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Effects of Wind-Hardened Snow on Foraging by Reindeer (*Rangifer tarandus*)

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ABSTRACT. Various methods were investigated for assessing the relationships between wind-hardened snow (*upsik*) and forage availability to reindeer. Mean bottom area of individual craters was not a function of depth, hardness or integrated hardness. Individual crater area was partially dependent on specific cratering time (r^2 = .60). Cratering time per active period increased with integrated snow hardness (r^2 = .88). Number of craters and total area cratered increased with decreasing site hardness. Reindeer always cratered microsites of lesser depth and hardness than found in the general feeding site. A threefold decrease in snow hardness resulted in a fourfold increase in forage availability.

Key words: *Rangifer*, snow hardness, snow depth, forage availability

RÉSUMÉ. On a examiné diverses méthodes pour évaluer les rapports entre la neige durcie par le vent (upsik) et l'accessibilité des rennes aux plantes fourragères. La superficie moyenne du fond des trous creusés individuellement n'était pas fonction de la profondeur, de la dureté ou de la dureté intégrée. La superficie des creux individuels dépendait en partie du temps de creusement spécifique (r^2 = 0,60). Le temps de creusement par période active augmentait avec la dureté intégrée de la neige (r^2 = 0,88). Le nombre de creux et la superficie totale creusée augmentaient quand la dureté du site diminuait. Les rennes creusaient toujours des micro-sites de profondeur et de dureté inférieures à celles trouvées sur le site d'alimentation général. Une neige trois fois moins dure quadruplait l'accessibilité aux plantes fourragères.

Mots clés: *Rangifer*, dureté de la neige, profondeur de la neige, accessibilité aux plantes fourragères

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INTRODUCTION

Snow can be a significant barrier to foraging by reindeer, particularly in tundra regions, where strong winds deposit and consolidate snow into hard layers. Andreyev (1977) reported relative forage abundance to vary from as much as 100% availability in early winter, when snow is shallow and/or soft, to 60% in mid-winter, and eventually to 10% in late winter, when snows are deeper and/or wind hardened and possibly ice covered. Estimation of winter range carrying capacity for *Rangifer* must consider the animal's ability to excavate craters, the size and number of craters that can be developed per feeding period and the amount of forage obtainable per crater (Pruitt, 1959; Miller, 1976).

Bergerud (1974b) stated that snow type is a function of topography as it alters wind speed and the movement of snow particles. Pruitt (1966, 1984) and Brooks and Collins (1984) also observed that distribution, thickness and duration of wind-deposited snow are closely correlated to the type (structure) of tundra plant communities. Brooks and Collins (1984) reported that different snow covers (distinguishable by hardnesses and depths) were consistently associated with specific vegetation types. They proposed that if forage availability could be related to type of snow cover, it would be possible to develop a snow cover classification system by which vegetation types could be characterized as to their winter values for livestock and wildlife. Thus, our objective was to assess possible relationships between characteristics of wind-hardened snow and *Rangifer* foraging success. Terminology (from Inuit and Lappish languages) recommended by Pruitt (1979) for the precise identification of snow- and ice-related phenomena are included in parentheses.

METHODS

Free-ranging reindeer, which are only occasionally herded in spring, were observed cratering/feeding in coastal hills and mountains of south-central Seward Peninsula, Alaska (Fig. 1) during March 1985 and February 1986. Tussock tundra, lichen meadow, sedge wet meadow and tall shrub vegetation (Swanson *et al.*, 1985) dominated the study area. All of these vegetation types were treeless, with snow covers developed under strong winds and occasional mid-winter thaws.

