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Where the wild things are: Seasonal variation in caribou distribution in relation to climate change

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Abstract: In this study, we develop a method to analyse the relationships between seasonal caribou distribution and climate, to estimate how climatic conditions affect interactions between humans and caribou, and ultimately to predict patterns of distribution relative to climate change. Satellite locations for the Porcupine *(Rangifer tarandus granti)* and Bathurst *(R. t. groenlandicus)* caribou herds were analysed for eight ecologically-defined seasons. For each season, two levels of a key environmental factor influencing caribou distribution were identified, as well as the best climate data available to indicate the factor's annual state. Satellite locations were grouped according to the relevant combination of season and environmental factor. Caribou distributions were compared for opposing environmental factors; this comparison was undertaken relative to hunting access for the Porcupine Herd and relative to exposure to mining activity for the Bathurst Herd. Expected climate trends suggest an overall increase in access to Porcupine caribou for Aklavik (NWT) hunters during the winter and rut seasons, for Venetie (Alaska) hunters during midsummer and fall migration and for Arctic Village (Alaska) during midsummer. Arctic Village may experience reduced availability with early snowfalls in the fall, but we expect there to be little directional shift in the spring migration patterns. For the Bathurst Herd, we expect that fewer caribou would be exposed to the mines during the winter, while more caribou would be exposed to the combined Ekati and Diavik mining zone in the early summer and to the Lupin-Jericho mining zone during the fall migration. If changes in climate cause an increased presence of caribou in the mining sites, monitoring and mitigation measures may need to be intensified.

Key words: development, hunting, *Rangifer tarandus granti, R. t. groenlandicus,* utilization density.

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Introduction

Numerous studies have documented the magnitude and trends of recent and projected climate change at the regional and continental scale (Zhang *et al.*, 2000; Zhou *et al.*, 2001; ACIA, 2004; Hinzman *et al.*, In Press). Knowledge of how caribou distribute themselves in relation to changing environmental conditions is crucial to our ability to project the future effects of climate change on caribou availability to user communities and the interaction of caribou with industrial development. While climate models have been developed to simulate how the environment may change over the next few decades, these models do not predict how living organisms will react and adapt to these changes. Furthermore, environmental assessment of the effects of proposed industrial development requires a good knowledge of the spatial and temporal movements of animals in relation to exposure zones. The better the knowledge of animal distribution, the more effective the mitigation measures will be.

Large migratory caribou herds in North America migrate from lichen-dominated, energy-rich winter-

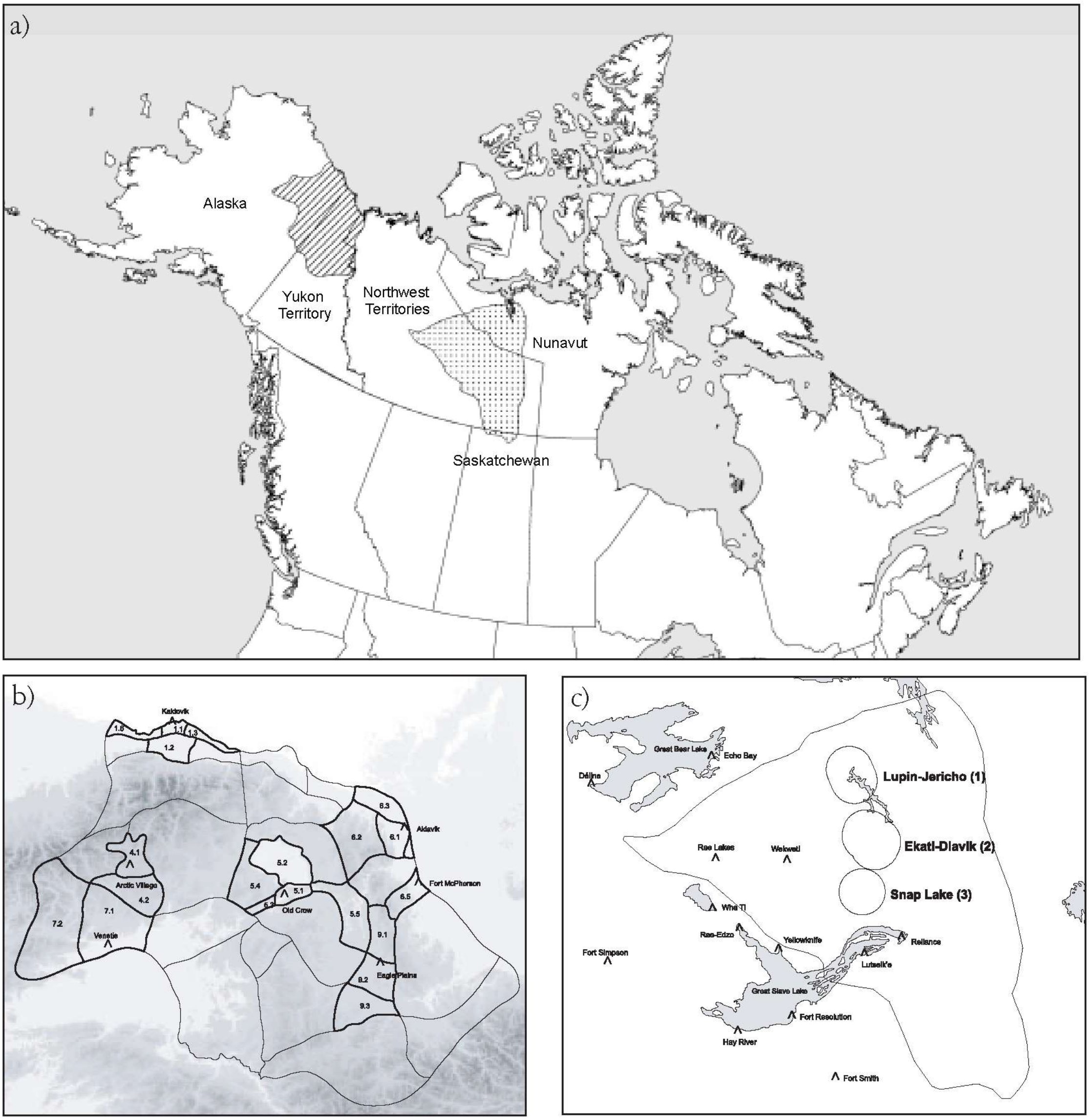


Fig. 1. a) Porcupine (stripes) and Bathurst (dots) caribou herd ranges; b) Porcupine caribou range with selected community access zones outlined in bold (see Table 2 for details); c) Bathurst caribou range with mining exposure zones (see Table 3 for details).

ing grounds south of the treeline to vascular plant-dominated, protein-rich calving and summer ranges along the arctic coast. The timing of calving generally coincides with the rapid growth of green vegetation, which is critical for the survival of newborn calves. After calving, the cows begin to form larger groups which are maintained due to insect harassment when warm, windless days persist into July. To avoid harassment, the herds will seek insect relief habitat such as coastal zones, windy mountain ridges or eskers, and snow patches.

