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The recent record of climate on the range of the George River Caribou Herd, Northern Québec and Labrador, Canada

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Abstract: Records from permanent meteorological stations in and around the range of the George River Caribou Herd have been analyzed for the 1950-1991 period in order to identify climatic factors potentially influencing the numbers, condition, and distribution of caribou. Winter conditions identified include a significant temperature decrease over the period and some years of extreme snowfall. Spatial variations in snow cover may be responsible for shifts in winter range. Indications are that summer climate has not varied significantly, but spring and summer conditions may not have been particularly favourable for plant productivity in the summer range of females and calves. Climatological observations more representative of the summer range are needed for a better understanding of ecological relationships there.

Key words: Bioclimate, climate change

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Introduction

Climate or, more specifically, climate variability and change has been proposed as a significant and sometimes principal factor in the population dynamics of caribou (e.g. Vibe, 1967; Miller *et al.*, 1982; Meldgaard, 1986). It has been suggested that recent climatic events and trends may have contributed to the present state of the George River Herd of woodland caribou (*Rangifer tarandus caribou*) (Messier *et al.*, 1988; Crête & Payette, 1990; Couturier *et al.*, 1990; 1996). This herd, which currently ranges over an area of about 400,000 km^2 in northern Quebec and Labrador (Fig. 1), experienced a more than 30-fold increase between the late 1950s (Bergerud, 1967) and the mid 1980s (Couturier *et al.*, 1990). Recent surveys place current numbers at about the same level as in the 1980s, i.e. approximately 700,000 animals, with substantial evidence for declining recruitment and poor condition of the animals (Crête *et al.* 1996; Couturier *et al.*, 1996; Huot *et al.*, 1994; Russell & Couturier, 1994).

As described by Couturier *et al.* (1990), the current range of the George River Herd extends from the southern limit of the open boreal woodland (*taiga*) across the forest-tundra zone and to some extent into the tundra, particularly in northern Labrador (Fig. 1). The calving ground of the George River Herd is located near the height of land in the northeast. A separate caribou population, the Rivière aux Feuilles Herd, is identified with a calving area west of Ungava Bay and has a winter range that overlaps with that of the George River Herd (Couturier *et al.*, 1990). Major differences between these two herds have been found by Crête *et al.* (1990) in the composition and relative abundance of forage plants on their respective calving grounds and the resulting diet of lactating females. In the areas surveyed, the proportion of ground cover represented by forage plants of all kinds was 31% in the George River calving area, compared with 78% in the Rivière aux Feuilles area. The relatively poor condition of cows in the George River Herd reported by Huot (1989) has been attributed to these differences (Crête *et al.*, 1990; Huot *et al.*, 1994).

Climatic conditions determine to a large extent the composition of the vegetation, its productivity in the growing season, and its accessibility to foraging animals in winter. The climatic record from stations in and around the range of the George River Herd should indicate whether there have been any widespread climatic events or trends that might have significantly affected range conditions during the recent period of population growth,