Development of 49 individual craters was observed from approximately 100 m by means of a spotting scope. Number of leg strokes, total cratering time (actual time spent striking snow with hooves) and total feeding time for the completion of individual craters were recorded. Depths and areas of tops and bottoms of craters were measured after reindeer abandoned them. Integrated Rammsonde hardnesses (Benson, 1962) of undisturbed snow profiles were measured 15 cm from craters. Rammsonde hardness (kg-f cm) represents the work required to push a cone-shaped penetrometer through a depth interval of snow. An integrated value represents the summation of all the hardnesses measured as it passes through to the bottom of the snowpack. Most wind-hardened, tundra snowpacks are too shallow and hard to be measured using a spring penetrometer but may be effectively sampled using a Rammsonde penetrometer (Skogland, 1978).

The activities of 20 reindeer (randomly identified within a herd of approximately 400) were scan sampled (Altmann, 1974) every 15 min for three 96 h periods (Collins and Smith, 1989). Percentage of active period used for cratering was determined for the duration of their stay at specific feeding sites. Nighttime observations were made with the aid of a starlight scope.

Cratering intensity in the general feeding site was determined from a series of 4 × 50 m belt transects. The number of feeding craters within the belts was used as an index to total area cratered. Fifty craters were randomly selected within each site and measured to determine mean depth, length and width at top and bottom. Transects were randomly probed to determine average snow depth for each site. Presence or absence of wind slab or drifts characteristically rejected for cratering were noted at every 50th pace in order to estimate the "percent of site usable." The unused

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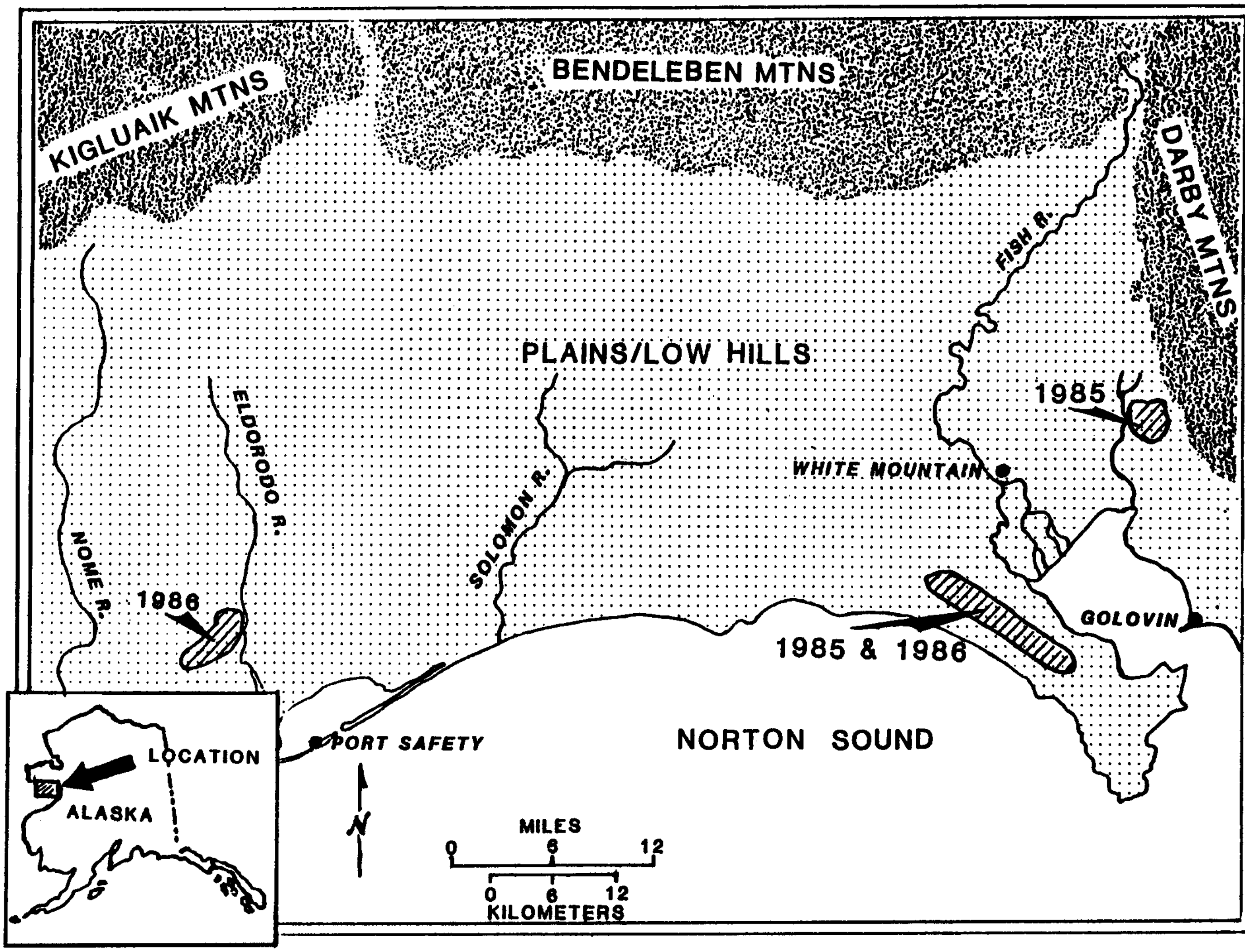

