ANNUAL AND SEASONAL DIFFERENCES IN SNOW DEPTH, DENSITY, AND RESISTANCE IN FOUR HABITATS ON SOUTHERN BANKS ISLAND, 1993-1998

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ABSTRACT

Between November 1993 and May 1998 we collected >5200 measurements of snow depth (cm) and resistance (kg • cm), and >1600 measurements of snow density (g • cm^{-2}) from fixed transects in four different habitats on southern Banks Island. Measurements were taken during early (November), mid- (February), and late-winter (April) in areas of low and high muskox density. Snow depth and density increased ($P<0.001$) as winter progressed in all habitats. Resistance peaked in mid-winter and was intermediary in late-winter. Snow depth was greatest in low lying wet sedge meadows and least in windswept stony barrens. Snow density and resistance were greatest in upland barrens and hummock tundra. Snow depth, density, and resistance were lowest ($P<0.05$) in winter 1997-98 than other winters; depth and density were greatest ($P<0.01$) in 1994-95. Snow was deeper in the low muskox density area; the difference in depth between areas increased throughout winter. Snow conditions in 1997-98 were the least severe of the study period.

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INTRODUCTION

Snow conditions greatly influence the availability of winter forage for herbivores, and in northern latitudes the lack of available winter food is a major population limiting factor (Andreyev, 1977; Adamczewski *et al.*, 1988; Sinclair, 1989; Gaillard *et al.*, 1998; Reynolds 1998). Snow depth is often an important factor because not only does it affect availability by the costs of removing the snow cover, but it also can impede basic locomotion which can be a substantial energy drain to the animal (Hobbs, 1989). Snow depth also influences the timing of snow melt which affects spring plant emergence (Klein, 1985; Jefferies *et al.*, 1992; Post and Klein, 1999).

The snow pack is rarely homogenous, especially as winter progresses. Ice layers, or layers of more denser, harder snow form which can further restrict access to forage. Snow density and hardness or resistance of the snow pack may become important factors influencing availability of forage and patterns of snow melt. Caribou will generally not crater through snow layers exceeding 9000 g • cm^{-2} hardness (Thing, 1977), and crater in microsites of lesser hardness than found in general feeding sites (Collins and Smith, 1991). Muskox also feed in sites of lesser hardness (Wilson and Klein, 1991; Raillard, 1992; Schaefer and Messier 1995a).

Studies elsewhere have described snow conditions in relation to the foraging behaviour of caribou and muskox (e.g. Pruitt, 1959; Henshaw, 1968; Lent and Knutson, 1971; Collins and Smith, 1991; Wilson and Klein, 1991; Wilson, 1992; Biddlecomb, 1992; Schaefer and Messier, 1996; Nellemann, 1998). Few studies have been conducted on Arctic Islands (Miller *et al.*, 1982; Raillard, 1992; Ouellet *et al.*, 1993; Schaefer and Messier, 1995a; 1995b; 1996) and these studies have been limited to early and/or late-winter periods. Conditions during mid-winter are unreported. On such islands, wind is a constant factor affecting snow conditions; there are always some areas blown free of snow and other areas drifted in with snow. Snow is much less of an impediment to locomotion. Freezing rains, which produce ground fast ice, can make forage essentially inaccessible and have been associated with overwinter die-offs of caribou on the High Arctic Islands (Miller *et al.*, 1977; Nagy *et al.*, 1996). Although there are weather stations scattered throughout the High Arctic, the majority of those are located in coastal areas. Among other things, they record the daily amount of precipitation. Unfortunately, herbivores are generally not distributed in coastal areas, and the amount of precipitation cannot provide an adequate description of snow conditions faced by herbivores. Descriptions of snow conditions on High Arctic Islands are limited.