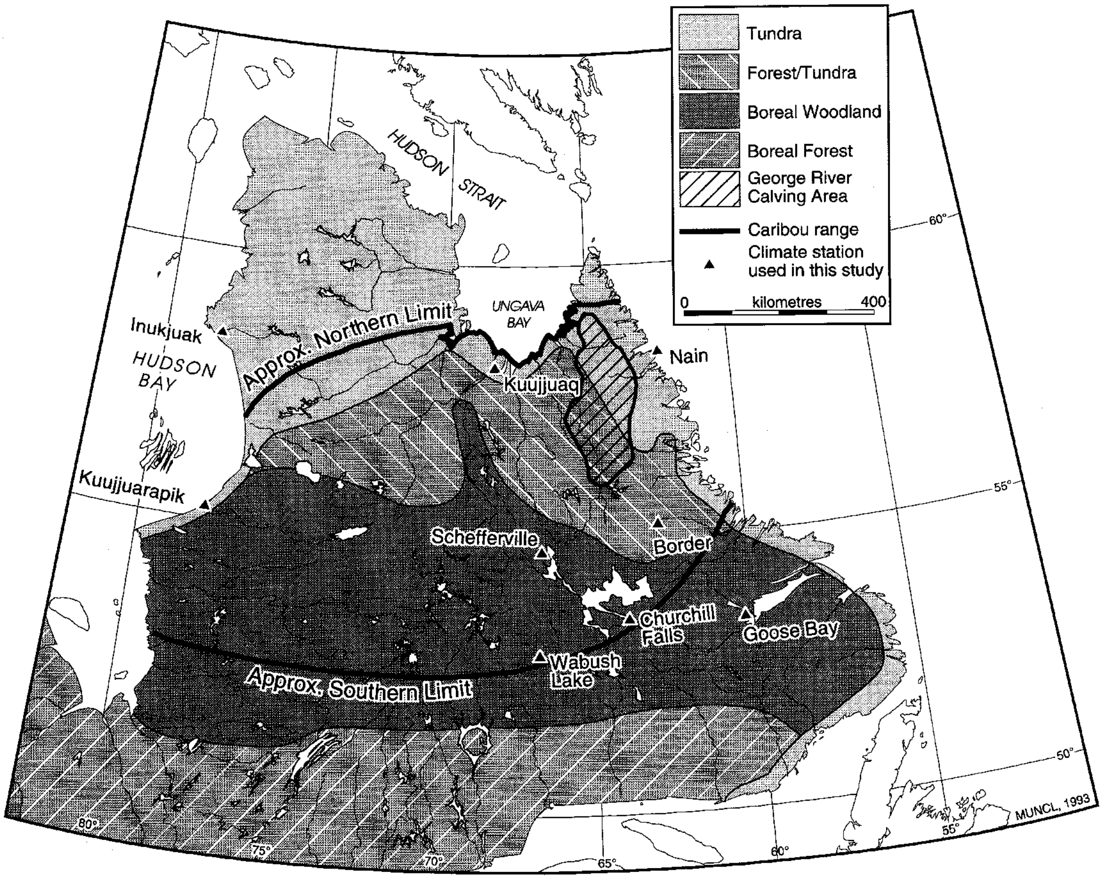

Fig. 1. Northern Quebec - Labrador, showing the location of climate stations used in this study, with bioclimatic zones according to Hare (1950) and range limits of the George River Herd according to Couturier *et al.* (1990).

subsequent leveling off and possible decline of the George River Herd. Such an analysis was carried out for northern Québec by Crête & Payette (1990) using records from two northern stations which they attempted to link to the longer record from Québec City and to black spruce krummholz heights near the tree-line. Their general conclusion was that the climate of the region was warmer during the first half of the 20th century, with consequent impacts on the caribou range through deeper winter snow and more frequent forest fires. By contrast, they inferred a trend toward a regional cooling in the latter half of the century which they associated with improved conditions and rapid growth of the George River Herd (Crête & Payette,1990).

We have conducted an analysis of the climatic record from northern Québec and Labrador for the 1950-1991 period from the standpoint of caribou bioclimate. This paper reports on the methodology and main findings. A more general review and analysis will be presented elsewhere. It is assumed, with some qualifications, that the various climatic factors reported in the literature as being important to reindeer and caribou elsewhere (e.g. Leader-Williams, 1988) are likewise relevant to the George River Herd.

Method

Nine climate stations located within or around the range of the George River Herd provided the basis for the analysis (Fig. 1). Standard climatic summaries (normals) for the 1951-1990 period were available from seven stations with uninterrupted records (Table 1). Digital data were available from the Canadian Climate Archive for 1950 through 1991. Five of the stations have complete records for the full period of analysis (Table 1). Nain has a short and interrupted record starting in 1970. The data available for Border were limited to the 1965-1978 period of manned observation there, although an automatic station has operated there more recently.