FIG. 1. Location of study sites on Seward Peninsula, Alaska, 1985 and 1986.

snow microsites were consistently rejected by reindeer for the duration of their stay in those feeding areas.

Mean site hardness was determined from a minimum of 30 Rammsonde penetrations between craters. A revised site hardness was also determined, to account for the tendency of some snowpacks to fracture with less force near crater edges. The revised values were calculated by multiplying site integrated hardness by the ratio of hardness 7.5 cm from the crater's edge to hardness ≥ 15 cm from the edge. A ratio of these distances was used, because wind-hardened snow (*upsik*) typically fractured into large pieces when stuck by a hoof ≤ 7.5 cm (three-quarters of a hoof length) from a crater's edge but did not fracture at ≥ 15 cm from the edge.

RESULTS AND DISCUSSION

Cratering Behavior

Typical cratering activity was preceded by a reindeer walking with its nose near the snow surface, then stopping and moving its muzzle closer to or against the snow. Presumably, the latter behavior was associated with the animal sniffing for forage (Bergerud, 1974a; Helle, 1984) and/or sensing snow hardness (Pruitt, 1979). The reindeer would then begin striking/stroking the snow with a forefoot.

Craters were developed in an oblong pattern (Table 1) oriented lengthwise with direction of the leg stroke. Size of crater at the snow surface appeared to be dependent on the forward and lateral reach of the animal's foreleg; after these limits were reached, the animal would reposition itself and begin a new crater, albeit sometimes in close proximity with a previous crater. Occasionally, these craters would break into one another, or dividing boundaries would be obscured by trampling and/or excavated snow. Sometimes, craters would

TABLE 1. Snow variables from 49 cratering bouts measured in 1985

Variable	Mean	Standard Deviation
Leg strokes[1]	42.0	43.4
Time at crater (sec)[2]	113.0	119.0
Cratering time (sec)	21.8	21.3
Crater length (cm)[3]	48.6	30.9
Crater width (cm)[3]	32.0	14.1
Crater depth (cm)[4]	14.3	7.2
Integrated hardness (kg-f cm)[5]	421.0	316.0

[1]Number of strokes during entire cratering bout.
[2]Measured from onset of cratering to abandonment of crater.
[3]Measured at top of crater.
[4]Measured at point estimated to be mean depth.
[5]Measured using Rammsonde penetrometer approximately 15 cm from rim of crater.

be abandoned before reaching full dimensions, either as extremely hard snow was encountered at the leading edge or as patches of unpalatable forages (e.g., mosses) were uncovered.

