POPULATION GENETICS OF WOODLAND CARIBOU (*Rangifer tarandus caribou*) ON THE ISLAND OF NEWFOUNDLAND

by

© Corinne D. Wilkerson

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Abstract

The purpose of this study was to characterize the genetic variation and genetic structure of caribou herds on the island of Newfoundland. A 2223 bp sequence of mitochondrial DNA from the Control Region and the cytochrome *b* gene was sequenced for 233 Newfoundland caribou (*Rangifer tarandus caribou*). Phylogenetic analysis identified 32 mtDNA haplotypes structured into four clades, labeled A, B, C and D. The hierarchical AMOVA revealed there is little genetic differentiation among defined herds, although there is some regional differentiation of the Avalon Peninsula. Avalon Peninsula caribou are genetically depauperate and distinct, possibly as a result of founder effects. The Nested Clade Analysis identified significant phylogeographic associations possibly due to restricted gene flow with isolation by distance, contiguous range expansion and long distance colonization possibly coupled with subsequent fragmentation or past fragmentation followed by range expansion. Most Newfoundland caribou show close relationships to woodland caribou in Quebec, and a small subset show close relationships to woodland caribou in Labrador. There is some genetic evidence to suggest that caribou populated Newfoundland by way of the Straight of Belle Isle as opposed to coastal refugia. Newfoundland caribou are genetically distinct from Eurasian reindeer (*Rangifer tarandus tarandus*) and there is no evidence to support successful interbreeding with reindeer introduced from Norway. In anticipation of continuing population genomic studies of Newfoundland caribou, the entire mtDNA genome for one Newfoundland caribou was sequenced (16,359 bp).

1.0 Introduction

1.1 Nature of The Problem

Woodland caribou *Rangifer tarandus caribou* populations are declining across most of Canada, due to factors such as, increased predation and habitat loss, and as a result most populations have been designated to be at risk (COSEWIC 2002). The Newfoundland population of woodland caribou, which is the focus of this study, remains at relatively high numbers (ca. 80,000 animals) and therefore has not been designated at risk. However, in recent years, signs of a population decline have been observed and numbers are predicted to decrease dramatically in the near future (Mahoney and Schaefer 2002, S. Mahoney pers. com.). Because the population is hunted annually for sport and as a food source for local residents it must be carefully managed in light of the predicted decline.

Preservation of genetic diversity is a key component to consider in the management of any species. Genetic diversity occurs at four levels of organization: among species, among populations, within populations and among individuals (Hunter 1996). It is generally accepted that a high level of genetic diversity allows a species to be adaptable to a range of conditions, thereby improving survivability, productivity, reproduction and physical condition. Isolated populations, such as the Newfoundland caribou, may have reduced genetic diversity and small gene pools associated with inbreeding that may result in poor environmental fitness, poor adaptability and increased risk of extinction in the face of environmental or other changes. Of course it is not

always the case that low levels of variation are manifested as reduced environmental fitness and in fact the opposite may be true, where homozygous genotypes may be positively selected as an adaptation to local conditions.

Little is known about the genetic diversity and genetic population structure of Newfoundland caribou herds or their relationships to caribou in North America and Eurasia. This lack of information limits our understanding of the viability of individual herds in the population, relationships with neighboring herds, and how caribou have populated and persisted on the island. This study aims to use mitochondrial DNA to characterize the genetic variability among and within herds on the island in order to evaluate the degree of gene flow among herds, and examine evolutionary relationships with caribou herds from mainland Canada and reindeer from Eurasia. The genetic information gathered from this study will greatly enhance our understanding of Newfoundland caribou population dynamics at the landscape level and will be integral in managing the caribou populations to preserve genetic diversity in light of the predicted population decline. Genetic comparisons with caribou populations from mainland Canada will help determine the degree of genetic differentiation from these populations and may give insight into the origins of the Newfoundland caribou population. Genetic comparisons with Eurasian reindeer (*Rangifer tarandus tarandus*) will help to verify whether interbreeding occurred with reindeer introduced to Newfoundland from Norway in the early 1900's and determine if any remnant populations of reindeer still exist.

1.2 Caribou as a Species

Caribou (*Rangifer tarandus* Linnaeus) are a holarctic species with extant populations in North America, Europe, Asia, Greenland, and Spitsbergen/Svalbard (Røed 2005; Kurtén and Anderson 1980; Banfield 1961). Caribou and reindeer are considered to be the same species, caribou refers to wild populations in North America and reindeer refers to wild and domesticated populations in Eurasia. Caribou are a member of the deer family (Cervidae), and are distinguished as being the only member of the family where both sexes have antlers (Kurtén and Anderson 1980; Banfield 1961). Caribou are a medium-to-large sized deer that possess a number of physical adaptations to arctic or sub-arctic environments (Banfield 1974; Banfield 1961), including a large, blunt and well-furred muzzle; short, broad and heavily furred ears; a short and well-furred tail; a compact body covered by long, thick pelage; and large feet with crescentic hooves that facilitate travel over snow-covered and boggy ground (Banfield 1974). In winter, the hooves grow longer and the hair between the toes forms tufts that cover and protect the pads from the snow and ice (Banfield 1974).