The selection of appropriate variables was made from consideration of what conditions are known

Table 1. Permanent Stations used in this study, with 1951- 1990 mean values for selected variables. (Source: Atmospheric Environment Service)

Station	Inukjuak	Kuujjuaq	Kuujjuarapik	Schefferville	Wabush Lake	Churchill Falls	Goose Bay
Year Established	1921	1947	1925	1948	1960	1968	1941
Summer (JJA) Temperature (C)	7,4	9,4	9,0	10,6	11,5	11,8	13,2
Annual Rainfall (mm)	251,1	262,0	387,1	402,2	476,0	497,9	557,3
Degree-day above 5C	333	492	556	604	741	745	995
Winter (DJF) Temperature (C)	-22,7	-21,9	-20,8	-21,6	-20,4	-19,9	-15,4
Degree-day below 0C	3395	3222	2891	3071	2779	2727	1955
Annual Snowfall (cm)	175,4	270,5	238,2	415,0	455,0	481,0	463,8
Snow on ground end of March (cm)	49	66	53	85	92	119	83
Days with Freezing precip.	8	9	10	12	11	13	14
Prevailing wind speed (km/h)	20	16	17	17	14	15	16
direction	W	SW	SE	NW	W	W	W

to be unfavourable for caribou, but in the knowledge that standard meteorological observations can only approximate the biophysical reality of the caribou range. For summer (June, July, August), the assumption is that sunshine, heat, and moisture are positive factors through their relationship to primary production, with allowance for different microclimatic responses to regional climate in the various vegetation and landscape types. The negative side of a warm summer is increased potential for insect harassment, unless mitigated by wind (Helle & Tarvainen, 1984; Walsh *et al.* 1992). The principal variables for summer are therefore air temperature, precipitation, and wind.

In winter (September to May, for the purpose of this analysis), deep snow, frequent thaws and icing make foraging and movement difficult (Pruitt, 1959; Leader-Williams, 1988). A cold winter and delayed spring can also be a major factor affecting reproductive success. As Verm (1977) concluded from a study of white-tailed deer, delayed emergence of new shoots leads to poor lactation in females, resulting in significantly lower birth weights and reduced survival of neonates. On the other hand, evidence presented by Miller & Gunn (1986) indicates that healthy calves can tolerate the direct effects of severe spring weather quite well. For the September through May period, then, the variables of interest include temperature, total snowfall, snow depth measured on the last day of each month, and total rainfall and frequency of freezing rain events.

Descriptive statistics were calculated from each station record for the 33-year period. Frequency distributions were calculated and used to distinguish "favourable" and "unfavourable" conditions. A conservative measure was used, namely the tail portions of the frequency distribution exceeding two standard deviations (2σ). For each bioclimatic year (defined as June through May), a particular variable was counted as unfavourable if its value exceeded the 2σ criterion. Both individual and composite scores were then considered for each station over the period. In order to assess the degree of spatial variability in conditions across the region, correlations were carried out between pairs of stations using the series of yearly values. Finally, in order to assess the possibility of climatic change, the data series were smoothed using a 5 year running average and examined for trends.

Results

Winter Range Conditions

Because of its location, Schefferville is the station that is most representative of the winter range area. Kuujjuarapik lies at the western hmit, while Border, Churchill Falls, and Wabush Lake coincide approximately with eastern and southern limits (Fig. 1). Interstation correlations were carried out on seasonal temperatures and snowfall by year among the following: Churchill Falls, Kuujjuarapik, Schefferville, and Wabush Lake (Table 2). For midwinter temperature, the correlations were all high and significant ($p < 0.01$). Correlations of total winter snowfall among the same stations were generally low and, with one exception, not statistically significant.

Midwinter (December through February) temperatures for Schefferville averaged -26.3°C (Fig. 2a), and the running mean shows a significant ($p < 0.05$) negative trend over the period. This decline is seen to varying degrees the other winter temperature records from the region, though not all meet the test of statistical significance. It is clear, however, that there is no evidence in these records for a regional warming.