Long term data have been collected on the population dynamics of Peary caribou and muskoxen on Banks Island (Nagy *et al.*, 1996; Larter and Nagy, 1999a; 1999b). Severe winter weather has been implicated as one of the major factors in the fluctuation of numbers of both caribou and muskoxen (Parker *et al.*, 1975). As part of a comprehensive range study on Banks Island, we monitored snow conditions in four different habitats over the course of the winter from November 1993 to May 1998. Concomitantly, we measured snow conditions adjacent to feeding craters of Peary caribou and muskox. In this report we provide baseline data on seasonal and annual variation in snow pack conditions faced by foraging herbivores on southern Banks Island. We document changes in snow depth, density, and hardness in four different habitats during early, mid- and late-winter over a 5 winter period. Snow conditions measured at herbivore feeding craters will be reported elsewhere (Larter and Nagy, in review a).

METHODS

Description of Habitats Sampled

Habitat descriptions were adapted from Kevan (1974), Wilkinson *et al.* (1976), and Ferguson (1991). There are 4 major habitats that Peary caribou and muskox forage in during winter: 1) wet sedge meadow (WSM), 2) upland barren (UB), 3) hummock tundra (HT), and 4) stony barren (SB), which cumulatively represent *ca.* 67% of the available habitat on Banks Island (N. Larter and J. Nagy, unpubl. data). WSM are generally level hydric and hygric lowlands characterized by *Carex aquatilis*, *Eriophorum scheuchzeri*, and *Dupontia fisheri*. UB are well drained sites found on the upper and middle parts of slopes. Vegetation is dominated by *Dryas integrifolia* and *Salix arctica*. HT is found on moderately steep slopes and is characterized by individual hummocks that are vegetated primarily by dwarf shrubs (*D. integrifolia*, *S. arctica*, and *Cassiope tetragona*). SB have a coarse gravelly substrate and are sparsely vegetated. This habitat is found on wind blown areas, ridges, and gravel and sand bars.

Snow Measurements

Fixed transects were located in each of the four habitats (WSM, UB, HT, SB) located in two different areas representing high (*ca.* 1.6-1.9 muskoxen/km^2; Camp Coyote) and low (*ca.* 0.3-0.4 muskoxen/km^2; Camp Bernard) muskox density (Figure 1). These sites had been identified as being representative during field work in June/July 1993. Ten stations were located along these transects. Snow conditions were measured at each station in early (26 October - 18 November), mid- (12-28 February), and late- (20 April - 4 May) winter from November 1993 to May 1998. At each station we took five measures of snow depth (to the nearest 0.5 cm) and hardness using a Rammsonde penetrometer (Geotest Instrument Corp., 1970; Raillard, 1992; Larter and Nagy, 1994), and two snow cores, using an Adirondack snow tube, to estimate snow density.

Snow hardness was determined by recording the number of times it took a 1 kg weight, dropped from a height of 30 cm, to force the head of the penetrometer to break through the snow pack and reach the substrate. Following Ager (1965), we derived resistance to penetration, *H(r)* (kg • cm), of the snow cover. Density was determined by placing the snow core in a preweighed plastic bag and weighing it with a Pesola spring scale.

During winter 1993-94, we were unable to measure snow density; snow depth and hardness were measured in early- and late-winter only. In February 1995 sampling at Camp Bernard was reduced to 30 measures with the penetrometer and 10 snow core samples/habitat from the ususal 50 measures and 20 samples, respectively. We recorded ambient temperature for each sampling period and calculated mean ambient temperature for early, mid-, and late-winter periods.

Occasionally there would be very little or no snow cover at a station. This occurred more often in SB throughout the study and during winter 1997-98. This did not present a problem for measuring snow depth or hardness with the penetrometer. Depth could be measured to the nearest 0.5 cm. A hardness recording of 0 was given whenever there was no snow or the snow pack was such that it could not support the weight of the penetrometer. Snow cores of ≤ 2 cm could not be weighed accurately, therefore we were often unable to get two snow cores from each station in SB habitat. We realize that this may bias snow density estimates for this habitat on the high side. We entered a value of 0.0 density only when ≥ 3 of the five penetrometer measures indicated snow depth at ≤ 1.0 cm. In these instances snow was not hard and would not prevent either caribou or muskoxen from digging through it (pers. obs.).

Fresh ground fast ice was present over the entire sampling area of SB at site 1 in November 1993. Because the penetrometer could not penetrate this ice we entered a value of 299 hits for the analysis.