Modern deer evolved in the Old World (Eurasia) and are thought to have begun populating the New World (North America) sometime during the Pliocene ~3.5 mybp (Banfield 1961, Geist 1998, Guthrie and Matthews 1971, Kurtén 1968, Kurtén and Anderson 1980). The origin of the genus *Rangifer* is unknown, however, some suggest it originated in Alaska, Beringia or the mountains of northeastern Asia and later migrated into Western Europe (Banfield 1961, Guthrie and Matthews 1971, Martin and Klein 1984). The earliest record of *Rangifer* in North America is from a 1.6 million year old

tooth found in the Yukon Territory; other early records include 45,500-year-old cranial fragment from the Yukon and a 40,600-year-old antler from Quebec (Gordon 2003). The ancestral origins of caribou prior to the last glaciation (Wisconsin), which occurred approximately 80,000 to 10,000 years ago, are not well understood, however, during the last glaciation it is known that caribou were abundant and distributed in non-glaciated refugia both north and south of the Laurentide ice sheet (Banfield 1961, Martin and Klein 1984).

The eight subspecies of caribou currently recognized (Figure 1) are believed to have developed in three isolated non-glaciated refugia, designated Beringia, Eurasian and Southern, which were created as the continental ice sheets expanded and retreated throughout the Wisconsin (in North America) and Weichselian (in Eurasia) glaciations (Røed 2005; Banfield 1961). The Beringia refugium, extending through Eurasia, Alaska and Yukon, gave rise to all of the North American tundra forms (*Rangifer tarandus granti* and *Rangifer tarandus groenlandicus*), arctic forms (*Rangifer tarandus platyrhynchus*, *Rangifer tarandus pearyi*, and *Rangifer tarandus eogroenlandicus*), Eurasian tundra form (*Rangifer tarandus tarandus*) and the Eurasian forest form (*Rangifer tarandus fennicus*) (Røed 2005; Kurtén and Anderson 1980; Banfield 1961). The Eurasian refugium, small isolated refugium in Western Eurasia, also gave rise to *R. t. tarandus* and *R. t. fennicus*, suggesting a diphyletic origin for these subspecies (Røed 2005). The Southern refugium in North America, extending from New Jersey, Kentucky, Missouri, Illinois, and Iowa to the mountainous region of the southwest –New Mexico and Nevada, gave rise to the American woodland caribou subspecies (*Rangifer tarandus*

caribou) (Røed 2005, Kurtén and Anderson 1980; Banfield 1961). Evidence of cold, tundra-like conditions and fossils of tundra animals, including caribou have been found in the area defined as the Southern refugium (Pielou 1991). The caribou population in Newfoundland is currently assigned to the woodland caribou subspecies *(Rangifer tarandus caribou)*, however, it was at one time considered as a separate subspecies (*Rangifer tarandus terranovae*, Bangs). It should be noted that the subspecies designations of caribou (and use of the subspecies concept in general) are rather subjective, however, when applied properly, they do recognize potentially important geographic variation (Cronin 2006).

Woodland caribou are distributed throughout the taiga/boreal region from Newfoundland and Labrador and Quebec in the east, across to British Columbia, Yukon and Alaska in the west (Banfield 1961). They are adapted to live in forested areas, and are generally found in mature boreal forest, associated barrens, and bog-fen complexes (Banfield 1961). Woodland caribou tend to have larger body size, longer legs and a shorter distance between their antlers than caribou adapted to open tundra, mountain or arctic habitats (Røed 2005). Woodland caribou primarily depend on ground lichens (*Cladonia* spp.) and arboreal lichens for food (Banfield 1961, Bergerud 1972), however, they also eat significant amounts of sedges, fungi, deciduous and evergreen shrubs, and other plant material, depending on the season (Bergerud 1972). They tend to live in small groups and are mostly sedentary, however, some populations undertake local, seasonal migrations (Banfield 1961). The primary predator of woodland caribou in most areas is the wolf (*Canis lupus*), however, other predators are also known to feed on

caribou , including, grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), golden eagle (*Aquila chrysaetos*), bald eagle (*Haliaeetus leucocephalus*), wolverine (*Gulo gulo*), lynx (*Lynx canadensis*) and coyote (*Canis latrans*) (Bergerud 1971; Banfield 1974; Siep 1991).

At the close of the 19th century, the distribution of woodland caribou in North America followed the proximate distribution of the Boreal Forest (Banfield 1961). During the 1900's, woodland caribou populations across North America underwent significant declines (Bergerud 1974). Increased harvesting that resulted from the expansion of European immigrants into North America and increased wolf predation are cited as the main causes of the decline (Banfield 1961; Bergerud 1974; Seip 1991). Currently, several woodland caribou populations across Canada (Figure 2) are designated as Endangered (Atlantic-Gaspésie population), Threatened (Boreal population, Southern Mountain population) or Special Concern (Northern Mountain population) by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002). The Newfoundland population is the only forest-dwelling population of woodland caribou that is not designated at risk.