By August, cool, freezing nights reduce insect activity. The dense aggregations disband while individuals forage intensively to replenish their body reserves in preparation for the rut and winter. From one year to the next, the herds may select quite different areas in which to winter, resulting in large cumulative wintering areas. The annual winter distribution appears to be a trade-off between favourable snow conditions and abundant lichen resources. There is some evidence that herds may also shift wintering areas periodically, perhaps in response to diminishing lichen biomass. Spring migration is first initiated by pregnant cows in late March or April.

If snow conditions are favourable, caribou may begin to drift north earlier and if unfavourable may delay movement either in their core wintering areas or along the migration routes (Eastland, 1991; Russell *et al.*, 1993).

The goal of our research was to improve our understanding of the relationship among caribou, human use of or effects on caribou, and climate. In this study, we estimate the effects of environmental factors on caribou distribution, provide predictions of caribou distribution relative to climate change scenarios, and consider the implications for hunting of caribou and use of caribou habitat. We achieve these goals by:

1. Estimating the seasonal patterns of distribution of the Porcupine and Bathurst caribou herds relative to key climate factors;
2. Predicting caribou distribution for given climate change scenarios;
3. Considering the implications of climate-related changes in caribou distribution for human activity.

Materials and methods

The study areas encompassed the annual ranges of the Porcupine caribou herd in the Northwest Territories, Yukon Territory and Alaska and the Bathurst caribou herd in Nunavut and the Northwest Territories (Fig. 1). During our study, the Porcupine caribou herd increased to 178 000 caribou in 1989, then declined to 123 000 by 2001. The Bathurst caribou declined from 350 000 animals in 1996 to 187 000 in 2003.

For the Porcupine caribou herd analysis, our primary objective was to assess the projected effects of climate change in relation to caribou availability to local communities for hunting. Through local knowledge interviews with community hunters, we delineated a

Table 1. Environmental classes and climate variables for eight seasons for the Porcupine (PCH) and Bathurst (BTH) caribou herds.

Season	PCH Date (mm/dd)	PCH Data Source	PCH Class	BTH Date (mm/dd)	BTH Data Source	BTH Class
1. Winter	12/1–3/30	1 Mar snow depth, Eagle Plains	Shallow snow <75 cm Deep snow >75 cm	12/6–4/14	Spring snow water equivalent, Snare & Yellowknife Basins	Shallow snow <200 cm Deep snow >200 cm
2. Spring migration	4/1–5/31	1 May snow depth–1 Mar snow depth, Old Crow	Early snowmelt >30 cm Late snowmelt <30 cm	4/15–6/2	30 Apr Snow on Ground, Lupin	Early snowmelt <20 cm[a] Late snowmelt >20 cm[a]
3. Calving	6/1–6/10	% Snow cover within extent of calving	Early snowmelt <20% Late snowmelt >20%	6/3–6/13	31 May Snow on Ground, Lupin	Early snowmelt = 0 cm[b] Late snowmelt >0 cm[b]
4. Post-calving	6/11–6/30	21 June NDVI–1 June NDVI, within extent of calving	Fast green-up >0.1 Slow green-up < 0.1	6/14–7/5	June Mean Temperature, Lupin	Fast green-up >7 °C Slow green-up <7 °C
5. Early Summer	7/1–7/15	Rank of total June precipitation & July mean max temperature, Old Crow	Few insects <20 Many insects >20	7/6–7/18	Rank of total June precipitation & July mean max temperature, Lupin	Few insects <9 Many insects >9
6. Mid to late summer	7/16–8/7	Rank of total June precipitation & July mean max temperature, Old Crow	Few insects <20 Many insects >20	7/19–8/22	Rank of total June precipitation & July mean max temperature, Lupin	Few insects <9 Many insects >9
7. Fall migration	8/8–10/7	Total September snowfall, Old Crow	Late snowfall <4.5 cm Early snowfall >4.5 cm	8/23–10/3	Total September snowfall, Yellowknife	Late snowfall <1 cm Early snowfall >1 cm
8. Rut/Late Fall	10/8–11/30	Total September snowfall, Old Crow	Late snowfall <4.5 cm Early snowfall >4.5 cm	10/4–12/5	Total September snowfall, Yellowknife	Late snowfall <1 cm Early snowfall >1 cm

[a] When April Snow on Ground was not available, January–April Total Snowfall and May Mean Temperature were used.
[b] When May Snow on Ground was not available, April Snow on Ground and May Total Snowfall were used.