The reindeer often displaced one another from craters in rapid succession, making it difficult to observe complete development of a crater by an individual animal. Often, six or more deer were observed feeding from the same crater within a period of 5 minutes, each successive deer displacing the previous one. This behavior greatly limited the number of successful observations of craters actually being developed. Furthermore, to ensure that exact measurements could be made of the crater, it was measured soon after its completion and abandonment. This caused the herd to withdraw from adjacent new craters back to core feeding areas, where most snow had already been disturbed. Thus, few distinct new craters would be dug during the remainder of that feeding bout, and it was not uncommon for the observer to measure only three craters during an entire 4-6 h feeding bout.

While cratering, reindeer consistently struck/stroked the snow at a rate of 2.0 leg movements per second, irrespective of snow condition or type of leg motion. Thing (1977) and Fancy (1985) observed the same rate among caribou.

Individual Crater Area

Mean bottom area of individual craters was not a function of depth (cm), hardness (kg-f) or integrated hardness (kg-f cm): $r^2 = .05$. In contrast, Helle (1981) found that craters were small in shallow snow and increased in size with snow depth, but he studied deeper and/or softer snowpacks than we did. Helle (1984) reported that in soft, deep snow reindeer may continue to expand craters over periods of several days or even weeks. In our study, individual craters sometimes became obscured by trampling and the excavation of adjacent craters, thereby producing what could be considered just one crater, but which in fact was a cluster of smaller individual craters (*suovdnji*). In most cases, disturbed snow surrounding craters recrystallized and greatly increased in hardness within 12 h of initial cratering, thereby effectively precluding further enlargement of the crater.

Area of individual crater bottom exposed per cratering bout was weakly correlated to total cratering time ($r^2 = .60$; Fig. 2) and number of leg strokes during the bout ($r^2 = .51$; Fig. 3). These weak correlations may have resulted because harder snow is not necessarily more difficult for the reindeer to excavate. Wind-hardened snow (*upsik*) fractured into relatively large slab-like pieces, which could be swept out of the crater by a single leg stroke. By comparison, fresh, unconsolidated snow and old, recrystallized snow (*pulak*) were more difficult to stroke clear of the crater. Wind-hardened snow, if struck within 7.5 cm of crater edges, usually fractured into large pieces with only one-fourth to one-third the force required for penetration in undisturbed snow. Thus, aside from initial penetration, excavation costs do not necessarily reflect greater snow hardness.

Reindeer utilized short, chopping leg strokes to break through hard, crusted snow (*upsik*) or ice layers (*sigulik*). A sweeping motion was used to excavate softer snow or to remove pieces of hard snow from craters. Thing (1977) observed the same two behaviors among caribou. Hence, a strong correlation between number of strokes and area cratered would not be expected unless accounting for snow conditions and type of leg movement.

Cratering Time

Cratering time per active period increased with increasing integrated snow hardness ($r^2 = .88$; Table 2; Fig. 4). Increased cratering time was at the expense of bedding time, whereas

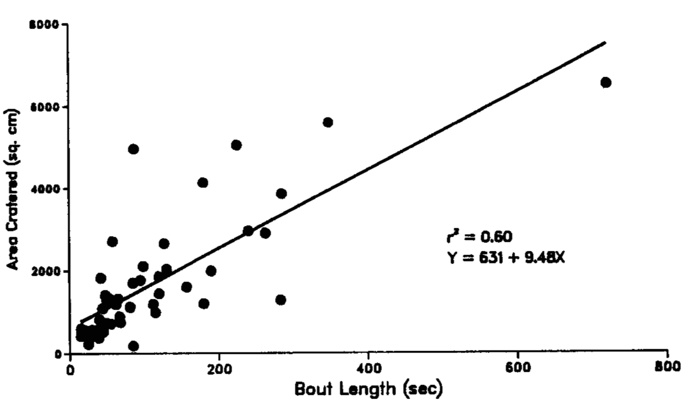

FIG. 2 Area cratered relative to cratering bout length.