1.3 Early Population History of Woodland Caribou Herds in Newfoundland

Caribou populated the island of Newfoundland sometime after the end of the Wisconsin Glaciation when the Laurentide ice sheet retreated. It is believed that caribou may have inhabited Newfoundland for as many as 8,000 years, likely originating from refugia located south of the Laurentide ice sheet, where it is thought all of the woodland

caribou subspecies originated (Banfield 1961; Kurtén and Anderson 1980; Røed et al. 1991; Røed 2005). There are different schools of thought as to how the founding populations of caribou populated the island of Newfoundland. One theory is that caribou came from Labrador over the ice on the Strait of Belle Isle to the northern tip of Newfoundland during an unusually cold winter (Hardy 1869). This would suggest that Newfoundland caribou are most closely related to caribou from Labrador and the Quebec North Shore. However, there here has been little documented movement of caribou between the island and Labrador/Quebec at the Strait of Belle Isle. The last documented event was made in the late 1800's by Captain C. Hardy based on information he gained from local fishermen (Hardy 1869). A second hypothesis is that caribou came from the eastern coastal plains refugia and/or various island refugia (Figure 3) located off the east coast of North America (Pielou 1991). Little is known of the inhabitants of these areas except that there were mastodons and mammoths on the southern parts of the coastal plains lands (Pielou 1991). It has been suggested that large active animals, such as caribou, may have journeyed frequently among the ring of refugia surrounding the Goldthwaite Sea and the islands of the coastal plains lands (Pielou 1991). Under this hypothesis, Newfoundland caribou would be most closely related to the caribou that once inhabited New England and the Atlantic provinces of Nova Scotia, New Brunswick and Prince Edward Island (Pielou 1991). Unfortunately, maritime caribou have been extinct since the late 1800's/early 1900's, and all that remains is a small population on the Gaspé Peninsula in Quebec (Figure 2), which is currently designated as Endangered (COSEWIC 2002). Whatever their origins, Newfoundland caribou are believed to have evolved

independently of mainland populations because of their long post-glacial isolation on the island. Under such circumstances, they may have developed unique behavioral and morphological characteristics, which may subsequently be due to unique alleles or genotypes.

Several significant events occurred over the past century that may have influenced the current genetic diversity and genetic population structure of caribou in Newfoundland. In the late 1800's a railroad was constructed across the center of the island in an east-west direction. The railroad intersected the path of fall caribou migration from the Northern Peninsula to southern parts of the island (Millais 1907). The railroad allowed easy access to thousands of caribou by hunters and resulted in substantial over-hunting until the government enforced game restrictions several years later (Millais 1907). In 1908, Sir Wilfred Grenfell brought 300 Norwegian reindeer to St. Anthony to provide a source of food for the locals (Millais 1907; Johnson 1967). The introduced reindeer herd flourished and rose to 1500 by 1913. However, when Grenfell left St. Anthony during the war most of the reindeer were killed by poachers (Johnson 1967). The remaining animals were relocated to Anticosti Island in the St. Lawrence River where they eventually died out (Bergerud and Mercer 1989; Johnson 1967).

During the reindeer introduction, a group of 50 reindeer were herded from St. Anthony, down the Northern Peninsula, through the Long Range Mountains, and east to Millertown (Johnson 1967). Along the way, these reindeer met with local caribou herds and likely introduced the nematode *Elaphostrongylus rangeriferi* (Scandinavian Brain Worm) to the Newfoundland caribou population (Lankester and Fong 1989). This

parasite causes the disease Cerebrospinal Elaphostrongylosis (CSE) and was first diagnosed in caribou of central Newfoundland during the mid 1970's (Lankester and Northcott 1979). The disease later spread to caribou herds on the isolated Avalon Peninsula around 1990, causing significant mortalities (Lankester and Fong 1998).

For reasons that are still not well understood, wolves were completely extirpated from Newfoundland in the early 1900's (Bergerud 1971; Mahoney and Virgl 2003). Wolf predation is considered the dominant, natural regulating factor in caribou populations (Seip 1991). The loss of this important predator from the Newfoundland caribou population may have had a significant effect on the population dynamics of caribou on the island.

Over the past century, caribou in Newfoundland have experienced dramatic population fluctuations that may have affected current levels of genetic variation. In the early 1900's caribou were abundant, with claims of population estimates ranging as high as 150,000 (Dugmore 1913) to 200,000 (Millais 1907) caribou. These estimates, however, were based largely on observations rather than a formal census. The population estimate for the interval of 1900-1910 was later revised to approximately 40,000 caribou based on estimates given in interviews by residents from across the island (Bergerud 1971). From about 1915 to 1925 the caribou population declined rapidly (Bergerud 1971) to such low numbers that there was concern that caribou would be extirpated from the island. This was around the same time that the wolf was extirpated from Newfoundland, and the decline of the caribou is cited as a possible reason for the wolf's extirpation. Due to the caribou population decline, the hunting season for caribou was

closed in 1925 (Bergerud 1971). It was believed there might have been as few as 200 caribou left on the island (Dugmore 1930); however other estimates suggested that the population declined to approximately 1,000 to 2,000 caribou (Bergerud 1971). At the time, the reason for the decline was largely attributed to over-hunting, which increased substantially when the railroad was built across the island in the late 1800's. However, it was later suggested that increased predation on caribou by lynx, which was brought on by a decline in their main prey base, the snowshoe hare, may have contributed significantly to the decline in caribou numbers (Bergerud 1971). Caribou in Newfoundland have been found to experience cyclical peaks and declines in their numbers every 60-90 years and this may have had more of an influence in their decline than over-hunting or lynx predation alone (S. Mahoney pers. com.).

By the early 1930's, caribou numbers began to increase and hunting was resumed in 1935 (Bergerud 1971). A peak population was reached around 1941, but declined again in the following few years (Bergerud 1971). By the mid-1940's, the population expanded and occupied much of its previous range (Bergerud 1971). A second peak of abundance was reached around 1951, after which caribou numbers declined yet again (Bergerud 1971). A census completed in 1957-58 estimated the population at approximately 6,500 caribou (Bergerud 1971). The population increased exponentially in subsequent years (Mahoney and Schaefer 2002; Mahoney et al.1991; Bergerud et al. 1983), numbering 23,000 to 44,000 in the mid-1980's (Williams and Heard 1986) and reaching a peak population of approximately 80,000 caribou by the mid-1990's.

