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Authors: Zalatan, R., Gunn, A., and Henry, G. H. R.

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Long-term Abundance Patterns of Barren-ground Caribou Using Trampling Scars on Roots of *Picea mariana* in the Northwest Territories, Canada

R. Zalatan‡*
A. Gunn† and
G. H. R. Henry§*

*Department of Geography, University of British Columbia, Room 217, 1984 West Mall, Vancouver, BC, V6T 1Z2, Canada.
†Department of Environment and Natural Resources, Government of the Northwest Territories, Box 1320, Yellowknife, Northwest Territories, X1A 3S8, Canada.
Anne_Gunn@gov.nt.ca
‡Corresponding author.
rzalatan@geog.ubc.ca
§ghenry@geog.ubc.ca

Abstract

The aim of this study was to reconstruct population dynamics of barren-ground caribou *(Rangifer tarandus groenlandicus)* herds from the frequency of trampling scars on tree roots of black spruce (*Picea mariana* [Mill.] BSP) in the forest-tundra of central Northwest Territories, Canada. Two groups of sites were sampled that roughly corresponded with the migration routes of the Bathurst and Beverly caribou herds. The caribou migrate annually for long distances from the forest to the open tundra in late spring, and return to the forest in the autumn. The scar frequency distribution was determined by careful crossdating and the influence of root age was assessed to account for the increasing underestimation of caribou abundance with the increasing age of the roots. The scar frequency distributions (dated from A.D. 1760 to 2000) from both groups of sites showed similar abundance patterns through time. Caribou numbers were high during the mid-1940s, and 1990s, and were very low during the 1920s, 1950s–1970s, and at the turn of the 21st century. These abundance patterns determined from scar frequencies correlate strongly with data obtained from traditional knowledge of Dogrib elders in the region and animal counts based on aerial photography. The scar frequency distribution developed in this study is the longest proxy record of caribou abundance to date.

Introduction

Barren-ground caribou *(Rangifer tarandus groenlandicus)* tend to undergo relatively regular changes in population size over decadal time scales (Skoog, 1968). Aerial surveys have provided accurate data on caribou numbers over the past few decades (e.g., Gunn, 2003); however, longer-term information is less available. Aboriginal knowledge of caribou populations does extend further back in time and has been compiled for the Bathurst herd in the Northwest Territories, Canada (Dogrib Treaty 11 Council, 2001). For other herds such as the Beverly herd, whose range is adjacent to the Bathurst herd, the traditional aboriginal information is not well compiled and census data are fewer.

Caribou abundance among different herds has been shown to be in synchrony at continental scales (Gunn, 2003). This synchronicity among herds has been well studied in Alaska, Greenland, and eastern North America (Gunn, 2003). However, knowledge of long-term abundance cycles for the central Canadian barren-ground caribou herds is not well understood. The only data that researchers and managers have to work with is that which is derived from aerial photography, and traditional knowledge (TK).

A recent method to describe changes in caribou abundance over decades is based on the application of dendroecology. Morneau and Payette (1998, 2000) and Boudreau et al. (2003) used this dendroecological technique to describe changes in the size of the George River caribou herd in the Quebec-Labrador region. The authors aged the scars left by caribou hooves on the top of surficial roots or low branches of spruce trees during their spring and summer migrations. The scars are formed when part of the bark is removed due to trampling, which causes cambium death and stops radial growth in that section of the root. A scar lobe forms around the damaged cambial tissue in subsequent years. The date of scar formation can be accurately determined using dendrochronology, and frequency distributions are then computed from the dated scars on root and stem samples. This method has made it possible to reconstruct caribou population activity and provides the longest proxy record for changes in caribou herd size.

The objective of this study was to evaluate the long-term population dynamics of barren-ground caribou herds in the central Northwest Territories, Canada through the use of dendroecology on trampling scars from spruce stands in the forest-tundra. Here, we consider three aspects of the methodology to properly evaluate the use of these data for reconstruction of caribou population dynamics: (1) the effect of root age on the scar frequency distribution; (2) the synchronicity of populations in neighboring herds; and (3) a comparison of the scar frequency distribution to historical and recent data available for the Bathurst herd.