Limited snow measurements were taken during field work in late-March (21st-27th) and mid-May (17th) 1993. Ten snow core samples were taken in WSM and five in UB during March; ten snow core samples were taken in WSM during May. These data were used for comparisons only.

Statistical Analysis

Snow depth and snow pack resistance were based exclusively upon measures with the penetrometer. Snow density was based exclusively upon snow cores samples. We used an unbalanced ANOVA design (proc GLM SAS 6.11 for Windows, SAS Institute Inc., 1995) to test for the effects of sampling time, habitat, sampling site, year, and site*time on snow depth, snow density, and snow pack resistance. We used the Scheffé multiple comparisons test to isolate significant ($P<0.05$) effects (proc GLM SAS 6.11 for Windows, SAS Institute Inc., 1995). Because a severe icing event in winter 1993-94 greatly affected the resistance in one habitat at one sampling site, we treated this as an outlier (Figure 2; Larter and Nagy, 1994) and reran the ANOVA deleting all resistance data for the 1993-94 sampling period.

RESULTS

Mean ambient temperatures varied annually, being lowest in mid-winter and highest in late-winter (Table 1).

Snow depth varied ($P<0.001$) by sampling time, habitat, year, and site and had a significant sampling time*site interaction. Snow depth: 1) increased ($P<0.05$) throughout winter, 2) was deepest ($P<0.05$) in WSM, followed by HT, UB, and SB, 3) was shallowest ($P<0.05$) in 1997-98 and greatest ($P<0.05$) in 1994-95, 4) was greatest ($P<0.05$) in the low density muskox area, and 5) became increasingly different ($P<0.05$) between low and high density muskox areas as winter progressed (Figures 3 and 4).

Snow density varied by sampling time, habitat, and year ($P<0.001$). Snow density: 1) increased ($P<0.05$) throughout winter, 2) was greatest ($P<0.05$) in UB and HT, 3) was lowest ($P<0.05$) in winter 1997-98, and 4) was greatest ($P<0.05$) in 1994-95 and 1995-96 (Figure 5).

Snow pack resistance varied by sampling time, habitat, and year ($P<0.001$). Resistance: 1) peaked ($P<0.05$) in mid-winter, 2) was intermediary ($P<0.05$) in late-winter, 3) was greatest ($P<0.05$) in UB and HT, and 4) was lowest ($P<0.05$) in winter 1997-98 (Figure 2).

Snow depth (mean ±SE) was estimated at 48.2 ± 5.3 cm and 30.0 ± 4.5 cm for WSM and UB respectively, from limited sampling in March 1993. These depths were similar to the greatest depths recorded during late-winter in UB (winter 1994-95) and greater than any late-winter depths recorded in WSM (Figure 3).

Snow density (mean ±SE) was estimated at $0.396\pm0.012\ g \cdot cm^{-3}$ and $0.401\pm0.017\ g \cdot cm^{-3}$ for WSM and UB respectively, from limited sampling in March 1993. These densities were greater than any late-winter densities recorded in either WSM or UB during the following 5 winters (Figure

5).

Snow depth and density in WSM were estimated at 17.3 ± 1.7 cm, and 0.423 ± 0.014 $g \cdot cm^{-3}$ respectively in May 1993. The depth was comparable to early-winter snow depths in WSM while snow density was the greatest measured for any habitat (Figures 3 and 5).

DISCUSSION

Snow conditions during the 5 winter periods showed consistent seasonal variation within years even though there was distinct variation between years: a 2.7-fold range in mean snow depth (Figure 3), a 1.4 fold range in mean snow density (Figure 5), and a 3.3 fold range in mean snow resistance (Figure 2) within any one habitat. During winter 1997-98, snow conditions were the least severe. During winter 1994-95, snow was deeper, denser, and generally more resistant than other winters. The only exception was greater snow resistance in SB during November 1993 as a result of localized ground fast ice. The limited measurements collected during winter 1992-93 imply that late-winter snow conditions were more severe than any recorded during the following 5 winters.