1.4 Current Status of the Newfoundland Caribou Population

The current population is thought to be past its cyclical peak of abundance and declining (S. Mahoney pers. com.). Evidence of the decline has been indicated by long-term studies of caribou on the Buchans Plateau in central Newfoundland (Mahoney and Schaefer 2002). Signs of the decline have been observed in the form of lower annual survival of adults, decreased adult body size, decreased recruitment, low calf survival, late calving, and reduced pregnancy rates (Mahoney and Schaefer 2002). Some herds have experienced zero calf survival in recent years (S. Mahoney pers. com.). Other indications that the population may be past its peak of abundance include observations of early autumn migration and late spring migration which may be related to the herd's own depletion of its summer forage (Mahoney and Schaefer 2002).

A number of factors influence the survival of Newfoundland caribou. Although wolves have been extirpated from the island, caribou are subject to predation by black bear (Mahoney and Virgl 2003), coyote (S. Mahoney pers. com.), bald eagle (S. Mahoney pers. com.), and lynx (Bergerud 1971). The population also suffers from various diseases and parasites, including Scandinavian brainworm (*E. rangiferina)*, warble fly (*Hypoderma tarandi*); throat/ nose bot (*Cepehenemyia trompe*), and tapeworm cysts.

Previous studies on the population dynamics of Newfoundland caribou suggest the entire population comprises four broadly defined yet discrete herds, the Interior Herd, the Humber River Herd, the Avalon Peninsula Herd, and the Northern Peninsula Herd (Bergerud 1971). However, for current management purposes by the province of

Newfoundland and Labrador, the population of caribou on the island is subdivided into 19 Caribou Management Units (or herds), which are based on calving ranges (Figure 4). These caribou herds are hunted between September and December of each year, with the exception of 4 herds (Avalon Peninsula, Burin Knee, Burin Foot and Blow Me Down Mountains), which are closed to hunting. Three of the herds occur on islands, (Fogo Island, Grey Islands and Merasheen Island) and have a limited hunting season. From 1961 to 1982, 384 caribou were taken from native Newfoundland ranges and introduced to 22 sites in Newfoundland unoccupied by caribou, including several small islands (Bergerud and Mercer 1989). A number of the introductions were successful, including three herds that are included in this study, St. Anthony, Merasheen Island, and Cape Shore. The St. Anthony herd likely originated from the central herds, however, information on the source of this introduction is not clear. The caribou on Merasheen Island were introduced from the Buchans Plateau in the 1970's (Anonymous 1973). Caribou in the Cape Shore herd were introduced from the Avalon Peninsula herd (S. Mahoney pers. com.).

This study defines the 19 Caribou Management Areas (CMU's) as separate herds and focuses on a sub-sample of 14 of theses herds. The study samples come from 13 hunted herds from across the island and one non-hunted herd. The hunted herds include; Lapoile, Buchans, Grey River, Gaff Topsails, Pot Hill, Mount Peyton, Middle Ridge, Hampden Downs, Adies Lake, Northern Peninsula, St. Anthony, Cape Shore, and one island herd, which is located on Merasheen Island (Figure 4). The one non-hunted herd included in the study is located on the Avalon Peninsula (Figure 4). The 1070 km^2

Avalon Wilderness Reserve protects the range of this herd from habitat loss and hunting. The Avalon herd was severely depleted in the 1960's but increased steadily thereafter (Bergerud et al. 1983) until they were exposed to Scandinavian Brain Worm in the 1990's and faced significant reductions. The Middle Ridge herd is one of the largest herds on the island, numbering approximately 15,000 caribou. Although this herd is hunted, much of its winter habitat is protected by the 2895 km^2 Bay du Nord Wilderness Reserve and the adjacent Middle Ridge Wildlife Reserve.

1.5 Mitochondrial DNA as a Marker and Caribou Genetic Studies

A number of studies evaluating the phylogenetic relationships of mammal populations have used mitochondrial DNA (mtDNA) as a molecular marker. The advantages of using mtDNA for phylogenetic studies are well-known and numerous. Mammal cells contain thousands of copies of mtDNA, which provide a high number of starting copies for amplification by Polymerase Chain Reaction (PCR) (Palumbi 1996). Mitochondrial DNA evolves 5 to 10 times faster than single copy nuclear DNA so it is particularly useful in assessing genetic relationships among closely related individuals in populations which have more recent divergence times (Avise 2004, Brown et al. 1979,). Mitochondrial DNA is maternally inherited and non-recombining; therefore it gives a direct history of maternal inheritance throughout time (Avise 2004, Wilson et al. 1985). Gene phylogenies and haplotype frequencies produced from mtDNA sequence information can give estimates of gene flow among populations (Hudson et al. 1992; Slatkin and Madison 1989, 1990) and when combined with geographic information can

be used to evaluate the genetic structure of a population (Avise et al. 1987, Avise 2000, 2004).