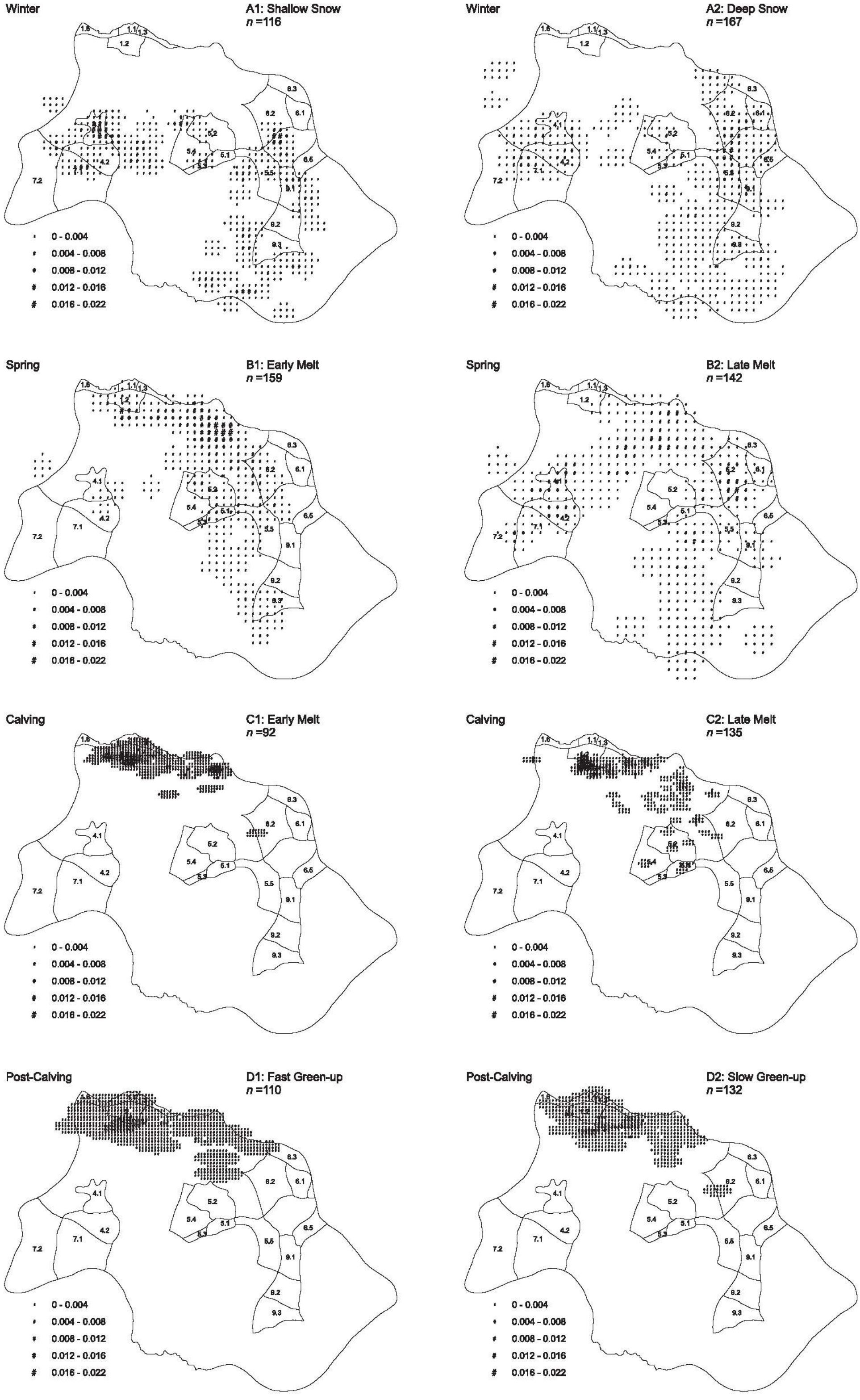
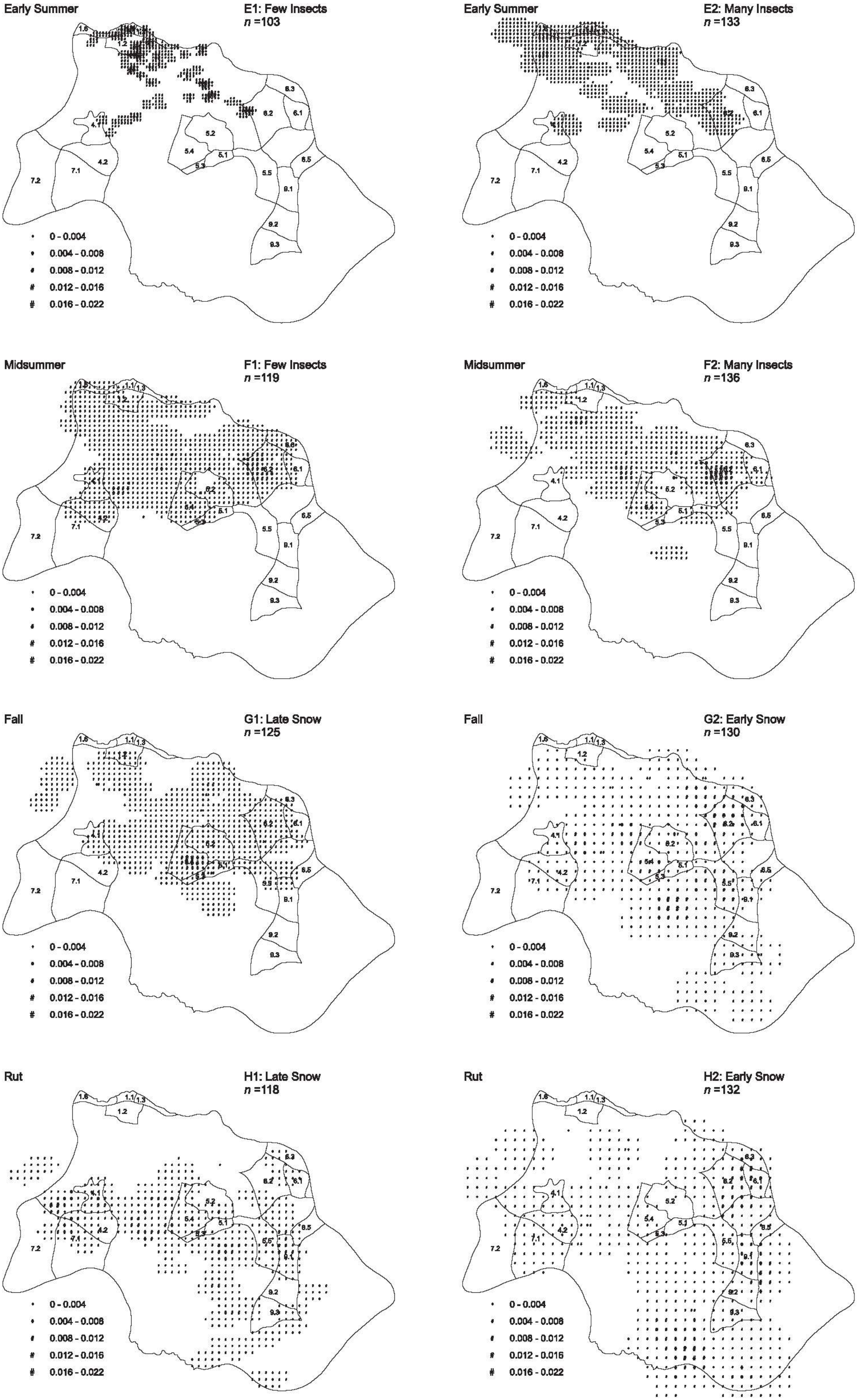


Fig. 2. Utilization densities of Porcupine caribou by season and environmental class with an overlay of the community access zones, 1985–2003. (Fig. 2 continues on next page).


