average temperature, and highest in 2004 the year with below average snow accumulation and below average temperature (Fig. 4.4). For mosses, mean percentage in the rumen was lowest in 1999, a year with above average temperature and above average snow accumulation, and highest in 1998 and 2005 (Fig. 4.4). Mean percentage of lichens in the rumen was lowest in 1998 (14.5%) and 2004 (21%), and highest in 1999 (30.4%) and 2005 (28.6%) shown in Fig. 4.4.

4.5 Discussion

Results here suggest differences in over-wintering environmental conditions are associated with significant variations in forage selection as measured by stable isotopes analysis (SIA). As environmental conditions changed on Southampton Island, rumen stable isotope signatures were affected, with the results of the two-factor MANOVA showing a significant interaction effect of snow thickness and temperature on rumen $\delta^{13}\text{C}$ and rumen $\delta^{15}\text{N}$. The effects of variations in winter temperature and snow cover on short-term feeding behaviour of caribou as reflected by rumen content, therefore, cannot be interpreted independently of one another. Muscle signatures were also significantly influenced by variations in winter weather conditions, but did not show significant interactions. Accordingly, the effects of variations in winter temperature and snow conditions on long-term feeding habits as reflected by muscle signatures can be interpreted independently of one another.

It has been suggested, based on a comparison between Southampton Island and Coats Island caribou herds, that competition for winter forage regulates the abundance of northern insular caribou populations and that climatic factors may also play a role by generating marked population fluctuations in some years (Ouellet *et al.*, 1993, 1994, 1996; Dragon, 2002). Population fluctuations were seen in the years presented in this study (Campbell, pers. comm., 2006). Studies also suggest that in northern environments, climatic factors, e.g. snow and ice, are highly variable and may mask the expression of density-dependent regulatory factors such as the overgrazing of forage species (*see* Skoog, 1968; Adamczewski *et al.*, 1988; Gunn *et al.*, 2006). In the five years for which data were available for this study, climate was variable and produced significant

differences in forage choices as represented by rumen content and isotopic signatures, particularly in 1998 and 2005 which had well below average temperatures and the thickest snow cover. As the population of the SI herd reaches its carrying capacity (Heard & Ouellet, 1994; Campbell, pers. comm., 2006), climatic factors become more determining, particularly, since overgrazing of lichen cover has been occurring (Ouellet *et al.*, 1993; Dragon, 2002).

In years where snow thickness was greatest, rumen content showed a higher percentage of mosses, whereas in 2004 when snow thickness was less, grasses were the highest percentage in the rumen content, indicating a change in foraging behaviour as climate conditions change. Changes in tundra plant community composition as a consequence of climatic warming are predicted, with an increase in shrubs and a decline in mosses and lichens, being the most significant changes (Epstein *et al.*, 2004). All are important forage species for SI caribou (Figs. 4.4), especially in years that have above average snow thickness (e.g. 1998 and 2005), with declines in mosses and lichens likely to result in a significant shift in rumen contents.

Similarly, Russell *et al.* (1993) noted lichens were a primary winter dietary source for the Porcupine herd, making approximately 40 - 70 % of the diet from the autumn migration to mid-winter. The contribution made by mosses to the diet during much of winter was typically <20%, but frequently as high as 41-49 % of the diet in late winter and during the spring migration as mosses and evergreen shrubs replaced lichens in the diet. Our results also indicate differences in winter and summer diet, as the adjusted muscle signatures differ significantly from the rumen signatures, indicating a seasonal

shift in dietary sources. Muscle signatures would represent long-term forage, whereas rumen signature would indicate short-term dietary choices.

If the current pattern of global warming continues, Southampton Island would experience the affects of higher temperatures and increased snow thickness predicted for the island (Hurrell, 1995; Maxwell, 1997; IASC, 2004). As snow thickness increases, caribou rumen contents shifted towards a higher percentage of mosses (Fig. 4.4), however, both mosses and lichens changes made will decline in availability as global warming occurs (Chapin *et al.*, 1995; Epstein *et al.*, 2004). In areas where winters are severe, reduced body weights of calves would result (Weladji & Holand, 2003), and this will likely have an effect on northern communities such as Coral Harbour, both economically and culturally.