Not surprisingly, snow was deeper in the relatively flat, low-lying WSM where it could accumulate, and shallowest on the windswept SB. Snow depth increased throughout winter in all habitats except SB (Figure 3). Interestingly, snow was deeper and accumulated more throughout winter in the low density muskox area (Figure 4). There was little difference in elevation between sampling sites in the two areas; 180-200 m in the high density versus 220-240 m in the low density area. The low density area is located to the east of Big River where watercourses tend to run in a N to S direction. To the west of Big River watercourses generally run in a NW to SE direction. Possibly the prevailing winds cause snow to accumulate more in the low density area. Snow cover remains longer in the low density area on a consistent basis (pers. obs.), which is likely related to increased depths, especially in late-winter. Lower muskox densities in this area may be related to differences in snow conditions between areas although forage and habitat distribution may play a role in density differences.

Although snow density was greatest in UB and HT habitats and tended to increase throughout winter, density generally ranged from 0.2-0.3 gm • cm^{-3}. Whether or not the statistical differences in snow density alone have any biological significance is debatable. Density would be expected to be greatest in late-winter as higher ambient temperatures (Table 1) and constant daylight would cause compaction and a higher water content of the snow pack.

Snow resistance was highest during mid-winter even though snow depth and density continued to increase from mid- to late-winter. The mid-winter peak was most noticeable during 1994-95 when snow depth and density was greatest (Figure 2). A decrease in resistance from mid- to late-winter is likely temperature related. Raillard (1992) found a significant positive relationship between ambient temperature and the number of blows it took for a Rammsonde penetrometer to penetrate the snow pack. The same snow pack was easier to penetrate as temperature increased. Ambient temperature during mid-winter is much lower than during late-winter (Table 1).

Given the pattern of increasing snow depth and density throughout winter, and snow resistance peaking during mid-winter, it is quite possible that forage availability is most restricted by snow conditions during mid-winter. Other studies on the winter feeding ecology of muskoxen and caribou on arctic islands have focussed on early and late-winter/spring periods (Raillard, 1992; Ouellet *et al.*, 1993; Schaefer and Messier, 1995a; 1995b; 1996), possibly missing an important period in their winter feeding ecology.

Snow conditions in WSM reported on other High Arctic Islands are comparable to or less severe than those we report from Banks Island from 1993-94 to 1997-98. Muc (1977) reported snow density of 0.26 gm • cm^{-3} at Truelove Lowland on Devon Island during May, comparable to our late-winter levels. Raillard (1992) reported 2.5-5.5 blows were required to penetrate a mean snow depth of *ca.* 18 cm in May at Sverdrup Pass, Ellesmere Island. We required 6.2-17.7 blows to penetrate

15.2-41.1 cm of snow during late-winter on Banks Island. Schaefer and Messier (1995a) reported mean snow depth ranged from 11.5-16.1 cm during early winter and from 18.3-21.8 cm during late-winter for areas predominantly, but not exclusively, WSM habitat near Wellington Bay, Victoria Island.

Miller *et al.* (1982) reported snow conditions of upland habitats from predominantly coastal areas of Prince of Wales and Somerset Islands during late-winter prior to melting. Mean snow depth was 25.3 cm on Prince of Wales and 29.7 cm on Somerset Island. Mean snow depth in UB and HT habitats on Banks Island during late-winter were fairly similar, ranging from 7.1-30.4 and 12.7-41.2 cm, respectively.

Has the range in snow conditions that we report from March 1993 to May 1998 had an impact on herbivore condition or demography? Based upon metabolites found in muskoxen urine, animals were more stressed during the severe icing winter of 1993-94 than during winter 1995-96. However, winter conditions had not been such that animals had suffered from prolonged nutritional deprivation (Larter and Nagy, accepted). Similarly for Peary caribou, metabolites in the urine did not indicate that animals had been subjected to prolonged nutritional deprivation (Larter and Nagy, 2000). The lowest overwinter survival of muskoxen calves during the study period was in winter 1994-95; the following summer saw the lowest calf production (Table 2). Snow depth, density, and resistance in WSM was highest in winter 1994-95 indicating that snow conditions may have been a factor limiting muskox calf production and overwinter survival during that year. Alternatively, muskox density on Banks Island peaked in summer 1994; animal density could also have been a factor limiting production and overwinter survival (Larter and Nagy, in review b). Calf production for Peary caribou was lowest following winter 1993-94 when severe icing affected SB and a large area of the traditional caribou wintering grounds (Larter and Nagy, 1994). Production was highest following winter 1997-98 when snow conditions in the upland habitats were least severe. Whether increased production resulted in increased recruitment is unknown. Overwinter survival did not have any relationship with snow conditions during the study period (Table 2). Based upon these data and the lack of any overwinter die-offs reported during the study period, it would appear that we have not reported any extraordinary snow conditions that could lead to starvation of animals at their current numbers.