Early Summer
E1: Few Insects
n =103
0 - 0.004
0.004 - 0.008
0.008 - 0.012
0.012 - 0.016
0.016 - 0.022
Early Summer
E2: Many Insects
n =133
0 - 0.004
0.004 - 0.008
0.008 - 0.012
0.012 - 0.016
0.016 - 0.022
Midsummer
F1: Few Insects
n =119
0 - 0.004
0.004 - 0.008
0.008 - 0.012
0.012 - 0.016
0.016 - 0.022
Midsummer
F2: Many Insects
n =136
0 - 0.004
0.004 - 0.008
0.008 - 0.012
0.012 - 0.016
0.016 - 0.022
Fall
G1: Late Snow
n =125
0 - 0.004
0.004 - 0.008
0.008 - 0.012
0.012 - 0.016
0.016 - 0.022
Fall
G2: Early Snow
n =130
0 - 0.004
0.004 - 0.008
0.008 - 0.012
0.012 - 0.016
0.016 - 0.022
Rut
H1: Late Snow
n =118
0 - 0.004
0.004 - 0.008
0.008 - 0.012
0.012 - 0.016
0.016 - 0.022
Rut
H2: Early Snow
n =132
0 - 0.004
0.004 - 0.008
0.008 - 0.012
0.012 - 0.016
0.016 - 0.022

set of community hunting zones within the range of the herd based on conditions affecting access to caribou (Fig. 2; Kofinas & Braund, 1998; Berman & Kofinas, 2004). Designations of "near" and "far" for each zone indicate the overall accessibility by hunters from the communities. "Near" indicates areas that are accessible within a day in normal conditions for each season whereas "far" refers to hunting areas that involve overnight travel and hence are less accessible to those people with employment. To simplify our initial analysis, we have not included the full set of hunting zones for each community, and instead focus specifically on a subset of zones.

For the Bathurst Herd, we explored a method for assessing effects of industrial development on caribou. We created 50 km buffer zones around the 4 potential or operational mines within the range of the herd (the potential Snap Lake mine and the operational Ekati, Diavik, and Lupin-Jericho mines; Fig. 3). We based the 50 km buffer on a preliminary analysis which suggested that satellite-collared cows spent less time than expected within 50 km of the Ekati mine. We include the proposed Snap Lake mine as a baseline site that can be used to note changes as human activity increases in the area.

Satellite locations from collared cows from the Porcupine (1985–2003) and Bathurst (1996–2003) caribou herds were compiled in a geographic information system (GIS). The data were analysed using Arcview 3.2a (Environmental Systems Research Institute Inc., 1992), SAS 8.2 (SAS Institute Inc., 1999) and Kernel HR (Seaman *et al.*, 1998), based upon the following steps.

We divided the annual cycle into eight seasons based upon caribou activities (Porcupine Caribou Technical Committee, 1993) and for each season selected a single environmental factor that may affect movement (Table 1). We then divided the years into two classes (e.g., early/late snowmelt; few/many insects) per season based on rankings of the environmental factor (Table 1). For the Bathurst Herd, Snow-on-Ground data were not available for all years. To determine which years classified as early or late snowmelt, we used January to April Total Snowfall and May Mean Temperature for spring migration and April Snow on Ground and May Total Snowfall for calving. These climate data were used in conjunction with the available Snow on Ground data to rank all years. Two to three random locations per caribou per class per season were selected to ensure that no animal was overrepresented. Two thousand eighty-two sample locations of 18 979 were selected for the Porcupine Herd and 928 sample locations were chosen from the 6015 Bathurst locations. These locations represented 68 animals for the Porcupine Herd and 48 animals for the Bathurst Herd.

We subsequently conducted a kernel analysis to create utilization density grids for the 16 different classes and calculated the proportional use of human use zones (e.g., hunting territories, development buffers) to analyse caribou movements relative to human activity. Finally, we performed a jackknife analysis to estimate the variance of the proportional use of the zones. For each season and environmental class, we sequentially deleted a single year of data and repeated the kernel analysis and used the results to calculate the variance and 95% confidence intervals on the proportional use of each human use zone (Smith, 2001). Pairs of environmental states within seasons were considered significantly different if the pairs had non-overlapping 95% confidence intervals, a very conservative assessment of significance (Payton *et al.*, 2003).

Results

Porcupine caribou herd

Shallow snow in the winter corresponded to two main distributions around zones 4.1 and 6.2 (Fig. 2-A1). Overall, caribou were more concentrated in those zones than in years with deep snow (Fig. 2-A2) but winter distributions were similar under both sets of conditions.

During spring migration, annual differences in movement patterns were distinguishable. With an early snowmelt (Fig. 2-B1), caribou were distributed further north and west along the North Slope than in late snowmelt years (Fig. 2-B2). There were two main migration routes when snowmelt was late; however animals that followed the Brooks Range from zone 7.1 northeast through zone 4.1 (Fig. 2-B2) may have simply been further along the route in years of early melt.

Caribou distributions during the calving season were more concentrated at the lower elevations towards the coastal plain in years of early snowmelt (Fig. 2-C1). Late snowmelt years (Fig. 2-C2) exhibited distributions further south of zones 1.2 and 1.3 in the Brooks Range as well as numerous pockets to the southeast.

Distributions during the post-calving period were very similar under both sets of environmental conditions. In years with faster green-up (Fig. 2-D1), caribou tended to form concentrations further west into Alaska and were less diffuse than in years of slow green-up (Fig. 2-D2).

Early summer distributions were concentrated in small dense pockets when the insect harassment level was low (Fig. 2-E1). Caribou were much more widely dispersed during years with many insects (Fig. 2-E2).

In midsummer caribou were scattered under both sets of conditions (Figs. 2-F1 and 2-F2). There was a main concentration located in zone 6.2 during years with many insects (Fig. 2-F2).