Aanes *et al.* (2000) found that annual variation in population-growth rate in Svalbard reindeer was strongly negatively related to winter precipitation, with the effect of climate being stronger at high densities. Therefore, fears about the condition of the SI herd as its carrying capacity is reached increase, as the adverse effects of these climatic conditions become more determining at higher densities (Ouellet *et al.*, 1996, 1997; Campbell, pers. comm., 2006). The significant interaction effect between environmental data on the isotopic signatures in our study (Table 4.2), would suggest that the condition of the Southampton Island caribou herd (*see* Chapter 3), might be negatively affected as winter climatic conditions affect forage selection (Table 4.3), and herd density increases (Dragon, 2002).

In addition, Post & Forchhammer (2004) predict that populations whose dynamics are entrained by environmental correlation face increased “extinction risk” as

environmental conditions become more synchronized spatially. These predictions become highly relevant to the study of ecological consequences of climate change on the Southampton Island caribou herd as the local weather on the island changes. Their results indicate that spatial autocorrelation in local weather has increased with large-scale climatic warming, and suggest that if future warming can increase population synchrony; it may also increase extinction risk.

Thus determining the ability of the Southampton Island ecosystem to withstand the possible consequences of human interaction, including increased atmospheric contaminants as they drive climate change, will be particularly important. Research suggests that adverse weather, such as increased snow accumulation, indirectly influences population size in arctic caribou herds by increasing vulnerability to predators (Boertje *et al.*, 1996; Lenart *et al.*, 2002). Future studies of effects of climate on caribou should also consider the role of harvesting (Boertje *et al.*, 1996; Lenart *et al.*, 2002; Gunn *et al.*, 2006). Greater knowledge of these environmentally induced effects would be beneficial in studies involving neighbouring herds, where future applications of SIA may be used to study caribou ecology.

Much more remains to be learned about how climate change affects the foraging behaviours of SI caribou, and the relationships between forage use and its effects on animal condition. We have shown a link between winter environmental conditions and caribou muscle/rumen isotopic signatures in this study. More detailed studies of foraging behaviours and range use by Southampton Island caribou are warranted so that more definitive conclusions may be drawn concerning the potential impact of climate change on herd size and population dynamics on an insular Arctic island. The use of Stable

Isotopes Analysis of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ to study barren ground caribou on Southampton Island has shown to be a valuable tool for investigating their ecology and should be included in these future studies.

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Table 4.1: Mean winter (Nov. 1 to Mar. 31) temperatures ($^{\circ}\text{C}$) and snow thickness (cm) for years of study. All means were significantly different from one another. Rank notes the years in terms of coldest to warmest (temperature) and thinnest to thickest (snow thickness).

Year	Mean winter temperature ($^{\circ}\text{C}$)	Mean snow thickness (cm)
1998	-28.9	35.5
1999	-24.11	25.3
2000	-25.81	11.7
2004	-27.41	15.8
2005	-28.21	39.7

Table 4.2: MANOVA results for the effects of winter (Nov. 1 to Mar. 31) temperature (°C) and snow thickness (cm) on Muscle and Rumen isotopic signatures. The *F* statistic is given as an exact statistic and *df*= degrees of freedom. Table generated using SPSS version 13.0.

Effect		Value	<i>F</i>	Hypothesis <i>df</i>	Error <i>df</i>	<i>P</i> -value
Intercept	Pillai's trace	1.000	181235.23	4.	247	<0.001
	Wilks' lambda	.000	181235.23	4	247	<0.001
	Hotelling's trace	2934.984	181235.23	4	247	<0.001
	Roy's largest root	2934.984	181235.23	4	247	<0.001
Temperature	Pillai's trace	.233	18.74	4	247	<0.001
	Wilks' lambda	.767	18.74	4	247	<0.001
	Hotelling's trace	.304	18.74	4	247	<0.001
	Roy's largest root	.304	18.74	4	247	<0.001
Snow thickness	Pillai's trace	.239	19.40	4	247	<0.001
	Wilks' lambda	.761	19.40	4	247	<0.001
	Hotelling's trace	.314	19.40	4	247	<0.001
	Roy's largest root	.314	19.40	4	247	<0.001
Temperature * snow thickness	Pillai's trace	.171	12.75	4	247	<0.001
	Wilks' lambda	.829	12.75	4	247	<0.001
	Hotelling's trace	.207	12.75	4	247	<0.001
	Roy's largest root	.207	12.75	4	247	<0.001

Table 4.3: Test of between-variable effects (MANOVA) of winter (Nov. 1 to Mar. 31) temperature ($^{\circ}\text{C}$) and snow thickness (cm) on muscle and rumen isotopic signatures. The r^2 for the relationships denoted by the superscripts in column 3 were: a= 0.279, b= 0.074, c= 0.088, and d=0.196. The F statistic is given as an exact statistic and df = degrees of freedom. Table generated using SPSS version 13.0.