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Table 1. Mean ambient temperature (°C) during the early, mid-, and late-winter sampling periods for each of the 5 winters and the 1993 sampling period.

	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98
Early Winter		-25	-17	-25	-17	-18
Mid-Winter			-40	-31	-30	-41
Late-Winter		-22	-4	-21	-12	-18
March	-24					
May	-4					

Table 2. Overwinter survival (%) estimates and calf production (calves per 100 adult females) for muskoxen (in high density muskox areas) and Peary caribou on Banks Island from 1992-93 to 1997-98 (adapted from Larter and Nagy, 1999a; 1999b).

	Muskoxen		Peary Caribou	
Year	Survival	Production	Survival	Production
1992-93	95	33.3	62	41.9
1993-94	63	38.9	86	23.3
1994-95	30	31.3	n/a	53.3
1995-96	44	56.3	62	66.7
1996-97	38	38.1	40	43.5
1997-98	65	47.2	53	74.3

Figure 1. Banks Island with the study sites and Big River indicated; Coyote Camp high density muskox area and Bernard Camp low density muskox area.

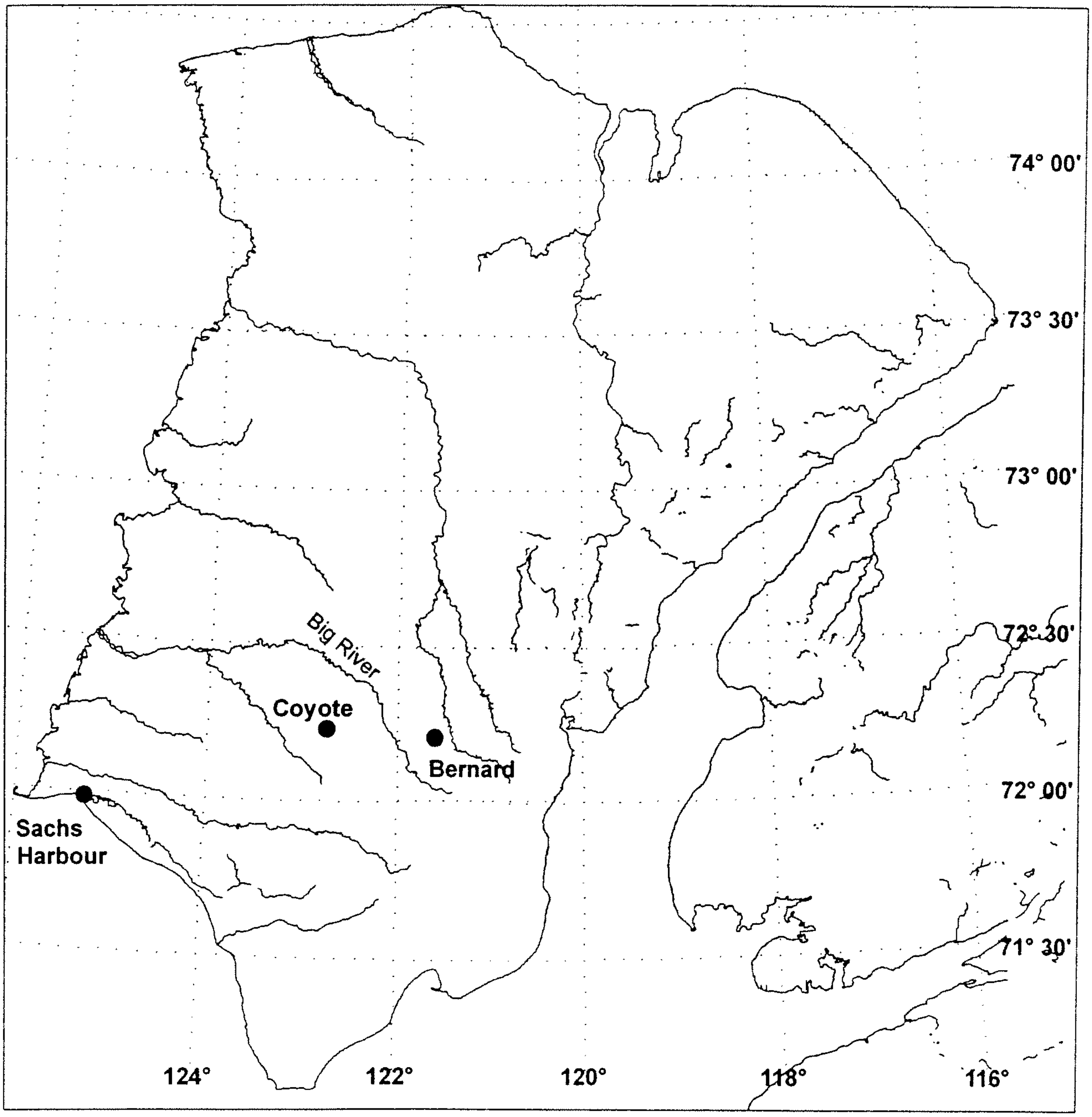

Figure 2. Snow pack resistance (kg • cm) in four habitats for 1993/94 to 1997/98. Note different y-axis scale for 1993-94.