Distributions in the late summer/fall migration season (Figs. 2-G1 and 2-G2) differed in latitude; in years with an early arrival of snow (Fig. 2-G2), caribou were located further south. The use of the area in years of early snowfall was also more diffuse.

During the rut/late fall season, the caribou distribution in years of late snowfall (Fig. 2-H1) was characterized by a band running east–west across the middle portion of the range with pockets of concentration and a few animals present in the southern tip of the range. During years when snow arrived early (Fig. 2-H2), the dominant distribution was north–south from zone 6.3 to the southern tip of the range. The distributions were more concentrated in years with late arrival of snow (Fig. 2-H1).

Based on the community access zones (Table 2) for the Porcupine caribou herd (Berman & Kofinas, 2004), we considered the implications of changes in caribou distribution on hunting. The effects are by no

Table 2. Proportion of zone (by area) occupied by the mean utilization density distribution for the Porcupine caribou herd. Data are presented by community hunting zone by season and environmental factor; * indicates that caribou were significantly more accessible during that condition. Only zones relevant to community access are shown so columns do not total 1.0.

Community Access	Zone	Winter		Spring Migration		Calving		Post-Calving		Early Summer		Midsummer		Fall Migration		Rut – Late Fall	
		Snow Depth		Snowmelt		Snowmelt		Green-Up		Insects		Insects		Snowfall		Snowfall	
		Shallow	Deep	Early	Late	Early	Late	Fast	Slow	Few	Many	Few	Many	Late	Early	Late	Early
Kaktovik	1.1 Near			0.002		0.008*		0.007	0.023	0.047	0.049	<0.001					
	1.2 Far			0.028*	0.001	0.344*	0.171	0.189	0.139	0.095	0.041	0.008	0.002	0.013*	<0.001		
	1.3 Far			0.003	<0.001	0.031	0.002	0.004	0.013	0.036	0.035	0.001					
	1.6 Far			0.001		0.005		0.031	0.023	0.021	0.073	0.006	0.001				
Arctic Village	4.1 Near	0.102*	0.020	0.005	0.054*					0.005	0.004	0.021*	<0.001	0.016	0.004	0.026*	0.004
	4.2 Far	0.023	0.055*	0.007	0.047*							0.018*		0.002	0.021*	0.034	0.027
Venetie Old Crow	7.1 Near	0.049	0.053	<0.001	0.039*							0.001*			0.005*	0.045	0.027
	7.2 Far	0.010	0.020		0.014*											0.012	0.002
	5.1 Near	0.004	0.008	0.025*	<0.001		0.016*					0.001	<0.001	0.016	0.008	0.003	<0.001
	5.2 Far	0.014	0.019	0.037*	0.003		0.022*					0.008	0.005	0.046	0.031	0.023*	0.001
	5.3 Far	0.009	0.001	0.001								0.001	<0.001	0.002	0.008	0.005	0.002
Aklavik	5.4 Far	0.028*	0.006	0.005			0.008*					0.032	0.040	0.145*	0.058	0.069*	0.006
	5.5 Far	0.028	0.084*	0.028	0.011							<0.001	0.007*	0.014	0.068*	0.033	0.019
	6.1 Near		0.016*	<0.001	0.008*							0.002	0.007	0.007	0.010	0.004	0.042*
Fort McPherson	6.2 Far	0.025	0.060	0.051	0.095	0.014	0.005		0.014*	0.028	0.066	0.193	0.223	0.097	0.112	0.013	0.079*
	6.3 Far		0.002	<0.001	0.001			0.001				0.010*	<0.001	0.002	0.017*	0.005	0.019
	6.5 Near	0.003	0.009	<0.001	0.001									0.001	0.002	0.008	0.011
	9.1 Near	0.035	0.045	<0.001	0.006									0.006	0.011	0.046	0.056
	9.2 Far	0.002	0.001	<0.001	<0.001										0.002*	0.005	0.021*
	9.3 Far	0.008	0.029	0.017*	0.003										0.007*	0.011	0.006