Methods

In the Northwest Territories, there are seven distinct barren-ground caribou herds. During August and September, the caribou move south from the tundra and into the forest-tundra transition zone along the treeline (Gunn et al., 2001). During the spring, caribou migrate to their calving grounds, which can be as far as 700 km away from their wintering grounds. Barren-ground caribou adult males stand about 115 cm high and weigh approximately 108 kg (238 lb) (Kelsall, 1968). The average life span of the barren-ground caribou is between 10 and 15 years. The population of the barren-ground caribou herds in the studied region range between 186,000 (2003 estimate of the Bathurst herd) to 276,000 (1994 estimate of the Beverly herd) (http://www.nwtwildlife.com/NWTwildlife/caribou/herds.htm).

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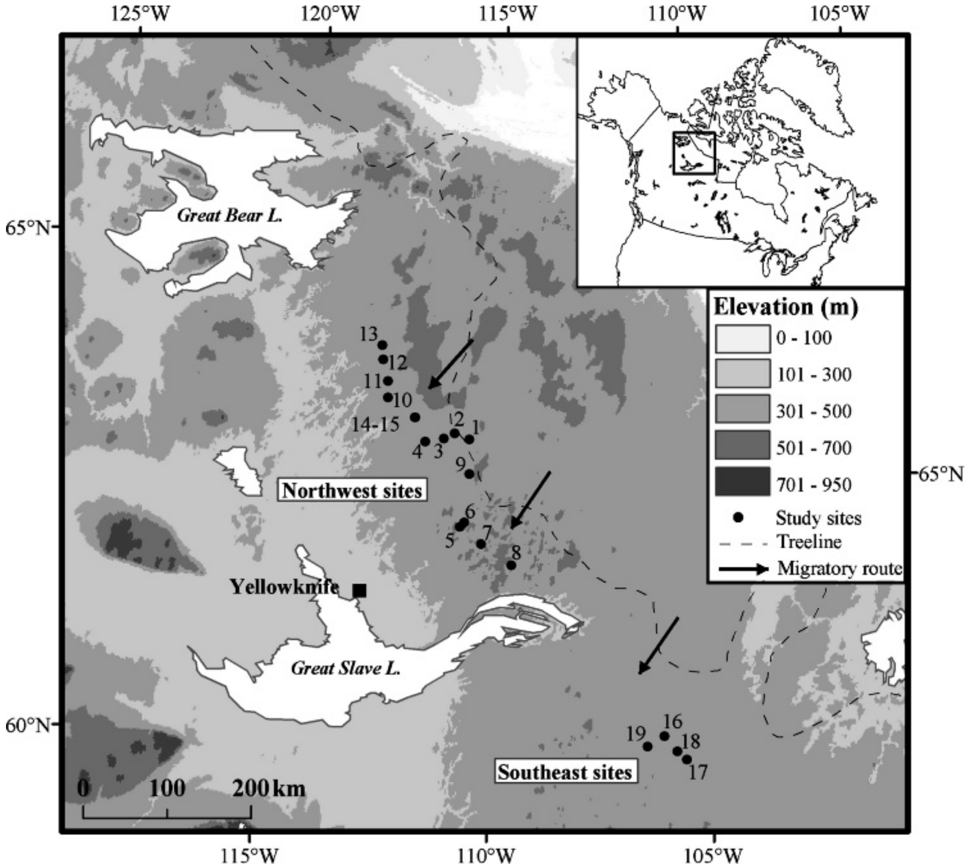

FIGURE 1. Sampling sites of scarred roots on *Picea mariana* (sampled 2002) and the summer migratory route of barren-ground caribou. The geographic coordinates of the sampling locations for the scarred roots are listed in Table 1.