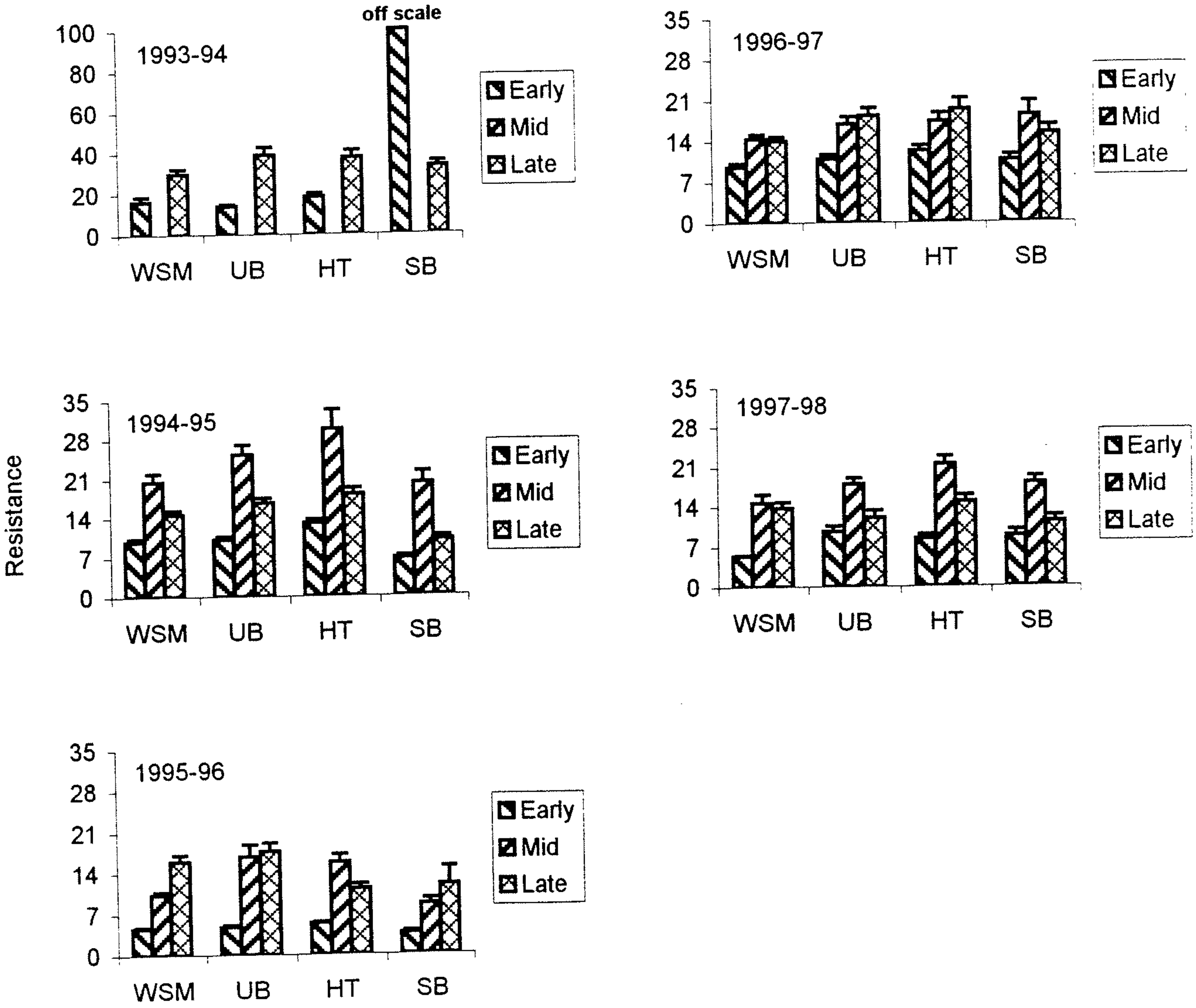

Figure 3. Snow depth (cm) in four habitats from 1993/94 to 1997/98, and for March and May 1993 in two habitats. Note different y-axis scale for 1993 data.