Source	Dependent Variable	Type III Sum of Squares	Df	Mean Square	F	P -value
Corrected Model	Muscle $\delta^{13}\text{C}$	59.81 ^a	3	19.94	32.21	<0.001
	Muscle $\delta^{15}\text{N}$	7.86 ^b	3	2.62	6.64	<0.001
	Rumen $\delta^{13}\text{C}$	6.92 ^c	3	2.31	8.04	<0.001
	Rumen $\delta^{15}\text{N}$	22.94 ^d	3	7.65	20.28	<0.001
Intercept	Muscle $\delta^{13}\text{C}$	117214.91	1	117214.91	189358.00	<0.001
	Muscle $\delta^{15}\text{N}$	3873.24	1	3873.24	9811.56	<0.001
	Rumen $\delta^{13}\text{C}$	143686.79	1	143686.79	500999.33	<0.001
	Rumen $\delta^{15}\text{N}$	51.44	1	51.44	136.41	<0.001
Temperature	Muscle $\delta^{13}\text{C}$	17.38	1	17.38	28.08	<0.001
	Muscle $\delta^{15}\text{N}$	7.73	1	7.73	19.57	<0.001
	Rumen $\delta^{13}\text{C}$	2.02	1	2.02	7.05	<0.008
	Rumen $\delta^{15}\text{N}$	19.12	1	19.12	50.70	<0.001
Snow thickness	Muscle $\delta^{13}\text{C}$	46.80	1	46.80	75.60	<0.001
	Muscle $\delta^{15}\text{N}$	.45	1	.45	1.14	<0.287
	Rumen $\delta^{13}\text{C}$	.03	1	.03	.12	<0.732
	Rumen $\delta^{15}\text{N}$	.87	1	.87	2.30	<0.131
Temperature * snow thickness	Muscle $\delta^{13}\text{C}$	.44	1	.44	.71	<0.401
	Muscle $\delta^{15}\text{N}$	.01	1	.01	.04	<0.852
	Rumen $\delta^{13}\text{C}$	3.93	1	3.93	13.70	<0.001
	Rumen $\delta^{15}\text{N}$	5.47	1	5.47	14.51	<0.001
Error	Muscle $\delta^{13}\text{C}$	154.75	250	.62		
	Muscle $\delta^{15}\text{N}$	98.69	250	.40		
	Rumen $\delta^{13}\text{C}$	71.70	250	.29		
	Rumen $\delta^{15}\text{N}$	94.27	250	.38		
Total	Muscle $\delta^{13}\text{C}$	127361.17	254			
	Muscle $\delta^{15}\text{N}$	4259.11	254			
	Rumen $\delta^{13}\text{C}$	156889.58	254			
	Rumen $\delta^{15}\text{N}$	178.55	254			
Corrected Total	Muscle $\delta^{13}\text{C}$	214.57	253			
	Muscle $\delta^{15}\text{N}$	106.56	253			
	Rumen $\delta^{13}\text{C}$	78.62	253			
	Rumen $\delta^{15}\text{N}$	117.21	253			