The 19 study sites were located along the treeline to the northwest and southeast of Yellowknife (between 65°09′N, 115°37′W and 61°32′N, 105°52′W; Fig. 1). The climate of this region is characterized by long, cold winters and short, cool summers with mean January and July temperatures of −26.8°C and 16.8°C, respectively (Meteorological Service of Canada 1971–2000 climate normals from Yellowknife airport, 62°27′N, 114°26′W, 206 m a.s.l.). Precipitation is low with an average annual total of 280.7 mm, falling mostly as rain during the summer months. The landscape consists of broad uplands and shallow lowlands, with rock outcrops, hummocky and ridged morainal deposits and eskers, and numerous lakes and wetlands (Traynor, 2001). Permafrost is generally continuous. The vegetation consists of open lichen woodland with patches of closed forest in the southern areas, to forest-tundra consisting of thinning patches of forest and shrub tundra, to low arctic tundra in the north (Matthews et al., 2001).

The sampling took place in the forest-tundra. Fifteen study sites were selected based on information from Dogrib elders who identified several regions across the treeline that were frequented by caribou (Dogrib Treaty 11 Council, 2001; Fig. 1). A further four sites were selected on the late summer range of the Beverly herd. A targeted sampling approach was essential to find black spruce *(Picea mariana* [Mill.] BSP) roots with trampling scars caused by caribou. Once the general location of the sites was identified, a series of highly trampled caribou trails were randomly chosen per site for sampling. External features such as exposed xylem and resin accumulation were identified on each scarred root. Roots found to be buried under understorey plants were all checked for possible scarring. The roots sampled were all at the ground surface and therefore digging was not necessary.

Caribou scars are formed on the top of surficial roots and sometimes on low branches (krummholz individuals) during the snow-free period. The scars are the result of debarking caused by caribou activity, which causes cambium death and radial growth stops in this section of the root. The shape of the scar is generally round, elliptical, or elongated with neat margins. Scars can be formed by other ungulates or by human activity (such as hiking trails), or fire, however there is little evidence that the study region has been affected by disturbance agents other than caribou. The scars found in this study were clearly trampling scars because charcoal was not detected on any of the scars and the samples were taken on roots and not on the stems of trees. In addition, frost and fire scars are structured differently and are therefore easy to differentiate from trampling scars.

Selecting sites used by barren-ground caribou populations increased our chances of finding old scars, thereby lengthening the scar chronology. The analysis was performed on two groups of sites: (1) the northwest sites (n = 15); and, (2) the southeast sites (n = 4). These grouped sites correspond generally to the range of the Bathurst and Beverly caribou herds, respectively. However, there can be considerable overlap in the ranges of these herds (http://www.nwtwildlife.rwed.gov.nt.ca/images/new_pa6.gif); therefore, the sites will be referred to as the northwest and southeast sites.

At each study site, we selected trampled caribou trails and collected surficial roots of *Picea mariana* trees where they crossed heavily trampled caribou paths. The number of roots sampled per site varied from 10 to 417, depending on the density of trails and the time available for sampling. For most of the sampling, only one root was cut per tree.

Cross-sections were sanded using progressively finer grades of sandpaper (240, 320, 400, and 600) and were prepared for crossdating as outlined in Stokes and Smiley (1968). Scars were dated by visually and statistically crossdating the rings prior to the scar. Crossdating ensures the exact year of formation of annual rings and it verifies the presence of missing, false or locally absent

TABLE 1

Geographic location, number of scars and samples for the northwest and southeast sites, Northwest Territories. Locations are also shown in Figure 1.