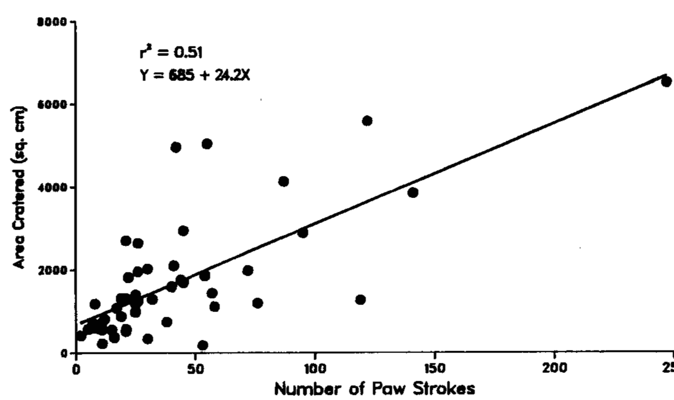

FIG. 3. Cratered area relative to number of leg strokes.

TABLE 2. Reindeer behavior on snow sites of varying hardness (percentages are based on 1920 observations per site)

	Snow site Rammsonde values (kg-f cm)							Correlation
Behaviour	164	282	391	456	750	981	1098	coefficient[1] (r^2)
% feeding[2]	53	52	52	42	43	52	52	0
% lying	41	40	37	38	25	30	35	.36
% standing	5	4	2	6	18	8	3	0
% walking	0.7	0.6	2	2	3	4	4	.94
% trotting	0	0	0.2	0.3	1.7	0.2	0	0
% cratering	nd	6	6	8	12	14	17	.97

[1]Correlation coefficients are derived from linear regression and are adjusted for degrees of freedom.
[2]This value does not include cratering time.

feeding time remained relatively constant across all snow types (Table 2). Time spent walking also increased with hardness, apparently in response to increased searching for less prohibitive feeding sites. In some cases, aggressive interactions involved in competition for craters may also have contributed to increased walking or standing (Helle, 1984).

Number of Craters per Feeding Site

Number of craters per feeding site increased with decreasing site hardness (r^2 = .47) and revised site hardness (Rr^2 = .56) (Table 3). Likewise, total area cratered was positively correlated with decreasing site hardness (r^2 = .52, Rr^2 = .63; Fig. 5). However, linearity of this relationship may be partially dependent on the size of herd doing the cratering. Exclusion of data from sites 5-86 and 6-86, which were grazed by approximately 3000 reindeer (compared with approximately 400 animals at the other sites) resulted in a stronger correlation (r^2 = .77). Displacement of reindeer from craters by one another is relatively more frequent in larger herds. Yet, regardless of herd size, decreasing snow hardness does stimulate greater cratering of a given site.

Selection of Feeding Microsites

Snow hardness, snow depth and animal mobility are factors affecting *Rangifer* selection of feeding microsites. In tundra regions, *Rangifer* generally will not crater through snow layers exceeding 9000 g/cm^2 hardness (Canadian Hardness Gauge) (Thing, 1977). We estimated that a 2½ cm layer of snow having a Canadian Hardness value of 9000 g/cm^2 would have a Rammsonde hardness of 105 kg-f cm (Benson and Bader, 1953). Using this value, we estimated that as much as 90% of some feeding sites were too hard for cratering (Table 3). This may be why most sites had less coverage by craters than those reported for softer snow conditions (Helle [1981], 22% and Sablina [1962], 18%, cited by Helle [1981]). Ability by *Rangifer* to detect forage through snow cover may also be relevant to snow depth and density relationships, but these were not addressed in our study.

None of the feeding sites was too deep for cratering, yet the reindeer always cratered microsites having lesser mean depth than the general feeding sites ($p < .001$; Table 4; Fig. 6). LaPerriere and Lent (1977) and Helle (1981) also reported that *Rangifer* consistently select the shallowest snow cover within feeding sites. Mobility was not a factor affecting preference for shallow snow, since most snow fully supported the reindeer, and all snow, soft or hard, was typically one quarter of the 60-70 cm depth considered restrictive to *Rangifer* movement (Thing, 1977).