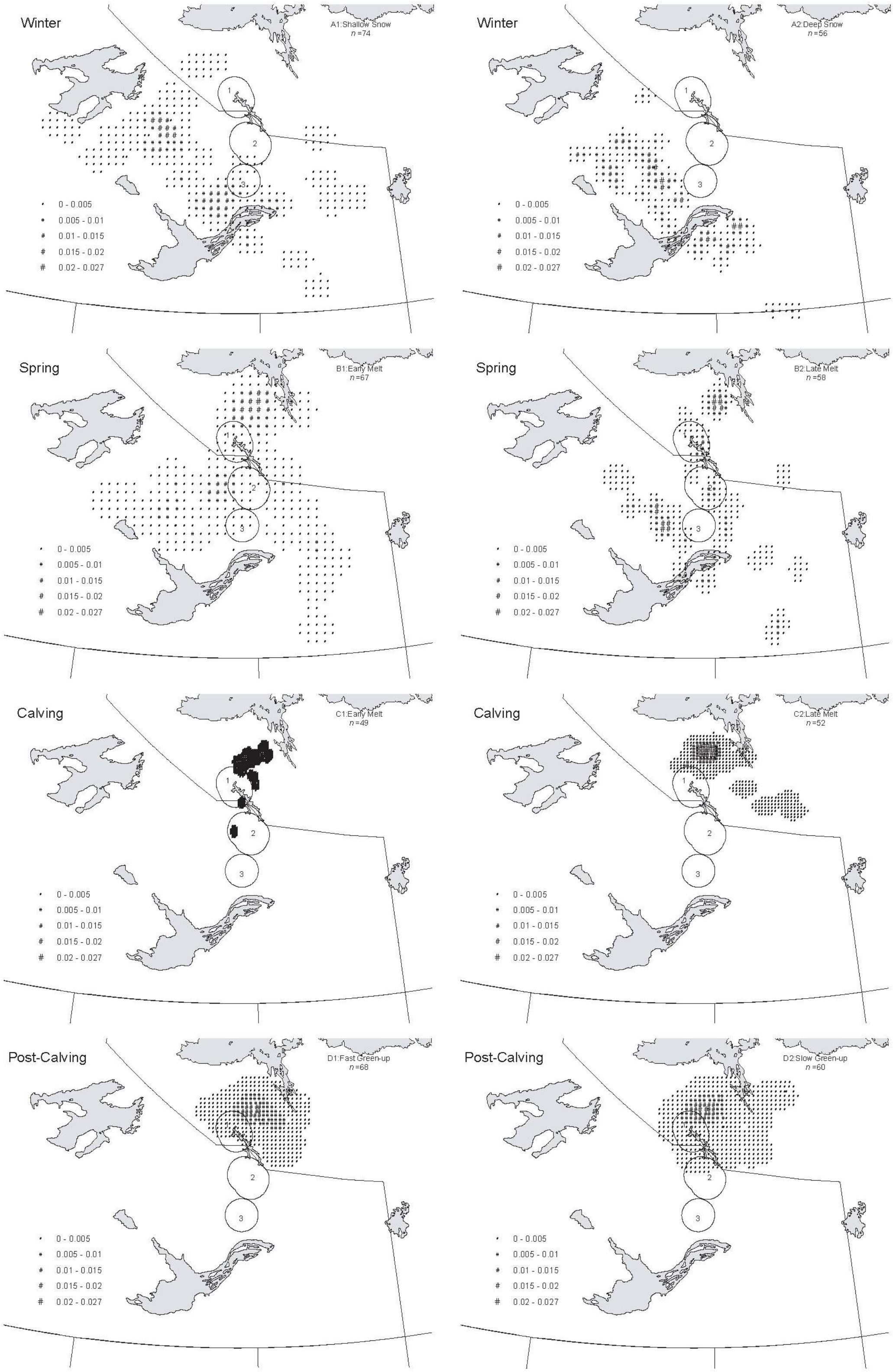
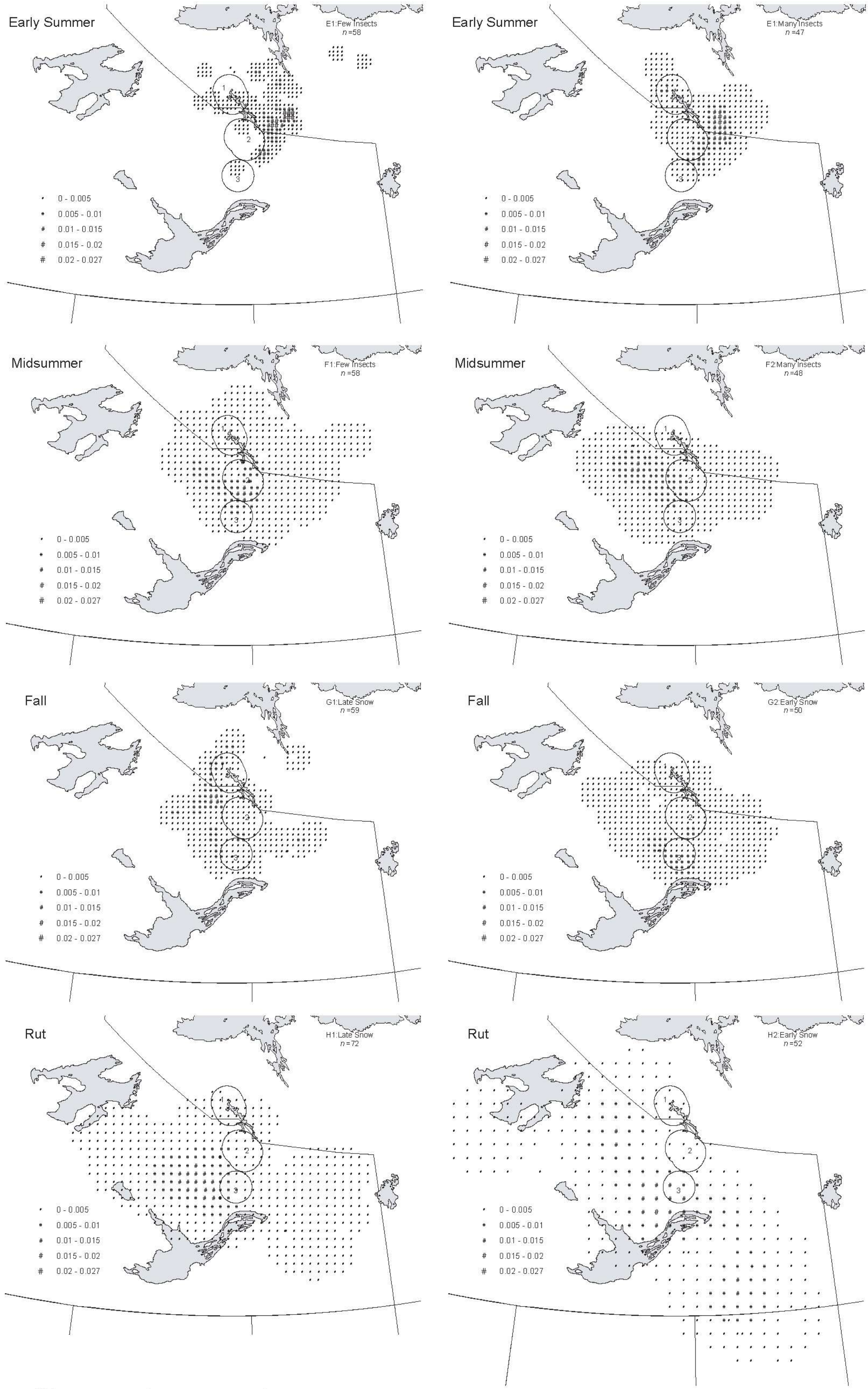


Fig. 3. Utilization densities of Bathurst caribou by season and environmental class with respect to mine sites (50 km buffer zones), 1996–2003. The mine zones are 1 Lupin Jericho, 2 Ekati-Diavik, and 3 Snap Lake. (Fig. 3 continues on next page).