Site	Number of Scars	Number of Scars (% of all sites)	Number of Samples	Number of Samples (% of all sites)	Location	
					Latitude	Longitude
Northwest sites						
1	61	3.1	36	1.5	64° 27.2′ N	112° 45.6′ W
2	19	1.0	21	1.1	64° 27.9′ N	113° 09.4′ W
3	12	0.6	10	0.5	64° 22.7′ N	113° 23.3′ W
4	8	0.4	12	0.6	64° 17.5′ N	113° 49.3′ W
5	62	3.1	108	5.4	63° 29.1′ N	112° 23.2′ W
6	190	9.5	282	14.2	63° 32.7′ N	112° 18.8′ W
7	47	2.4	143	7.2	63° 21.9′ N	111° 46.2′ W
8	42	2.1	139	7.0	63° 13.9′ N	110° 55.2′ W
9	41	2.1	100	5.0	64° 04.8′ N	112° 31.1′ W
10	34	1.7	72	3.6	64° 37.7′ N	115° 04.4′ W
11	90	4.5	136	6.8	64° 47.7′ N	115° 12.2′ W
12	125	6.3	121	6.1	65° 00.8′ N	115° 29.1′ W
13	77	3.9	93	4.7	65° 09.8′ N	115° 37.5′ W
14	37	1.9	32	1.6	64° 30.8′ N	114° 15.0′ W
15	102	5.1	153	7.7	64° 30.5′ N	114° 14.6′ W
Total	947		1458			
Southeast sites						
16	225	11.3	245	12.3	61° 45.1′ N	106° 29.0′ W
17	321	16.1	282	14.2	61° 32.5′ N	105° 52.3′ W
18	436	21.9	417	20.9	61° 36.5′ N	106° 07.3′ W
19	62	3.1	75	3.8	61° 36.0′ N	106° 49.3′ W
Total scars	1044		1019			
Total (all sites)	1991	100	2477	100		

rings (Fritts, 1976; Cook and Kairiukstis, 1990; Yamaguchi, 1991). Most scars were dormant season scars, which were formed in late summer/early fall when caribou migrate through the study sites upon returning from the calving grounds. However, it is possible during a winter with low snow-pack, that some scars are formed in the spring when caribou are on their way up to the calving grounds. The seasonal dormant phase of the cambium extends over 2 calendar years (Morneau and Payette, 2000). It is not possible to determine the exact date that scars formed, as the year of scar formation could vary by +1 year. As a standard, the year of scar formation is taken as the most recent year (Morneau and Payette, 1998). At times, annual rings were wedged (or pinched) near the edge of the scar, which made it difficult to identify the exact scar ring. Only scars that were successfully crossdated were included in subsequent analysis.

Once the date of scar formation was determined, the scar frequency distribution (5-yr-age classes) was computed to represent the intensity of caribou activity (Morneau and Payette, 1998, 2000). The Kolmogorov-Smirnov test for goodness-of-fit was used to determine if the scar frequency distributions for both herds were significantly different. To ensure the validity of the results, the scar frequency was compared to other available data, such as traditional knowledge (TK), and animal counts from aerial surveys and photography. Research on the TK data was conducted by the West Kitikmeot Slave Study in conjunction with the aboriginal elders of the Dogrib Nation. The data were used to index Bathurst caribou herd abundance to the 1920s (Dogrib Treaty 11 Council 2001). The TK data were only recorded back to the 1920s because the elders would not provide any information on caribou population abundance and migration that they had not directly witnessed or felt certain about.

Aerial surveys of caribou herds in the Northwest Territories are performed by the Department of Resources, Wildlife and Economic Development (RWED). Biologists estimate the number of breeding females in a herd by performing aerials surveys above the calving grounds. Since all breeding females calve around the same time in early June and in the same general area, it makes it possible to ensure that all the animals counted belong to a single herd. The percentage of the herd that should be made up of breeding females is used to estimate the size of the entire herd. A series of photos (e.g. 2600 photos were taken for the 2003 estimate) are taken while flying at 600 m above ground level. A standard error is calculated for each year that a survey is done.

To effectively reconstruct caribou population abundance using dendroecolgy, two analyses were performed. The first involved determining the influence of root age to obtain an objective scar frequency distribution independent of the age of the root itself. This was done by plotting the scar frequency distribution using only roots established prior to 1900 (the year to which the data set was eventually truncated). This analysis was used to account for the increasing underestimation of caribou abundance with the increasing age of the roots. The second analysis was used to address the underestimation of caribou activity with time, assuming a constant loss of scars. Various factors contribute to the loss of scars through time such as the death of scar-bearing roots, fading of scars by weathering, decomposers, and repeated caribou trampling activity (Morneau and Payette, 2000). We applied a log-linear regression and used the residuals to obtain a more accurate depiction of the abundance patterns of these herds. Departures from the negative exponential model were used to demonstrate the years of high and low caribou abundance.