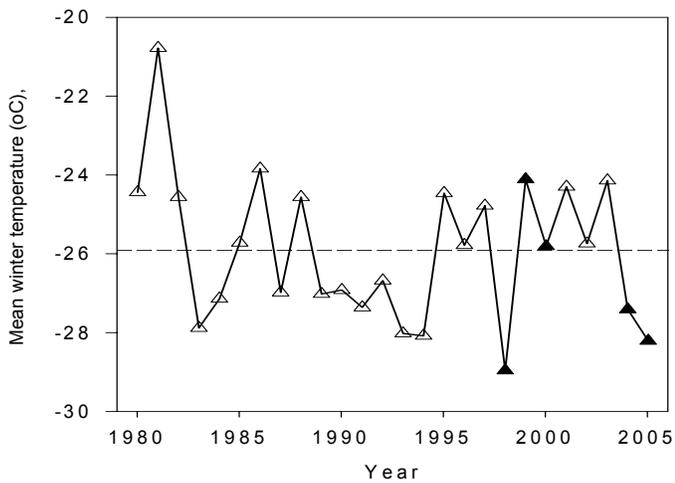
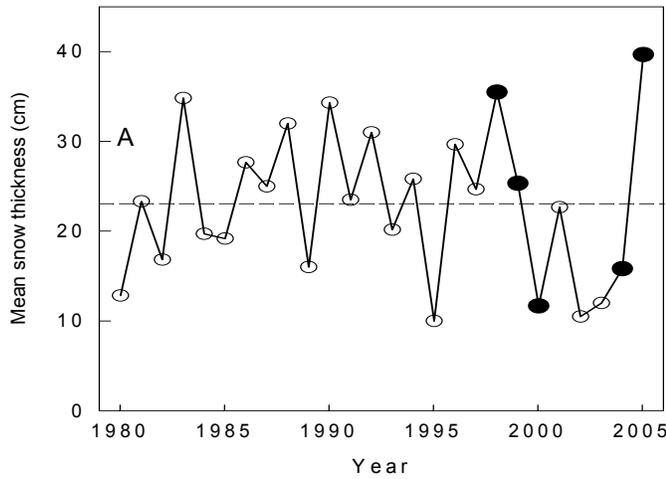


Figure 4.1: Mean winter (Nov. 1 to Mar. 31) temperature ($^{\circ}\text{C}$), and snow thickness (cm) for the years 1980-2005, on Southampton Island. The 25-year mean is plotted as a broken line. Years for which caribou isotope data were obtained are highlighted as filled circles and triangles on the plots.