Average winter snowfall at Schefferville was 415 cm, accounting for 52% of the annual precipitation. The depth of snow on the ground at the end of March averaged 85 cm for the period. No long-term trend is evident in snowfall, although there were consistently higher than average amounts from 1971 through 1983. As reported by Barr & Wright (1981) the Schefferville meteorological instrument site was relocated in 1970 to an airport site, with the potential for an artificial enhancement of the snow catch as a result of runway clearing operations. Nevertheless, the record shows a decline beginning in the mid-1980s (Fig. 2b), while Churchill Falls and Wabush Lake also showed a decrease in winter snowfall through the mid-1980s.

Winter rainfall at Schefferville averaged about 150 mm, was higher in the late 1960s, declined by half in the early 1970s, then increased in the early 1980s and remained consistently high through the end of the period. Schefferville had an average of 12.1 ($\sigma = 6.6$) winter days with freezing rain over the 1950-91 period (Fig. 2c). The frequency of such events showed a pronounced decrease from the early 1970s onward. By contrast, freezing rain events reported at Kuujjuarapik, Churchill Falls, and Wabush Lake increased in frequency from the mid-1970s to the mid-1980s, while the record from Goose Bay shows no significant trend.

Table 2. Interstation correlations (*r*) for winter range of the George River Herd. The upper value in each pair refers to winter temperature and the lower to total annual snowfall.

	Kuujjuarapik	Schefferville	Wabush Lake
Churchill Falls	0.68**	0.94**	0.94**
	0.01	0.21	0.48*
Kuujjuarapik		0.86**	0.82**
		0.01	0.11
Schefferville			0.92**
			0.61**

* Significant at p=0.05
** Significant at p=0.01

Particularly severe recent winters can be identified from the Schefferville record. The 1971-72 winter was one of widespread cold over all of northeastern Canada. 1957-58 and 1968-69 were significant for freezing rain at Schefferville, but were not exceptional at the other stations. Total winter rainfall amounts were high in 1957-58, 1968-69, 1983-84, 1988-89, and 1990-91. The 1976-1977 winter saw significantly above average snowfall at Schefferville and Border, but near average at Kuujjuarapik and Goose Bay. In the winter of 1980-81, all of the stations in the southern part of the region had above average snowfall except Churchill Falls, although Kuujjuarapik was only slightly above normal. 1988-89 is distinctive in that all of the winter range stations had negative snowfall anomalies in the 20 to 30% range.

Calving area and summer range

There are no stations in or near the plateau area east of the George River, which is the calving grounds and summer range for cows and calves of the George River Herd (Huot *et al.* 1994). The closest inland station, Border (465 m a.s.l.), had a relatively short record and only recently has been reestablished as an automatic station. Nain and Kuujjuaq are at coastal locations east and west of the area, but only Kuujjuaq has a complete record of observations for the 1950-1991 period. Schefferville can be included because of its elevation (522 m a.s.l.) and relative proximity to the southwest part of the summer range. Interstation correlations for summer temperature and precipitation (Table 3) indicate that Nain and Kuujjuaq have dissimilar summer regimes. Neither coastal station represents the interior plateau area as well as Schefferville; however, from consideration of its latitude and location near the tree-line, Kuujjuaq (Fig. 3) will serve to illustra-

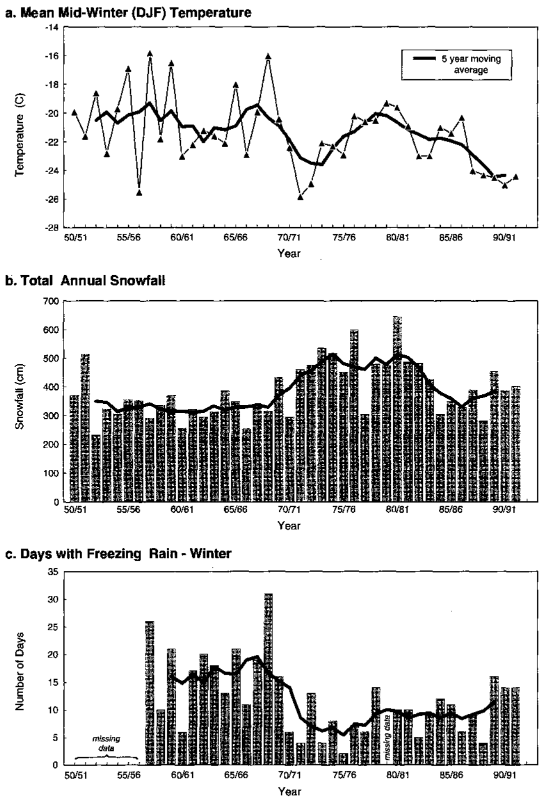

Fig. 2. Winter temperature, snowfall, and frequency of freezing rain recorded at Schefferville, Quebec, 1950-91, representing conditions on the winter range of the George River Herd.