Results

SCAR FREQUENCY DISTRIBUTIONS

Statistical and visual crossdating of 2477 root samples collected from *Picea mariana* trees yielded 1991 trampling scars

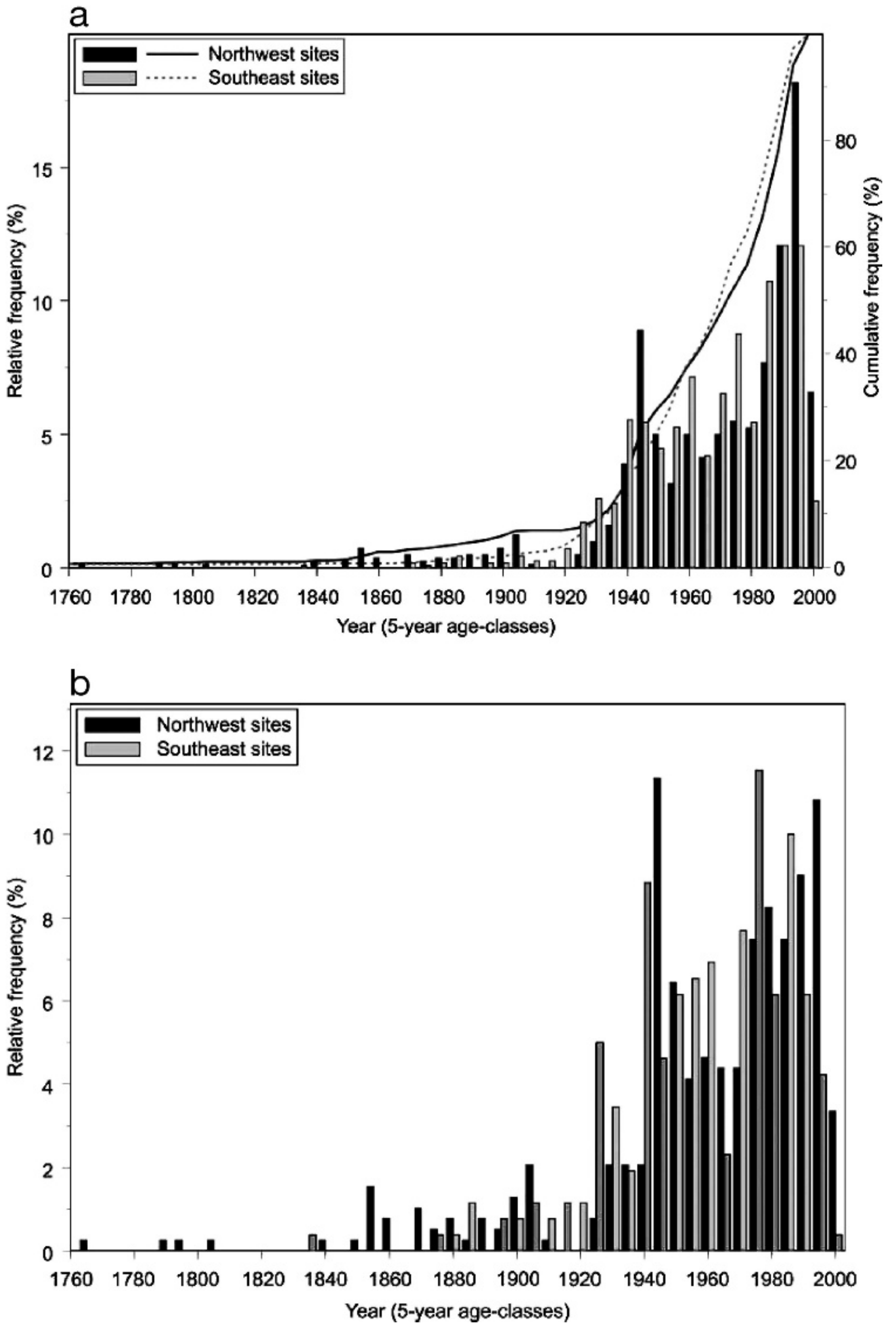

FIGURE 2. Scar frequency distribution (a) using all samples from sites 1–19 (r_s = 0.88, $P <$ 0.05, n = 24) and cumulative frequencies of the number of samples; and (b) using only scars located on roots established before 1900 (r_s = 0.63, $P <$ 0.05, n = 24).