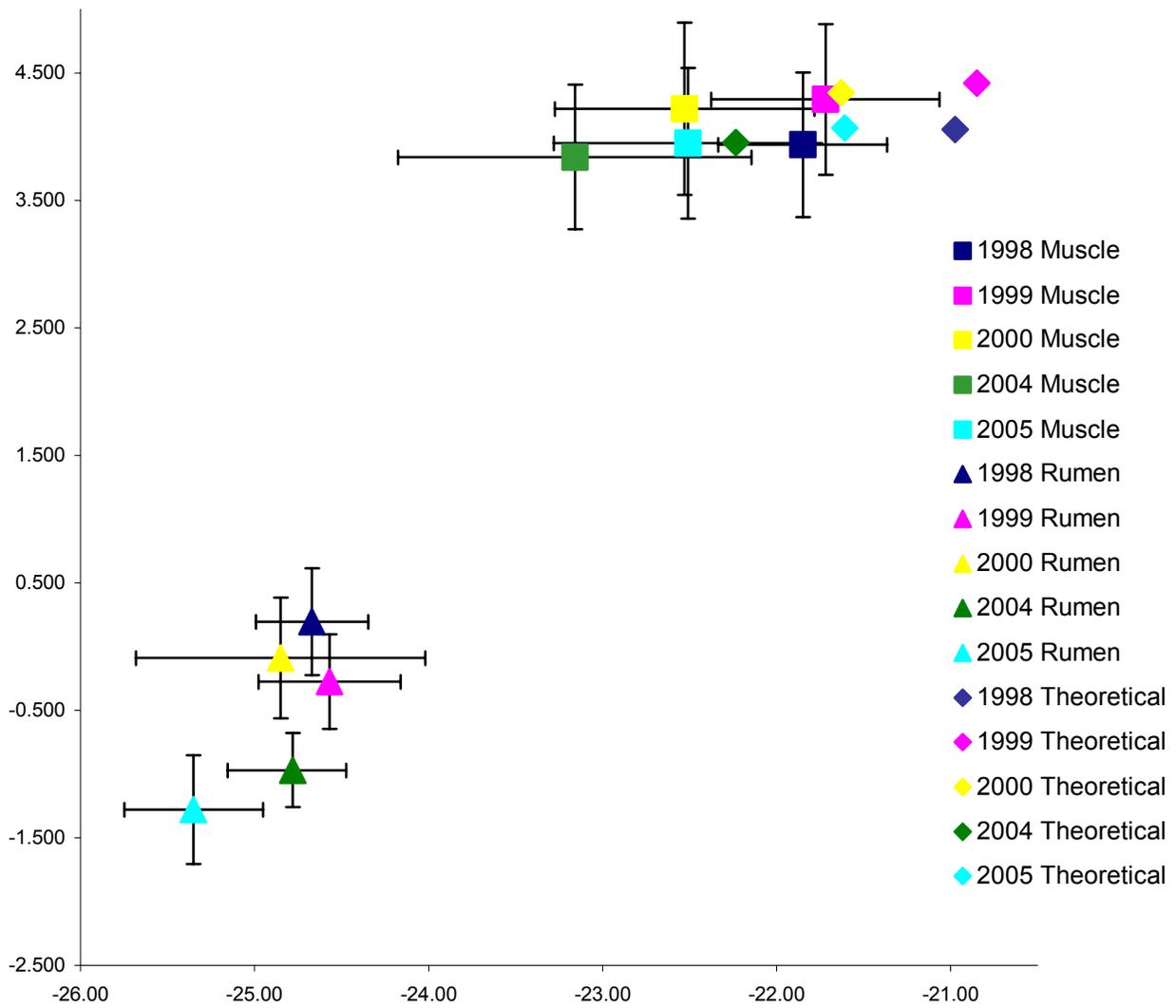


Figure 4.2: Mean ($\% \pm$ standard deviation) isotopic signatures for Southampton Island caribou rumen (triangles), muscle (squares), and theoretical summer (diamonds) samples, separated by year.

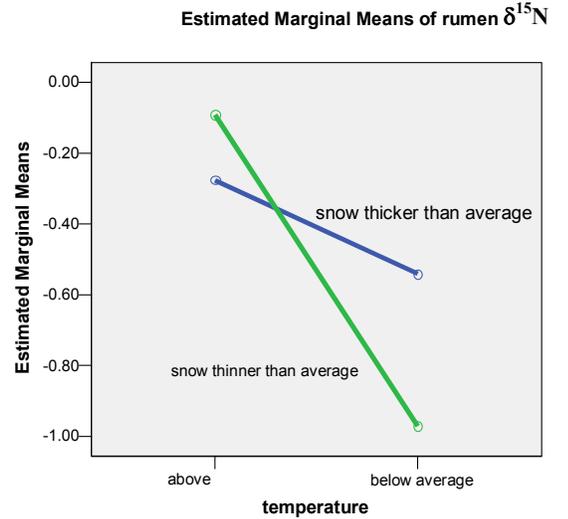
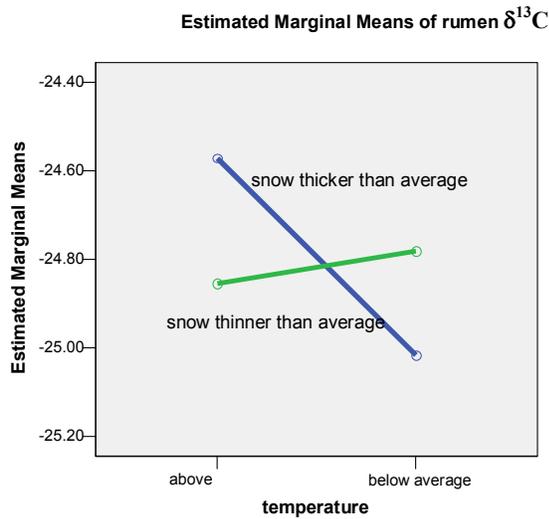
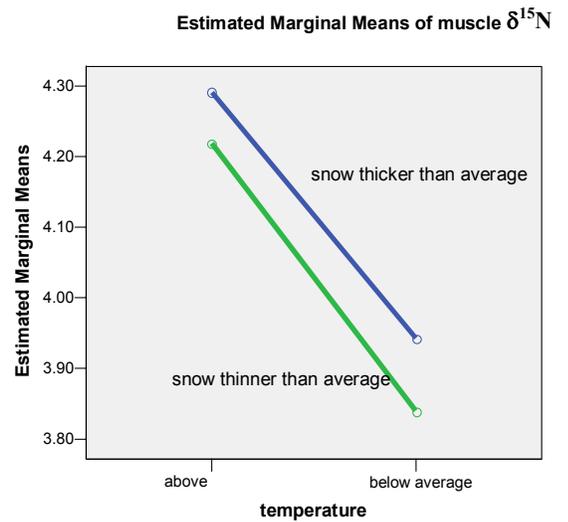
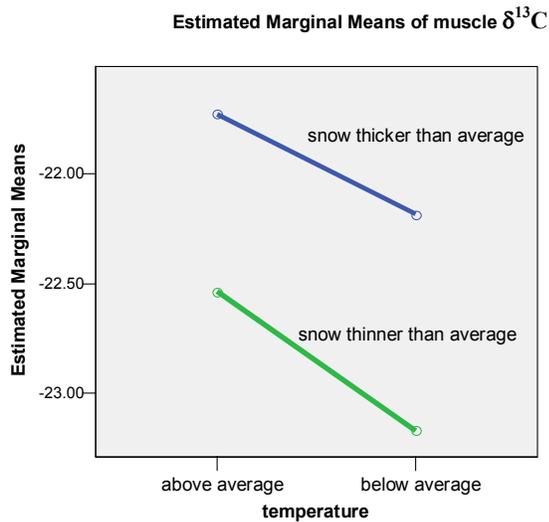