te conditions on the summer range in comparison with Border and Schefferville.

Kuujjuaq had a mean summer temperature of 9.4°C over the 1950-91 period. The mean summer temperature at Border was 8.9°C for the shorter period of record there, compared with 10.4°C at Schefferville. Summer temperatures throughout the region were slightly lower in the late 1960s and early 1970s, but there has been no long-term trend (Fig. 3a).

Average summer precipitation at Kuujjuaq was 168 mm (σ =40 mm), compared with 254 mm (σ =80 mm) at Border and 258 mm (σ =67 mm) at Schefferville. Kuujjuaq showed a slight decrease between the 1970s and 1980s (Fig. 3b), while Schefferville experienced a decline of about 20% between the mid 1970s and the late 1980s.

The number of days during the June neonatal period with combined subfreezing temperatures and strong winds (speed > 20 km h^{-1}) doubled at Kuujjuaq between the mid-1970s and mid-1980s, with the summer of 1986 being a particularly extreme one in this regard (Fig. 3c). Comparable data are not available from Border for this period, but because wide regional spatial coherence generally exists in temperature patterns and to a lesser extent in winds, it is likely that similar conditions were experienced there.

Summary

From the frequency distributions of all measures, summer and winter, taking into account only those years in which a variable equals or exceeds two standard deviations, a rough assessment was made of years that were presumably unfavourable for caribou. These years are identified in Table 4. Only rarely did more than one variable exceed the criterion, so most of the unfavourable years represent ones in which, for example, winter snow was excessive *or* freezing rain was frequent, not both. Generally, severe winters are more frequent than severe summers, though this is to some extent an artifact of the method and the fact that precipitation data tend to be positively skewed. For the summer range, represented here by Kuujjuaq, it seems that there were more unfavourable years in the second half of the period. For the winter range, best represented by Schefferville, the period of the mid-1960s through the mid-1970s was unfavourable. Kuujjuarapik, at the western limit, experienced such conditions about a decade earlier.

Discussion

The results presented here are based mainly on data from seven meteorological stations, most of which are on the periphery of the George River range. Correlation analysis in this study as well as more rigorous analysis elsewhere (Jacobs, 1989) indicates that the seasonal temperatures and temperature trends evident in such records are representative of conditions in the study area. Thus, the decline in winter temperatures since the 1960s that was found to be statistically significant at Schefferville is valid as to sign, if not magnitude, for the region as a

Table 3. Interstation correlations (r) for summer range of the George River Herd. The upper value in each pair refers to summer temperature and the lower to total summer precipitation.

	Kuujjuaq	Nain	Schefferville
Border	0.76**	0.80**	0.90**
	0.25	0.21	0.65*
Kuujjuaq		0.50*	0.80**
		0.03	0.18
Nain			0.67*
			0.08

* Significant at p=0.05.
** Significant at p=0.01.