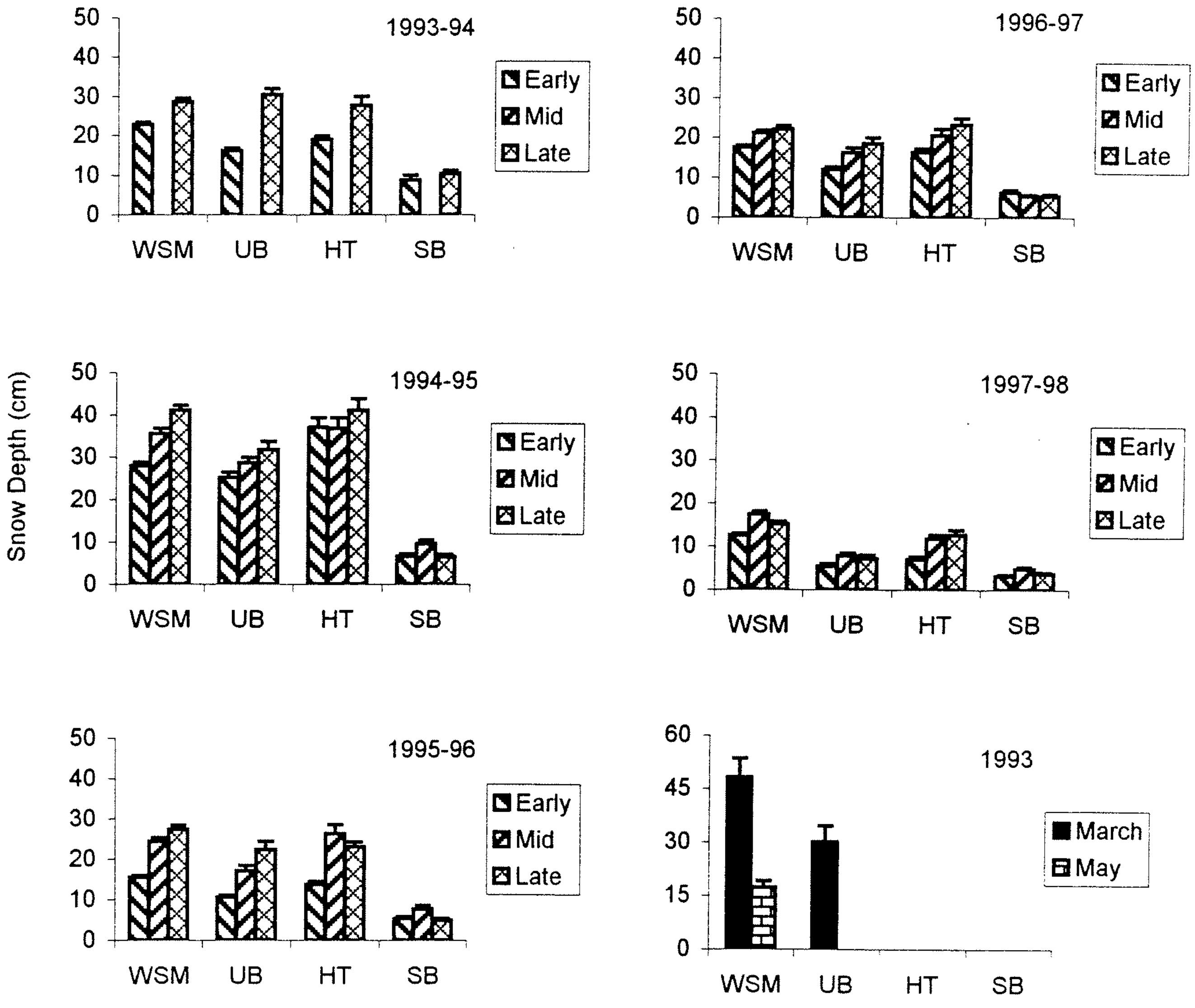

Figure 4. Overwinter changes in mean snow depth (cm), pooled over years, between areas of high and low muskox density (site 1 and 2 respectively).