Figure 4.3: MANOVA plots for the effects of mean winter (Nov. 1 to Mar. 31) temperature ($^{\circ}\text{C}$) and mean winter snow thickness (cm) on, muscle $\delta^{13}\text{C}$, muscle $\delta^{15}\text{N}$, rumen $\delta^{13}\text{C}$, and rumen $\delta^{15}\text{N}$. Estimated marginal means are plotted against each other using SPSS version 13.0

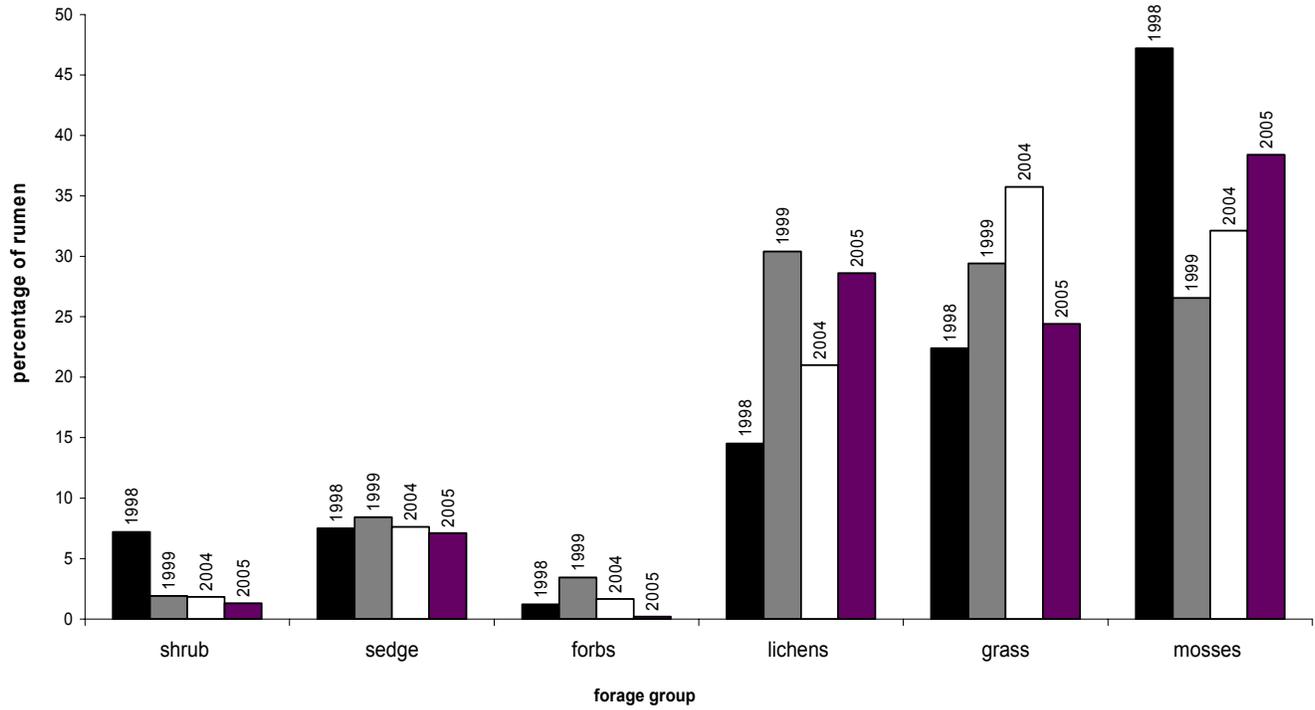


Figure 4.4: Annual mean percentage of forage plant groupings in rumen samples used for detailed rumen content analysis of caribou. No rumen analysis was completed in 2000.

Chapter 5

General Conclusions

5.1 General

The predicted changes in climate for Canada's Arctic include higher temperatures and greater precipitation, which together increase the likelihood of rain and freezing rain in spring and autumn (Maxwell, 1997; IASC, 2004). Ecologists have argued that caribou on Arctic islands are in a "non-equilibrium grazing system" where sporadic, unpredictable changes in key environment variables, such as snow and ice, govern the fate of caribou herds (Caughley & Gunn, 1993; Miller & Gunn, 2003). Accordingly, the implications of climate change on caribou forage availability and animal condition need to be better understood, in order to make appropriate management decisions for individual herds (Gunn *et al.*, 2006).

The non-invasive nature of SIA (i.e. use of already deceased animals) negates any stress normally placed on herds when using capture methods, and provides a cost-effective tool for the study of caribou at the landscape scale. The SIA results from this study and others (Griffith *et al.*, 2000; Barnett *et al.*, 2001) provide one means of assessing the importance of habitats with regard to seasonal food intake. Keratin in hooves provides a timeline of past feeding ranging from 6 to 10 months (Griffith *et al.*, 2000), while muscle tissue reflects bulk seasonal diet and can identify annual shifts in diet and the potential short-term implications to caribou condition. Collagen in connective tissue retains the average isotopic ratios of forage plants over several years

and therefore may prove useful in assessing long-term nutrition of forage vegetation, particularly when assessed with seasonal and dietary trends (Barnett *et al.*, 2001).

More detailed SIA of forage vegetation on Southampton Island is recommended, as Barnett *et al.* (2001) indicate that feeding on mushrooms and late summer green forage provides important contributions to protein production. The ability to measure the isotopic composition of small quantities of sulphur in biological materials rapidly and accurately provides many new opportunities to investigate lichens as bio-monitors, suggesting that under certain circumstances lichen thalli may act as archives of changing atmospheric conditions (Wadleigh, 2003).

Sex-specific responses of ungulates to climatic fluctuation may be age dependent, as is the case for most density-dependent and density-independent effects (Gaillard *et al.*, 2000; Clutton-Brock & Coulson, 2002). Although our results suggest some sex-specific responses to climate fluctuations (Table 4.3), especially in pregnant females, they would benefit from supplemental aging data to determine if they are age dependent.

SIA data yields a time-integrated signal reflective of spatial and temporal variation in feeding ecology and as such is capable of detecting trophic interactions that may otherwise be unobservable from temporally limited rumen content analysis. SIA, together with detailed rumen analysis and fecal signatures, may provide greater information on these interactions. Subsistent harvesting of caribou by Inuit is practiced throughout the Arctic, providing an easy means of involving local stakeholders in the active collection of plant, fecal, and tissue samples for the scientific study and management of caribou populations.

Sampling at various times throughout the year is also recommended as the next step towards fine tuning the capabilities of SIA for understanding the dynamics of the interactions of caribou with their environment. Links between winter environmental conditions and caribou muscle/rumen isotopic signatures were found in this study using a cost effective logistically simple approach. Changes in forage preference were observed using the mean rumen content analysis, and indicate that the herd is potentially at risk as their arctic environment is altered by global climate change.

The use of Stable Isotopes Analysis of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ to study barren ground caribou on Southampton Island, has shown to be a valuable tool for investigating their ecology and should be included in future studies. This was the first attempt at using stable isotope analysis on an insular caribou population, and the results show that SIA is a promising, and economical tool in studying terrestrial mammalian ecology in the remoteness of Canada's Arctic.

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