(Table 1). The number of scars found was evenly distributed between the two groups of sites: 48% (n = 947) within the northwest sites (sites 1–15) and 52% (n = 1044) within the southeast sites (sites 16–19). For all sites, 97% (n = 1933) of the scars were dated with certainty.

The earliest scars in our samples were formed in the northwest sites during the 1760s, although they were scarce until the 1870s (Fig. 2a). The scars from the southeast sites appear in the 1835 age-class. The majority (97%) of the scars were formed after the 1900s. No scars formed from 1910 to 1930 in the northwest sites. The frequency of scars increased steadily through time with the highest frequency of scars in the 1945, 1990, and 1995 age-classes, in addition to the 1975 age-class for the southeast sites. There was a general trend toward increasing scars through time until the present, with a sudden drop in the number of scars in 2000. Similar population abundance patterns were observed at both groups of sites (Spearman's rank correlation, r_s = 0.88; $P <$ 0.05, n = 24), and the scar frequency distributions were not different (KS, $P >$ 0.05).

To assess the influence of age of roots on scar data, the scar frequency distribution was plotted using roots established prior to 1900, and included only those present over the entire period of the truncated scar frequency distribution (Fig. 2b). The scar frequencies for both groups of sites showed the same patterns of major increases and decreases (Spearman's rank correlation (r_s = 0.63; $P <$ 0.05, n = 24). All sites showed low numbers until the 1920s,

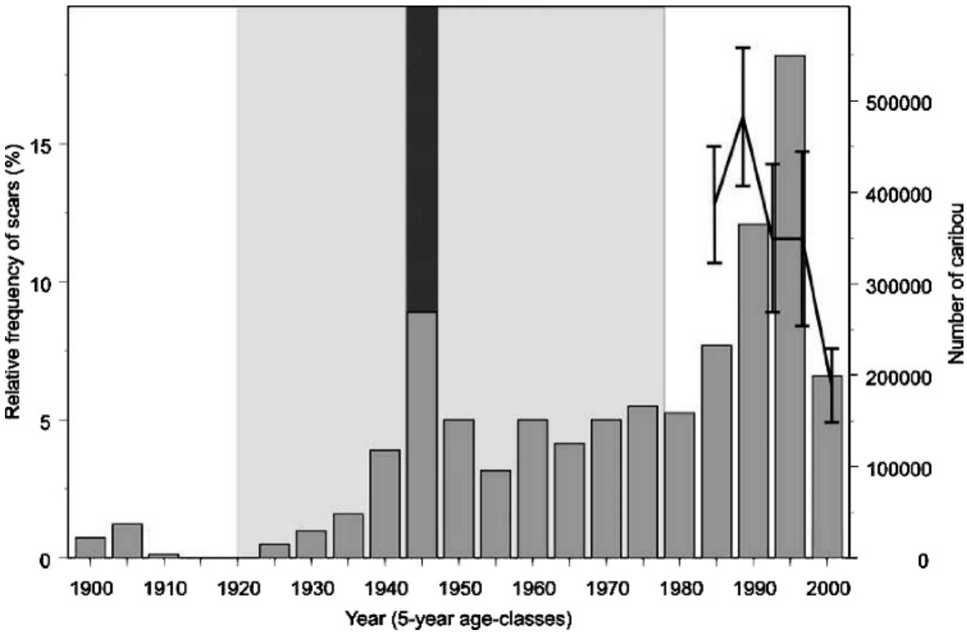

FIGURE 3. Bathurst herd caribou numbers from aerial photography surveys (1984–2003; black line; means ± SE), and abundance patterns (high = dark gray shading or low = light gray shading) derived from traditional knowledge of elders from the Dogrib First Nation relative to the scar frequency distribution for the northwest sites (Bathurst herd; bars).

again from 1955 to 1970 and in 2000. The scars showed an increase in caribou numbers during the 1940s until the mid-1950s, and from 1980 to 2000. However, the complete scar frequency distribution (Fig. 2a) showed much more marked peak in the 1990s than the restricted distribution (Fig. 2b).