Fancy (1985) concluded that caribou select shallow snow sites in order to reduce the costs of cratering. Later, he (Fancy, 1986) reported a computer-simulated energy budget for caribou demonstrating that a 10% increase in daily costs of cratering activity resulted in less than a -0.3% change in the animal's daily energy balance and that a 10% increase in dry matter intake resulted in a +61% change in daily energy balance. A 10% difference in dry matter intakes between feeding sites is readily possible where differences in vegetation

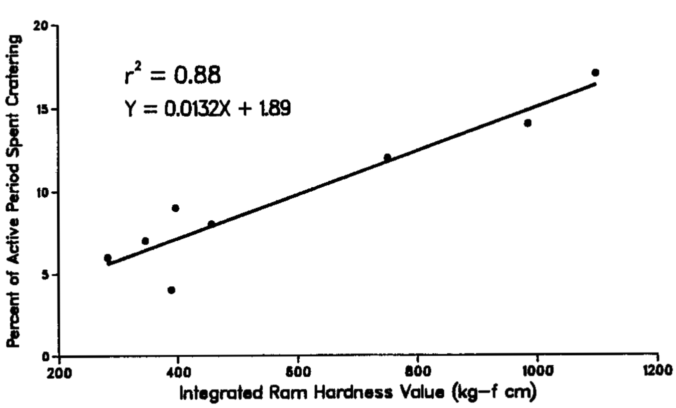

FIG. 4. Cratering time relative to variations in snow integrated hardness.

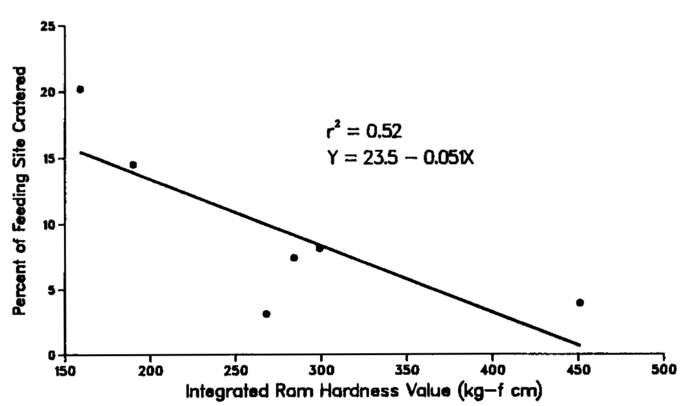

FIG. 5. Percent area of feeding site cratered relative to integrated hardness of snow.

TABLE 3. Snow cover, crater characteristics and forage exposed at different feeding sites

Site	1-86	2-86	3-86	4-86	5-86	6-86
No. of transects	30	29	30	30	30	27
Mean site hardness (kg-f cm)[1]	451	284	190	159	299	268
Fracturability index[2]	0.23	0.24	0.31	0.29	0.34	nd
Revised site hardness[3]	103	67	58	46	102	nd
No. of craters[4]	568	1016	1144	2350	1740	646
No. of craters·ha^{-1}	947	1752	1907	3917	2900	1196
Mean crater depth (cm)	18.8	15.5	15.9	14.2	12.4	10.9
Mean crater area (m^2)	0.41	0.42	0.76	0.51	0.28	0.26
Surface coverage by craters (%)[5]	3.9	7.4	14.5	20.2	8.1	3.1
Vegetation exposed (%)[6]	2.2	5.2	5.7	8.5	6.4	2.3

[1]Integrated hardness, measured using a Rammsonde penetrometer. Minimum sample size was 30.
[2](Integrated hardness at 7.5 cm from crater edge) × (integrated hardness ≥ 15 cm from crater edge)$^{-1}$.
[3](Fracturability index) × (mean site hardness).
[4]Total number of craters in all transects.
[5](Mean surface area of craters × number of craters) × (area censused)$^{-1}$ × 100.
[6](Mean bottom area of craters × number of craters) × (area censused)$^{-1}$ × 100.

availability are of the magnitude we observed. For example, a threefold decrease in integrated hardness (450-159 kg-f cm) resulted in a fourfold increase in vegetation availability to reindeer (2.2-8.5%) (Table 3). Consequently, we believe that forage availability rather than energy expenditure should be the primary consideration in evaluating the limits of wind-hardened snow to *Rangifer* foraging success.