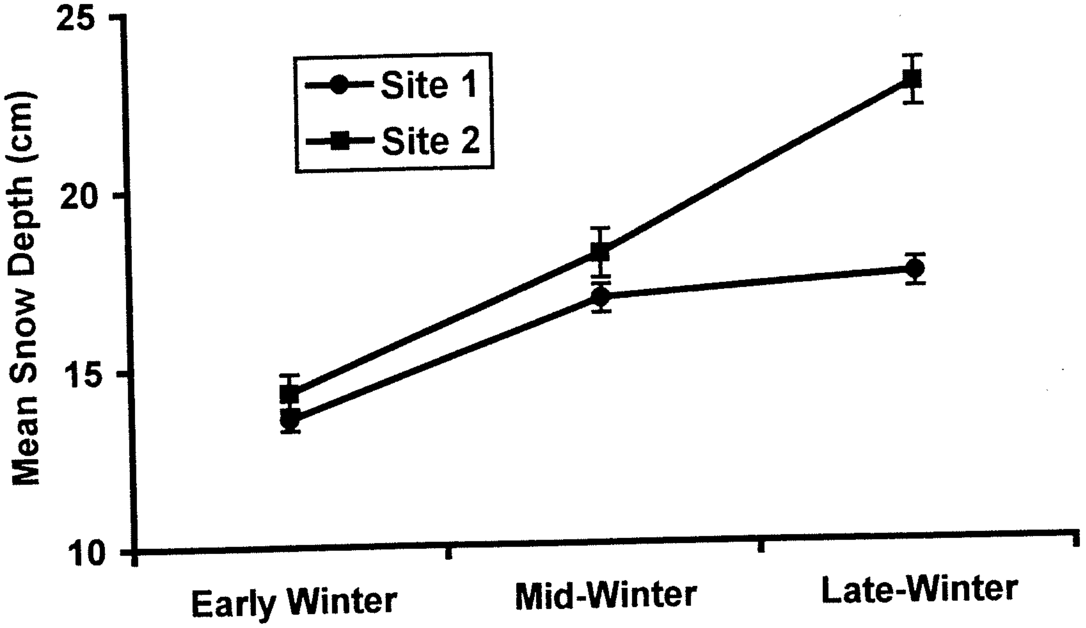

Figure 5. Snow density (gm • cm^{-3}) in four habitats from 1993/94 to 1997/98, and for March and May 1993 in two habitats.