We compared the scar frequency distribution from the northwest sites (corresponding to the Bathurst herd; truncated to 1900) to information on caribou abundance from Dogrib elders, and from animal counts based on aerial photography (Fig. 3). A similar calibration of the data for the southeast sites (Beverly herd) was not possible because aboriginal knowledge has not been compiled and there have been fewer population estimates based on aerial photographic surveys. The qualitative description of "high" or "low" population of caribou was derived from aboriginal elder's narratives and describes the abundance of caribou from the 1920s to the 1970s (Dogrib Treaty 11 Council, 2001). The population estimates were from aerial photographic surveys and describe caribou abundance from 1984 until 2003. The information from the Dogrib elders and the scars both showed low numbers of caribou during the 1920s, followed by a high peak in caribou numbers during the mid-1940s, then a low period from 1950 to 1970. The aerial photography data showed an increasing trend in caribou abundance after the 1970s, with a peak in the mid-1980s, followed by a significant drop in caribou abundance in 2000. In the 1990s, the scar frequency showed a continual increase, while the population numbers remained relatively stable. Scar frequencies then showed a notable decrease after 2000.

RESIDUALS OF THE LOG-LINEAR REGRESSION

The scar frequency distributions for all sites demonstrated an exponential decrease in scars through time. Figure 4 illustrates the residuals of the log-linear regression for both groups of sites, which were used to remove the long-term depletion pattern in the

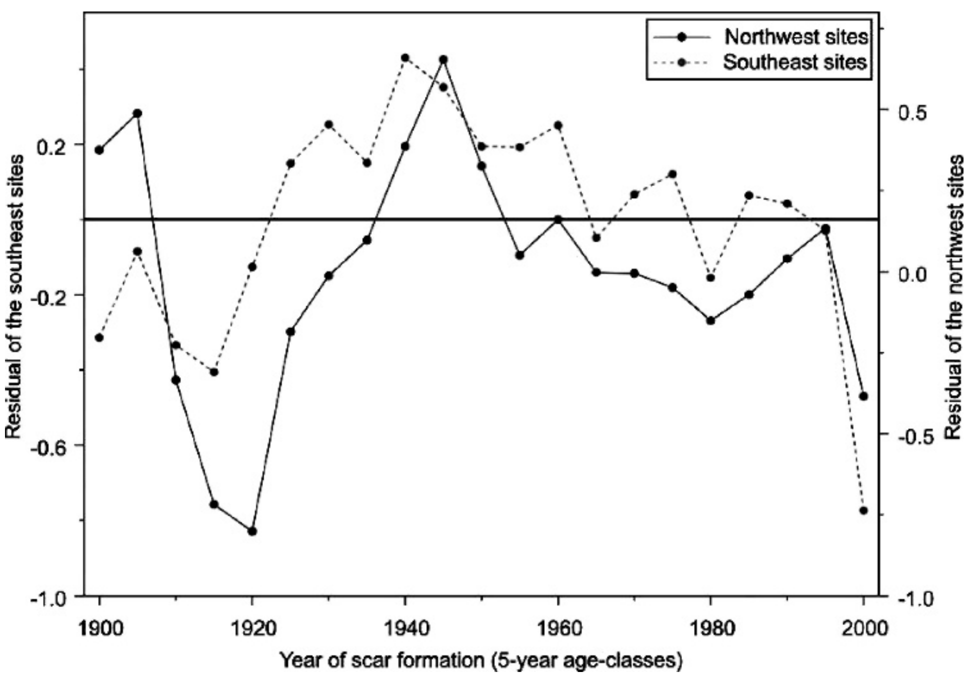

FIGURE 4. Residuals of the log-linear regression on the scar-frequency distribution of trampling scars for both groups of sites.

number of scars and to accentuate the fluctuations in the scar frequency distributions. The large oscillations in the residuals around the regression line follow a pattern similar to that of the fluctuations in the scar frequency distribution. The chronologies of residuals from both sites were positively correlated (Spearman's rank, $r_s = 0.55$; $P < 0.05$). The correlations remained significant when the recent (1950–2005) and older (1900–1950) parts of the chronologies were considered separately (Spearman's rank, $r_s = 0.55$ and $r_s = 0.87$; $P < 0.05$, respectively).