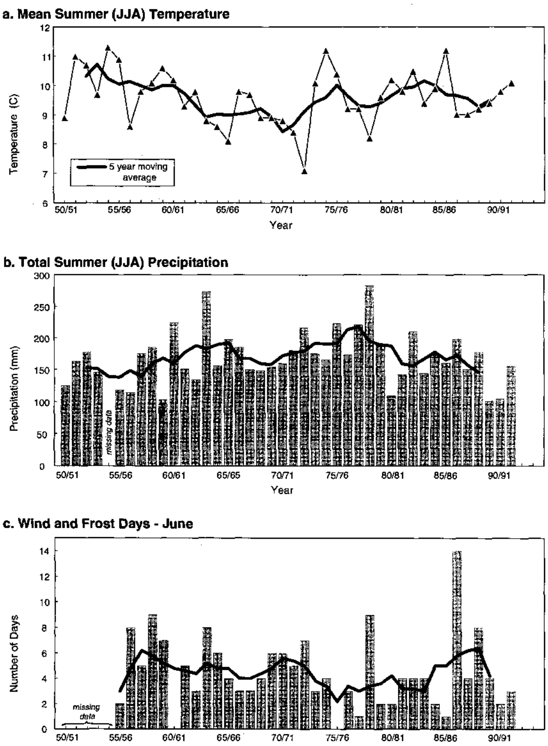

Fig. 3. Summer temperature, precipitation, and days with combined windspeed > 20 km hr^{-1} and temperature < 0°C recorded at Kuujjuaq, Quebec, 1950-91, as an indication of conditions in the summer range area of the George River Herd.

whole. This is consistent with other studies of regional temperature trends in Canada (Gullett *et al.*, 1992). Likewise, the absence of any trend in summer temperatures in the station records can be confidently applied to the region as a whole. These results may be compared with those of Crête & Payette (1990), who inferred from the Québec City record a regional cooling in both seasons since the 1950s, compared with the preceding half-century.

Snowfall and rainfall data cannot be so easily extrapolated beyond the vicinity of the reporting stations, and snowdepth data are even more subject to spatial variability (Jacobs, 1989). Crête & Payette (1990) found that they could not extrapolate precipitation trends from the Québec City record, as they did for temperature. Pruitt (1959) recognized the large spatial and temporal variations in the characteristics of snow cover over caribou range. He argued that for purposes of explaining caribou winter range conditions, "...conventional snow data as reported by the existing net of meteorological observatories are not only insufficient but may actually be misleading" (Pruitt, 1959:1759). With that in mind, one should be cautious in how the snowfall record from these few stations is interpreted. Winter precipitation totals at Schefferville were relatively high from 1974 through 1983, with the 1980-81 amount nearly twice the period average. From this evidence, Couturier *et al.* (1990) inferred stressful conditions on the winter range in that year, as well as for a number of years in the 1974-83 interval. The fact that most other stations in the area had above average snowfall in 1980-81 lends support to that argument, despite previously mentioned concerns about the effects on the record of the relocation of the Schefferville station, although it should be noted that the reported depth of snow on the ground at Schefferville at the end of March, 1981 was not exceptional.

It is to be expected that, with declining winter temperatures, there would a decrease in the amount of snowfall, as was observed at Schefferville in the early 1980s. Since then, however, while temperatures continue to decline regionally, both snowfall and winter rainfall have risen slightly. Such a combination has the potential to increase stress on the caribou on their usual winter range. This might explain an observed shift of the herd westward in the late 1980s (cf. Messier, *et al.*, 1988) and, most recently, the apparent overwintering of significant numbers of caribou along the northeast Labrador coast (Couturier *et al.*, 1996).

Because of the lack of a truly representative observing station in the calving ground and summer range area, any conclusions about climatic conditions there are necessarily tentative. Based on observations made in the 1940s, Rousseau (1968) described the George River Plateau as having cool, windy summers in which scattered snow patches are likely to remain into the next winter. As noted, there seem to have more June days with combined wind and subfreezing temperatures in the mid-1980s than in the previous decade. This period coincides with the caribou population increase, i.e. there is no evidence for increased calf mortality. This would seem to support the conclusion of Miller & Gunn (1986) that caribou neonates generally have a good tolerence for severe weather. Again, climatic impacts on forage conditions seem to be more important. Crête & Payette (1990) noted the effect of residual snow cover in delaying the emergence of green shoots in some years.