Early Summer
E1:Few Insects
n =58
1
2
3
0 - 0.005
0.005 - 0.01
0.01 - 0.015
0.015 - 0.02
0.02 - 0.027
Early Summer
E1:Many Insects
n =47
3
0 - 0.005
0.005 - 0.01
0.01 - 0.015
0.015 - 0.02
0.02 - 0.027
Midsummer
F1:Few Insects
n =58
0 - 0.005
0.005 - 0.01
0.01 - 0.015
0.015 - 0.02
0.02 - 0.027
Midsummer
F2:Many Insects
n =48
1
0 - 0.005
0.005 - 0.01
0.01 - 0.015
0.015 - 0.02
0.02 - 0.027
Fall
G1:Late Snow
n =59
0 - 0.005
0.005 - 0.01
0.01 - 0.015
0.015 - 0.02
0.02 - 0.027
Fall
G2:Early Snow
n =50
0 - 0.005
0.005 - 0.01
0.01 - 0.015
0.015 - 0.02
0.02 - 0.027
Rut
H1:Late Snow
n =72
2
3
0 - 0.005
0.005 - 0.01
0.01 - 0.015
0.015 - 0.02
0.02 - 0.027
Rut
H2:Early Snow
n =52
1
2
3
0 - 0.005
0.005 - 0.01
0.01 - 0.015
0.015 - 0.02
0.02 - 0.027

means clear-cut. For example, with respect to near hunting zones, only Arctic Village had improved access during winters of shallow snow, while Aklavik hunters had improved access to caribou during winters of deep snow. Spring migration allowed Kaktovik hunters some access to the herd but despite the more northerly distribution of caribou in years with early snowmelt, the animals were still located too far south to significantly improve Kaktovik access within the near hunting zone. Old Crow benefited from early snowmelt but Arctic Village, Venetie and Aklavik hunters all had better access in years with late snowmelt.

During calving, early snowmelt provided increased access for Kaktovik residents while late snowmelt benefited Old Crow hunters, which was likely due to delayed northbound migration. The environmental conditions during the post-calving and early summer seasons did not significantly affect community access to caribou. In midsummer, the Alaskan communities of Arctic Village and Venetie had greater access to caribou when the insect harassment level was low. During fall migration, only Venetie hunters experienced greater caribou access when snow arrived early. In the late fall, early snowfall increased access for Aklavik residents but decreased access for Arctic Village hunters (Table 2).

Bathurst caribou herd

For the Bathurst caribou, shallow snow years in winter (Fig. 3-A1) were characterized by a broad range encompassing areas further to the north, west and east than the distribution in deep snow years (Fig. 3-A2). Caribou were most concentrated southeast of Great Bear Lake in shallow snow years whereas in deep snow years, caribou were concentrated in areas near Great Slave Lake. In deep snow years, caribou were located as far south as the Saskatchewan border.

Spring migration showed similar concentrations west of Bathurst Inlet for both early (Fig. 3-B1) and late (Fig. 3-B2) snowmelt. However, the early melt distribution included terrain further to the west as well as an area east of Great Slave Lake to Saskatchewan. In late melt years, the distribution was comprised of smaller isolated pockets and included terrain close to Great Slave Lake.

Calving distributions were focussed in the area west of Bathurst Inlet. During early melt (Fig. 3-C1), some cows were further south and within the mining zones while in late melt years (Fig. 3-C2) the focus area was broader with some caribou located further to the southeast. Those cows further south were nonbreeders who then caught up to the breeding cows by early postcalving.

Post-calving distributions (Figs. 3-D1 and 3-D2) were also very similar between the slow and rapid green-up. In years exhibiting slower green-up (Fig. 3-D1), the area extended to both the south and east, closer to the mining zones.

During early summer, the main difference between distributions was a more continuous distribution in years with many insects (Fig. 3-E2) than in years with few insects (Fig. 3-E1). However, the same area was used under both sets of conditions and the same area contained the greatest densities of caribou.

Into midsummer, the distributions (Figs. 3-F1 and3-F2) remained similar. The few insect years had a broad diffuse coverage (Fig. 3-F1), with greater use of Nunavut (northeast of the mining zones).

During autumn, the densest concentration of caribou was found northwest of zone 2 for years with late arrival of snow (Fig. 3-G1). There was also a small concentration at the southern tip of Bathurst Inlet. During years with early snow (Fig. 3-G2), the densest concentration was located within north of zone 3 and the coverage extended further west and south than in late snow years. The distribution during years of early snow had two gaps in the centre.

During the rutting period, late snowfall (Fig. 3-H1) occurred with a continuous distribution north of Great Slave Lake with a few isolated patches to the east of the lake. During years with early snow arrival (Fig. 3-H2), the distribution was much broader. Range use included a band of coverage from Great Bear Lake southeast to Saskatchewan.

For the Bathurst caribou herd, zones of exposure to mines were analysed for differences in caribou distribution between pairs of conditions (Table 3). During the winter season, more caribou were located outside the mining zones when the snow was deep and fewer caribou were exposed to the Snap Lake mining zone than in years of shallow snow. During spring migration, more caribou remained outside the mining zones when the snow melted early compared to when snowmelt was late. Significantly more caribou were located within the Ekati–Diavik zone in years of late melt. During calving, significantly more caribou were exposed to the Lupin–Jericho and the Ekati–Diavik mining zones when snowmelt was early and fewer caribou were outside of the mining zones during early snowmelt. There was no significant difference in caribou distribution during the post-calving season.

During early summer, Bathurst caribou were 3.5 times more likely to be located within the Ekati–Diavik mining zone when the insect harassment level was high. There was no significant difference in distributions either during midsummer or during rut. During the fall migration period, more caribou were

Table 3. Proportion of zone (by area) occupied by the mean utilization density distribution for the Bathurst caribou herd. Data are presented by mine site (50 km buffer zone) by season and environmental factor; * indicates that caribou were significantly more accessible during that condition. Column totals for zones 0 through 3 total 1.0.

Mining exposure	Zone	Winter		Spring migration		Calving		Post-calving		Early summer		Midsummer		Fall migration		Rut – Late fall	
		Snow depth		Snowmelt		Snowmelt		Green-up		Insects		Insects		Snowfall		Snowfall	
		Shallow	Deep	Early	Late	Early	Late	Fast	Slow	Few	Many	Few	Many	Late	Early	Late	Early
No Exposure	0	0.961	0.999*	0.921*	0.809	0.885	0.983*	0.888	0.804	0.883	0.707	0.676	0.775	0.758	0.734	0.842	0.942
Lupin–Jericho	1			0.033	0.095	0.095*	0.017	0.112	0.189	0.052	0.085	0.032	0.013	0.076*	0.020	0.012	0.005
Ekati–Diavik	2	0.006		0.039	0.090*	0.027*			0.008	0.051	0.168*	0.216	0.156	0.093	0.107	0.074	0.007
Snap Lake	3	0.032*	0.001	0.007	0.006					0.015	0.040	0.075	0.057	0.073	0.139	0.073	0.046

exposed to the Lupin–Jericho mining zone with a late arrival of snow.