Discussion

The scar frequency distribution developed in this study is the longest proxy record of barren-ground caribou abundance possible. With the use of dendroecology, we have shown that it is possible to reconstruct the abundance patterns of these barren-ground caribou herds. The presence of trampling scars at all sites suggests that the forest-tundra is an ideal region for estimating past caribou activity. The method is based on scar production as a result of caribou activity, and does not represent actual numbers of caribou. Assuming the capacity of conifer roots to produce scars remains constant with time (a reasonable assumption), the scar frequencies can be used as a proxy for caribou abundance (Morneau and Payette, 1998; 2000).

The record extends caribou abundance data back to the 1760s, although the scars were scarce until approximately 1900. The most prominent peaks in the scar frequency distribution were seen during the mid-1940s, and the late 1980s and 1990s. Periods of low scar frequency occurred in the 1920s, 1950s–70s and at the turn of the 21st century. The loss of scars with time did not influence the population reconstruction since the scar frequency distribution using only roots established before 1900 demonstrated a broadly similar abundance pattern. Both groups of sites showed similar patterns in scar frequency, indicating that the different herds within the sampling area experienced similar changes in abundance over time. Given the scale of these synchronous changes in caribou abundance, it is likely they are linked to changes and variability in large-scale climate, such as the Arctic Oscillation (Aanes et al., 2002; Post and Forchhammer, 2002, 2004). We investigate the link between the abundance patterns and climate in a future study.

High numbers of scars were associated with the growth of the herds between the mid-1940s to the 1990s, as seen from the Dogrib traditional knowledge (TK) and aerial photography data. The trends seen in data from TK are analogous to those depicted in the scar frequency distribution from 1920 to 1970. High numbers of caribou during the 1980s and 1990s and sudden drop in the 2000 age-class were observed in the aerial photography data. The large standard error associated with the aerial photography data may account for the earlier peak observed during the mid-1980s (SE ± 72,000 in 1986). This provides evidence for the strength and accuracy of the scar frequency distribution as a proxy for caribou abundance. Despite the earlier peak in the mid-1980s from the census data, there were synchronous patterns in caribou abundance using the different methods.

Morneau and Payette (2000) found a similar synchronous relationship between estimates of the herd size and trampling scar data for the George River caribou herd, with increasing caribou numbers from the early 1940s until the early 1990s. Synchronous changes in the scar frequency distribution at the various sites and among the different datasets demonstrate the strength of the spatiotemporal pattern in caribou population abundance in this region. The stability of caribou migration patterns has not been quantified over the last 100 yr, however, the synchronicity in the scar frequency data to the TK and aerial photography data, suggests that any changes in migratory routes has not affected the results.

We applied a log-linear regression to account for the loss of scars with time, assuming that this loss is constant (Morneau and Payette, 2000). The residuals of the regression were then used to depict the abundance patterns of the barren-ground caribou at these sites. The chronology of residuals illustrated the overall trends in caribou activity as seen in the scar frequency distribution. The similar trends in the TK, caribou numbers and trampling scars suggest that changes in the scar frequency distributions corresponded to changes in the rate of scar formation. Subsequently, variations in the rate of scar loss with time, which corresponds to caribou movements along trails and root mortality, were most likely minor in comparison to the changing rate of scar formation.

This study further validates the use of dendroecology for understanding the population dynamics of barren-ground caribou herds (Morneau and Payette, 2000, 1998). The identification of common trends in the scar frequency distributions among sites can lead to further investigation regarding the spatial and temporal patterns throughout the range of the barren-ground caribou herds. The sites selected for this study represent a substantial portion of the range of barren-ground caribou. However, the length and lack of synchronicity in the scar frequency prior to 1900 needs to be addressed with further sampling and analysis. Nevertheless, further use of this method has the potential of providing valuable information about the long-term abundance cycles of all barren-ground caribou herds across northern North America.

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