Genetic relationships of caribou populations in North America and Europe have been studied using a variety of molecular markers, including, the major histocompatibility complex (Olsaker and Røed 1990; Cronin et al. 1995); *k*-casein (Cronin et al.1995); serum transferrin (Røed 1991; Røed 2005; Røed & Thomas 1990; Røed et al. 1991); microsatellite loci (Côté et al. 2002; Courtois et al. 2003; Cronin et. al 2003; Cronin et al. 2005; Cronin et al. 2006; Jepsen et al. 2002; McLoughlan et al. 2004; Røed 2005; Røed & Midthjell 1998; Valkenburg et al. 2000; Wilson et al. 1997; Zittlau et al. 2000); restriction enzyme analysis of mitochondrial DNA (Cronin 1992); mitochondrial DNA cytochrome *b* gene (Byun et al. 2002; Cronin et al. 2005; Cronin et al. 2006); and mitochondrial DNA Control Region (Cronin et al. 1995; Flagstad & Røed 2003; Gravlund et al. 1998; Røed 2005). A number of these studies have included caribou from the Newfoundland population (Cronin 1992; Cronin et al. 2003; Cronin et al. 2005; Røed et al. 1991). A study of transferrin alleles in North American caribou identified caribou from Brunette Island, Newfoundland as more closely related to woodland caribou (*R. t. caribou*) from Manitoba, Ontario and the Gaspé Peninsula than to barren-ground caribou (*R. t. groenlandicus*) from the North West Territories (Røed et al. 1991). A study of the cytochrome *b* gene of mitochondrial DNA identified two unique genotypes in Newfoundland caribou, which were also identified as most closely related to other woodland caribou (*R. t. caribou*) from Labrador, Quebec, and Alberta rather than barren-ground caribou (*R.t groenlandicus* and *R. t. granti*) from northern Canada and

Alaska (Cronin et. al 2005). Both of these studies (Røed et al. 1991; Cronin et al. 2005) and others (Flagstad & Røed 2003; Gravlund et al. 1998) identified a high degree of genetic separation between *R.t caribou* and other caribou subspecies, which suggest that the ancestral populations of *R. t. caribou* likely survived the Wisconsin glaciation in separate refugia located south of the continental ice sheet, while other *Rangifer tarandus* subspecies survived north of the ice sheet.

1.6 Mitochondrial Genomic Studies and their use for Newfoundland Caribou

A limitation of most population genetic studies is the lack of resolution attained when only a few loci are examined. In mitochondrial DNA studies, a particular gene or region of the genome is chosen for examination based on some previous knowledge of the degree of variation in that area with the expectation that it will provide enough resolution to decipher the genetic relationships accurately. Ideally, the best resolution would be attained using the entire mitochondrial genome (16 Kbp). Traditional sequencing methods are too laborious for such large-scale population genomic studies. A new biotechnology called iterative DNA "re-sequencing", uses a DNA microarray to generate >30Kbp of sequence data in a single experiment (Carr et al. 2008). Experiments with a first-generation microarray designed for mtDNA have shown it to be an accurate, efficient, time and cost effective method for DNA sequencing (Carr et al.2008). An experimental design has been developed to use the mtDNA microarray, known as the "ArkChip", to sequence multiple distantly related vertebrate species of interest in one experiment (Carr et. al 2008). In order to sequence the whole mtDNA genome for a

particular species of interest a species-specific microarray must be designed. The design of the microarray is expensive so it is designed for a high-profile species of interest, such as, the Atlantic Cod (*Gadus morhua*). Using the microarray designed to sequence the Atlantic Cod mtDNA genome, additional complete mtDNA genomes of homologous mtDNA from other species of interest, including, the Newfoundland caribou (*R. t. caribou*), are sequenced in the same experiment (Carr et al. 2008). The use of this technology will be beneficial for wildlife population genomic studies, as it will enable a standardized, co-ordinated investigation of multiple species of interest to Species-At-Risk agencies, managers and recovery teams (Carr et al. 2008).

Sequencing the mtDNA genome using this approach still requires at least one copy of the mtDNA genome for the species of interest as a basis of reference and comparison. In some cases, whole mtDNA genomes can be accessed from public databases (GenBank http://www.ncbi.nlm.nih.gov/Genbank/index.html), however, they are not readily available for all species. In anticipation of continuing population genomic studies of Newfoundland caribou using the "ArkChip" design, the whole mtDNA genome will be sequenced using traditional sequencing methods. This sequence will serve as a measure of accuracy for the "ArkChip" design and to provide a basis of comparison for additional samples. At the time this study began, the mtDNA genome for caribou had not yet been published, however, in January 2006 the mtDNA genome for reindeer (*R. t. tarandus,* 16,362 bp) was published on GenBank http://www.ncbi.nlm.nih.gov/Genbank/index.html (Wada et al., Tokyo University of Agriculture, unpublished). The availability of the reindeer mtDNA genome presents an

opportunity to compare the whole mtDNA genomes for two subspecies of caribou, reindeer of Eurasia (*R. t. tarandus*) and woodland caribou of Newfoundland (*R. t. caribou*).