Discussion

Changes in caribou distributions can be predicted in response to climate change. Over the past 50 years, climate trends have been towards warmer wetter winters and springs in both caribou ranges (ACIA, 2004). Within the Porcupine range, the summers have been warmer and the autumn seasons have been cooler and wetter (Zhang *et al.*, 2000). For the Bathurst caribou herd, the summers have become slightly warmer and wetter and the autumn seasons have become wetter (Zhang *et al.*, 2000). Current climate models predict warmer temperatures in both ranges for all seasons, but no changes to the spring snowmelt. The models predict widely varied precipitation changes from 30% decreases to 46% increases; however the majority of the models predict some increase in total precipitation (Canadian Institute for Climate Studies, 2004).

Given warmer and wetter conditions, our analysis suggests more years with deep snow in the winters across the ranges of both herds, more insects in the summer, and fall seasons with later snowfalls. Changes in the spring seasons are projected to be small with a one °C increase in temperature, with no change in snowmelt (Canadian Institute for Climate Studies, 2004). However, frequency and severity of icing events may be better indicators of changes in caribou distribution.

These expected climate trends suggest an overall increase in access to Porcupine caribou for Aklavik hunters during the winter and rut seasons, for Venetie hunters during midsummer and fall migration and for Arctic Village during midsummer. Generally, the primary hunting seasons for communities are the autumn and spring migration seasons with little to no hunting occurring during the calving and rutting periods (Kofinas, 1998). Arctic Village may experience reduced availability with early snowfalls in the fall, but we expect there to be little directional shift in the spring migration patterns. In recent years many elders have observed increased variability in conditions affecting caribou movements, and commented that they cannot predict the weather or the movements of these two herds as they did in years past. (Kofinas *et al.*, 2002; Thorpe *et al.*, 2002). Climate change may alter the ideal timing of hunts and if communities continue with traditional hunting times and locations, they may be less successful than in the past.

For the Bathurst Herd, with more years with deep snow in winter, more insects in the summers and fall seasons with later snowfalls, we would expect that fewer caribou would be exposed to the mines during the winter, while more caribou would be exposed to the Ekati–Diavik mining zone in the early summer and to the Lupin–Jericho mining zone during the fall migration. It is unclear whether the distribution within the Ekati–Diavik zone in early summer represents a selection or avoidance strategy. It is possible that caribou avoided the mining zone in years with few insects but were forced into the mining zones when insect levels were elevated. There is also the possibility, however, that the mining zone exhibited characteristics which provided insect relief. If changes in climate cause an increased presence of caribou in the mining sites, monitoring and mitigation measures may need to be intensified.

The analysis presented here is preliminary and will undergo further modification; the intent is to present our methods for understanding caribou–climate–human relationships. To date, our procedure does not account for serial correlation among seasons. For example, there is a correlation between shallow winter snow and late spring melt within the Porcupine caribou annual range, indicating that the spring caribou distributions may be a result of winter snow depths rather than spring melt. Currently, we are also analysing NDVI data to use green-up and snow cover to classify the data during the Bathurst calving and post-calving seasons. Furthermore, we are investigating the possibility of using Snow Water Equivalent data from satellite data to inventory the winter conditions (Derksen *et al.*, 2003), rather than relying on climate data from a single station within the range of the herd.

Due to the limited number of years of data, thirteen years for the Porcupine caribou and eight years for the Bathurst caribou, a dichotomy of environmental conditions was used. A division of the seasonal data into three categories ("normal" years, "good" years, and "bad" years) would have resulted in a loss of statistical power, with too few samples. Thus, some data were separated into opposing classes even though the climatological conditions did not differ greatly. With a long-term set of satellite and climate data, separating the data into normals and extremes may provide a clearer picture of the relationship between caribou distribution and climate.

Another limitation to this approach is the sparse number of collared animals in any given year (8–24 females per year for the Porcupine Herd; 8–17 females per year in the Bathurst Herd). Patterns of caribou distribution ascertained from these satellite locations provide valuable information, in spite of the acknowledged fact that the current number of collars does not capture all movements within the herds. For example, hunters may be able to access caribou even if the satellite locations do not indicate the presence of caribou in a specific zone. Nonetheless, these preliminary results do help to construct testable hypotheses that can be explored with more rigour in the future. One option for exploring the validity of our caribou distribution analysis is to compare our conclusions with the community monitoring data of the Arctic Borderlands Ecological Knowledge Co-operative (Kofinas *et al.*, lecture, 10th NACW). The analysis here also assumes that the climatic condition does not affect hunters' access to caribou hunting grounds. For example, while our analysis may determine that caribou are in closer proximity to a user community during a year of early spring melt, it does not account for the fact that early spring melt may severely restrict river travel by hunters, and thus result in an overall decrease in successful harvesting. This limitation suggests the need to integrate this analysis with more socio-economically sensitive travel-cost models developed for the Porcupine region (Berman *et al.*, 2004).

With further refinement, this methodology will increase our understanding of human–caribou relations. The methodology and assumptions developed here are applicable to other caribou herds as we were easily able to adapt the initial procedures from the Porcupine caribou to the Bathurst Herd. The success of the application depends upon the availability of sufficient years of satellite collar data and the completeness of the climate records for stations within the herd range. We also require knowledge of the herd ecology to designate meaningful seasons. The use of satellite data for NDVI and, potentially, Snow Water Equivalent data may assist in ranges where climate data are incomplete or where climate stations are sparse. To date, we do not have a satellite measure for insect harassment, however, temperature and moisture information are available from satellite data.

Conclusion

This methodology has provided hypotheses for validation as well as insights into the effects of climate change on caribou distribution and the resulting effects on availability of caribou to local communities and the exposure to industrial development sites. The protocol is flexible enough to be expanded to other herds and other human activities. Zones can be created in a GIS to consider roads, railways, forestry, oil and gas activities and infrastructure and ultimately the cumulative effect of all human activities could be analysed. Furthermore, the methodology provides the opportunity for discussion by managers and resource users and for reanalysis when additional data become available.

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