Hearn *et al.* (1990) reported a decrease in George River caribou summer survival rates over the 1983-87 period, while winter survival rates remained constant. Huot *et al.* (1994) have attributed the poor body condition of George River caribou in recent years to deteriorating quality of the summer range as a consequence of overgrazing. Crête *et al.* (1996) have described a severely impacted vegetation over extensive areas there, and its recovery may be compounded by a less than optimal summer climate. There have been some recent warm summers with below average precipitation at both Kuujjuaq and Schefferville, though Nain does not share this pattern. Probably as a consequence of cooler, drier, and windier conditions than in the lowlands, insect harassment does not appear to be serious in the George River Plateau area (Messier *et al.*, 1988; Huot *et al.*, 1994). This may in part explain its attractiveness as summer range, despite the poor quality of forage.

The lowland forest-tundra south and west of the George River Plateau is frequented in summer by males and barren females (Crête *et al.*, 1990). Vegetation in these areas exists under different bioclimatic conditions from the upland tundra, is more productive, and will respond differently to regional climatic forcing. Though the cows and calves may pass through these areas after leaving the upland tundra areas in late July or early August, the evidence of their condition in fall would seem to indicate that the nutritional shortfall experienced on the summer range is not being made up in transit (Huot, 1989; Huot *et al*, 1994). It is noteworthy that a small, apparently distinct woodland caribou population, the Caniapiscau Herd, was reported to have a calving area and summer range in the bog and fen areas west of Schefferville and to be feeding primarily on aquatic plants and grasses (Paré & Huot, 1985).

Table 4. Years of potentially unfavourable climatic conditions in summer (S) and winter (W) on the range of the George River Herd based on 2σ departures from means of the relevant variables.

YEAR	STATION			
	Inukjuak	Kuujjuaq	Kuujjuarapik	Schefferville
1950-51		W		W
1951-52		W		W
1954-55	W			
1955-56	W		W	
1957-58			W	W
1958-59			W	
1961-62			W	
1962-63			W	
1963-64		W	W	W
1964-65		W		W
1965-66				S
1966-67			W	
1968-69		W	W	W
1969-70	S	W		W
1970-71		S		
1971-72	W			W
1972-73	S			S
1973-74				W
1974-75				W
1975-76		W		
1976-77	W			W
1977-78	W			
1978-79		SW	W	
1979-80	W			
1980-81				W
1981-82				W
1982-83	W	W	W	
1983-84		W		
1984-85		W		
1986-87	W	S		S
1987-88	W			
1989-90	W			
1990-91	W			

Conclusion

Based on a review of the records for the past 42 year period, there is no clear evidence for a major, long-term shift or trend in climatic conditions over the range of the George River Caribou Herd that might explain changes in the condition of the herd. The most significant trend, that of a decline in winter temperatures, is unlikely to have had a negative impact on the caribou and has been argued as an improvement over conditions in the early part of the century (Crête & Payette, 1990). Our analysis indicates with some confidence an increase since the 1980s in snowfall and winter rainfall in the historic wintering areas. This may have caused increased stress and encouraged movement into areas of lesser winter precipitation.

More problematic is the summer range, which biologists have identified as the critical element in the ecology of the herd and to which current problems of the condition of the animals are attributed. This area is not well-represented by existing climate stations. However, it can be concluded that summer temperatures in the area show no significant trend over the period. With less confidence, there is an indication of reduced summer precipitation and more frequent periods of strong winds and subfreezing temperatures during the neonatal period. The latter may not necessarily have a direct impact on calves, but the combination will negatively affect range productivity.

For the George River Herd, as is the case with caribou in many other areas, it is not possible to demonstrate a simple causal relationship between climate and population dynamics. It seems that climate affects this complex system in a variety of ways. In the most recent period, the weight of evidence points to habitat deterioration on the summer range as the main problem affecting the herd. Similar deterioration does not seem to be occurring in summer range areas of other caribou populations in northern Québec under present climate. This may be a matter of different bioclimatic responses among differing habitat types under the same regional climate, or of a particular range that is deteriorating with overgrazing, irrespective of the climate. Further research should be directed at the mesoscale or subregional differences in climate and vegetation and their interrelationships, as much as to the question of why there continues to be such a strong preference among females of the George River Herd for what appears now to be a marginal summer range.

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