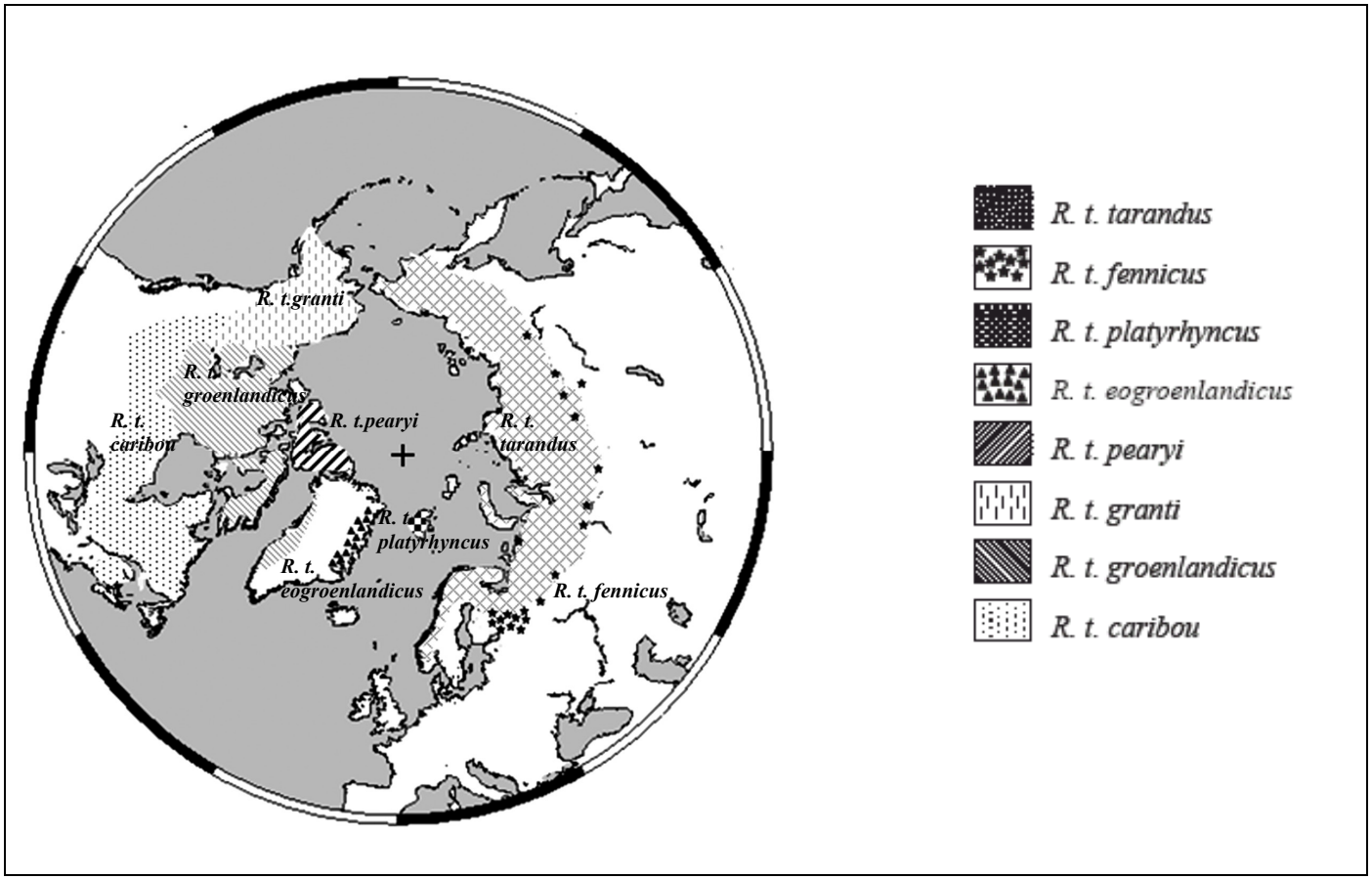


Figure 1. Global Distribution of eight extant subspecies of caribou. North American boreal form (*Rangifer tarandus caribou*), tundra forms (*Rangifer tarandus granti* and *Rangifer tarandus groenlandicus*), arctic forms (*Rangifer tarandus platyrhynchus*, *Rangifer tarandus pearyi*, and *Rangifer tarandus eogroenlandicus*), Eurasian tundra form (*Rangifer tarandus tarandus*) and the Eurasian forest form (*Rangifer tarandus fennicus*) [From Røed 2005].