MANAGEMENT IMPLICATIONS

Snow not only imposes site-specific limitations on forage availability, but we and others (Helle, 1984; Helle and Tarvainen, 1984) have observed that annual patterns of snow distribution often result in significantly reduced forage biomass at those sites most easily and repeatedly accessed by *Rangifer*. Consequently, portions of tundra pastures are highly susceptible to overgrazing in winter if reindeer are regularly allowed to select their own feeding sites. Furthermore, under the absence of herding, as is typical in Alaska, valuable late-winter pasture is utilized in early or mid-winter when other accessible but less preferred pasture is still free of inhibitory snow conditions. By the time late winter arrives the reindeer have no choice but to graze "less preferred" sites, which by then have developed severely restrictive snow covers.

Considering the constancy of relationships between vegetation, topography and snow in tundra sites, it should be possible to predict site-specific availability of forage as influenced by snow cover. Incorporation of this information into grazing plans would result in better distribution of grazing, favoring improved health and productivity of both reindeer and range.

Of the several behavioral and physical indicators of forage availability and use examined in this study, number of craters, total area cratered per individual per unit time and integrated snow hardness were most useful. These measures should be applied by reindeer herders and land managers in assessment of winter range values and in development of grazing plans. Successful application of grazing plans in Alaska will require greatly improved skills and commitment by reindeer herders (Collins, 1986). Emphasis on proper grazing distribution and forage utilization will pay additional dividends by placing the herder in regular contact with his animals. This will increase reindeer tractability, reduce stress, allow earlier attention to health problems, reduce predation and facilitate identification of animals exhibiting desired behaviors and reproductive performance.

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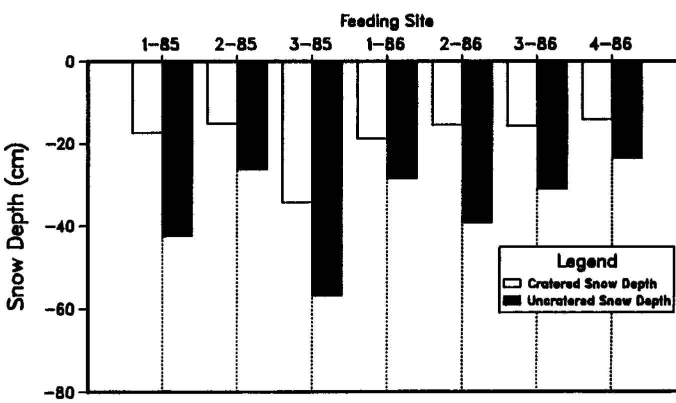

FIG. 6. Relationship of mean crater depth to mean depth of uncratered snow at specific feeding sites.

TABLE 4. Crater depth versus uncratered snow depth within feeding sites[1]

Site	n	Craters (mean depth)	s.d.	n	Uncratered snow (mean depth)	s.d.	Level of significance[2]
1-85	50	17.5	4.1	50	42.5	7.4	$p = 0$
2-85	50	15.2	4.0	50	26.4	6.4	$p = 0$
3-85	50	34.5	7.7	50	57.0	12.8	$p = 0$
2-86	50	18.8	5.2	50	28.6	8.7	$p < .001$
3-86	50	15.5	3.9	50	39.3	26.8	$p < .001$
4-86	50	14.2	2.9	50	23.7	7.0	$p = .001$

[1]Craters were randomly selected within the feeding site. Depths of uncratered snow were determined from randomly selected points along transects through feeding sites.
[2]Level of significance was determined by a standard t-test.

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