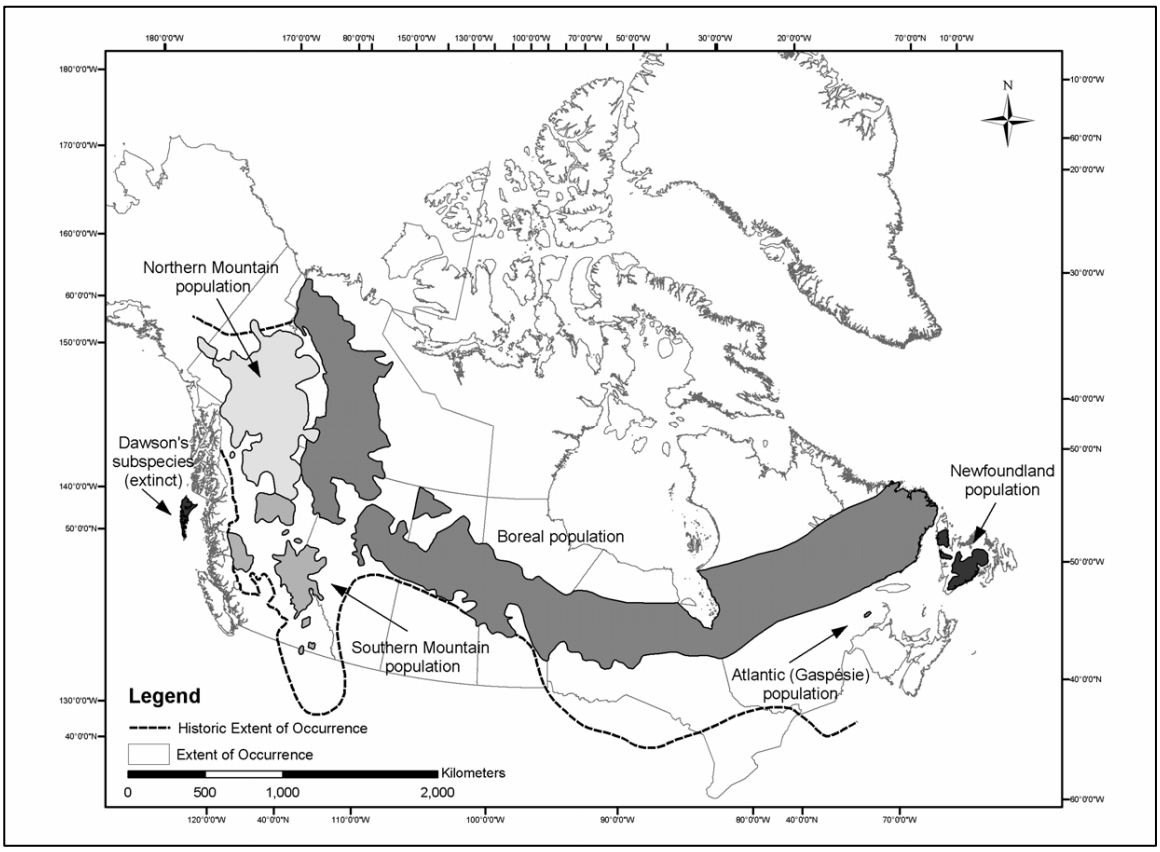
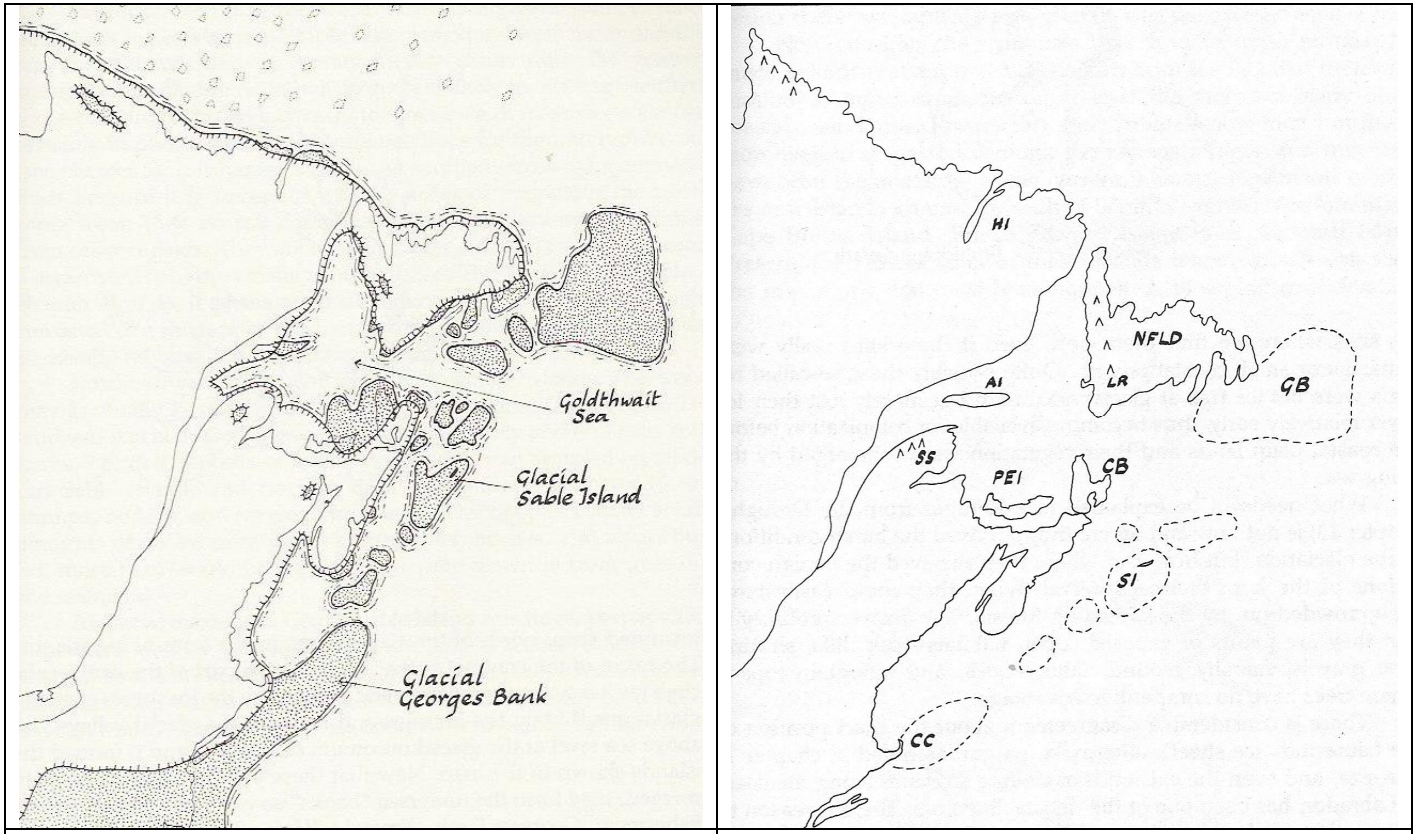


Figure 2. Extent of occurrence of forest-dwelling woodland caribou (*Rangifer tarandus caribou*) in North America in 2001. The subspecies is divided into the following populations: Newfoundland, Atlantic (Gaspesie), Boreal, Southern Mountain, Northern Mountain, and Dawson's (extinct). The current range is indicated by solid lines and the southern limit of historical range is indicated by the dashed line [from COSEWIC Status Report 2002].



(a) from Pielou 1991 (Fig 6.4) | (b) from Pielou 1991 (Fig. 6.5)

Figure 3. Locations of coastal refugia along the eastern coast of North America during the Wisconsin glaciation [from Pielou 1991]. (a). Patterns of land, sea and ice at glacial maximum (shaded areas = land). (b). Map outlining submarine banks that correspond to refugia during Wisconsin glaciation (GB=Grand Banks, SI=Sable Island, CC=Cape Cod).

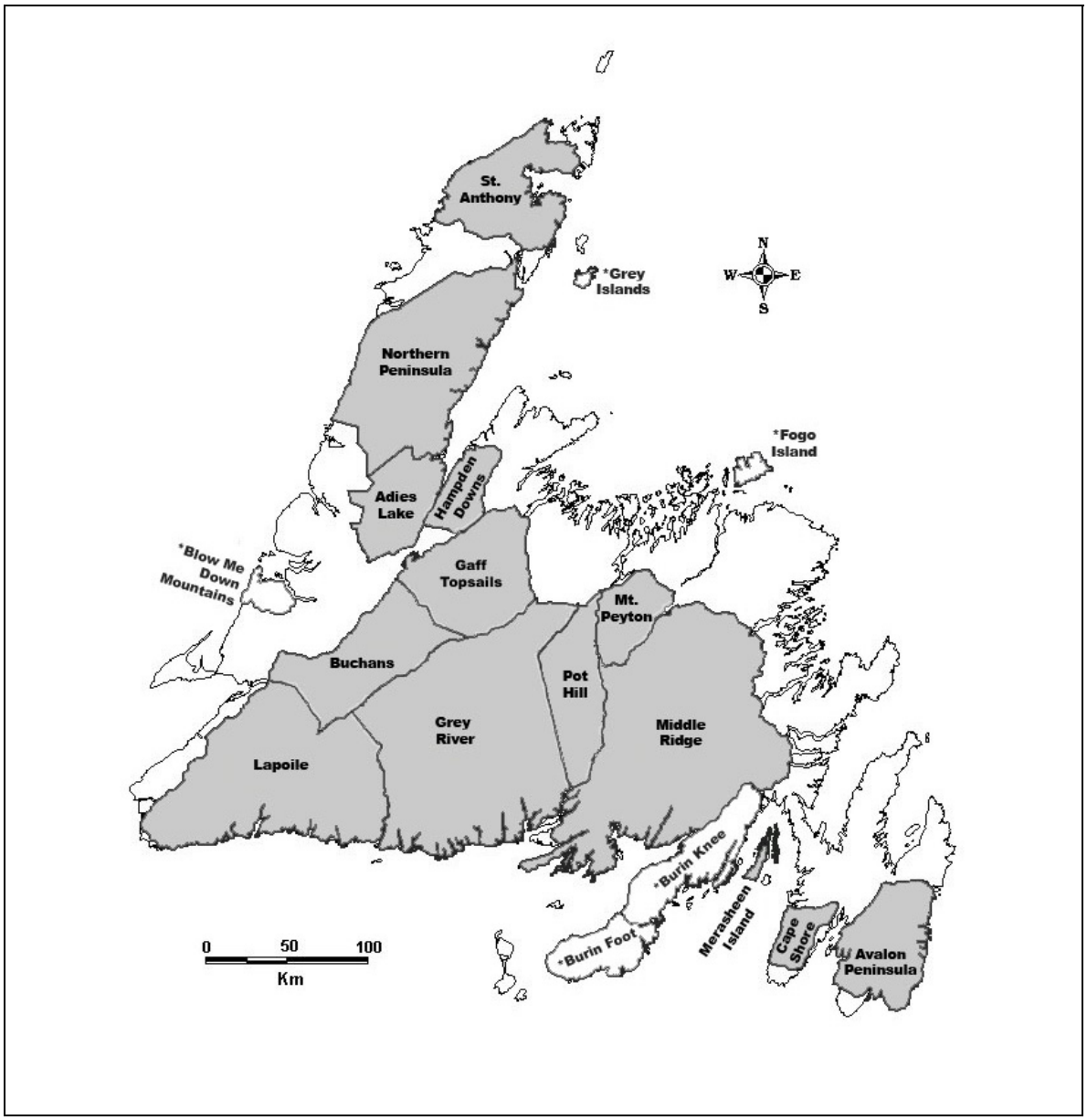


Figure 4. Distribution of Caribou Management Units (herds) across the island of Newfoundland. Grey shaded areas represent the 14 herds used in the present study. Of the 14 herds used in the study, 3 were introduced from other parts of Newfoundland; St. Anthony, Cape Shore, and Merasheen Island. Areas marked with an asterisk (*) were not used in the present study (Blow Me Down Mountains, Grey Islands, Fogo Island, Burin Foot, Burin Knee). [Map from Government of Newfoundland and Labrador].