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Effect of Muskox Carcasses on Nitrogen Concentration in Tundra Vegetation

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ABSTRACT. We observed a steep gradient of nitrogen concentration in plants growing around carcasses of four adult muskoxen that had been lying for five or more years on the tundra in the Canadian Arctic. The gradient reached an asymptote at 2 m distance from the carcasses. The carbon-to-nitrogen ratio increased significantly from 1 to 3 m and then stabilized. These results suggest that the effects of carcasses last for several years on the tundra and create nitrogen-rich plant growth in their immediate surroundings. The lush growth around the carcasses in otherwise grazed areas indicated a low level of grazing on the fertilized plants.

Key words: nitrogen, carcass, muskox, *Ovibos moschatus*, vascular plants, mosses, tundra, Canada

RÉSUMÉ. Nous avons observé un fort gradient de concentration en azote dans les plantes poussant autour de 4 carcasses de bœufs musqués gisant depuis 5 ans ou plus dans la toundra de l'Arctique canadien. Le gradient atteignait une asymptote à 2 m des carcasses. Le rapport carbone/azote augmentait de façon significative de 1 à 3 m, puis se stabilisait. Nos résultats suggèrent que les carcasses créent dans la toundra des micro-communautés de plantes riches en azote dans leur environnement immédiat et que cet effet dure plusieurs années. L'abondance de végétation autour des carcasses, dans des endroits autrement broutés, révélait que les herbivores utilisaient peu les communautés végétales fertilisées.

Mots clés: azote, bœuf musqué, carcasse, *Ovibos moschatus,* plantes vasculaires, mousses, toundra, Canada

INTRODUCTION

Nitrogen (N) is a limiting resource for biological production in northern ecosystems, and addition of N often results in increased plant growth (Shaver and Chapin, 1980; Tamm, 1991; White, 1993). Processes involved in N turnover are thus important for the structure and functioning of Arctic ecosystems. Mammalian herbivores play a key role in N turnover: they remove N when ingesting plants and redistribute it through faeces and urine (Hobbs, 1996). Interestingly, feeding generally occurs over large areas, whereas deposition of N is concentrated to some specific spots (Williams and Haynes, 1995). Herbivores thus increase the patchiness of N availability, with measurable impacts on plant distribution and growth (McKendrick et al., 1980). The apex of the effect of herbivores on N redistribution occurs after their death, when carcasses deposit a local and concentrated pulse of nutrients into the soil.

The impacts of animal carcasses on soil and plant N concentration have been measured in several ecosystems (e.g., Towne, 2000), but to our knowledge no quantitative data exist for the tundra. Nutrient cycling in the Arctic is severely slowed down by low temperatures, short summers, and, in many places, low water availability. Therefore an animal carcass should have a prolonged impact on its surroundings. We studied tundra vegetation adjacent to muskox carcasses in the Canadian Arctic to quantify the gradient of N concentration in plants growing at various distances from carcasses.

METHODS

Four muskox carcasses were studied: two adult males on Banks Island, one adult male on Melville Island, and one adult female on Ellef Ringnes Island (Table 1). From previous experience, we concluded that bone colour and the appearance of hair and skin remains indicated that carcasses were ca. five years old (except for the carcass on Melville Island, which was probably over 10 years old). We noted the most abundant vascular plant species growing within 1 m of the carcass, and collected fresh aboveground plant parts in 1 dm^2 quadrats located along a transect at 1, 2, 3, 4, 5, 7.5, and 10 m from the centre of the muskox. The line transect was laid in a direction perpendicular to the slope gradient. For the muskox found on Ellef Ringnes Island, sampling was possible only at 0, 0.5, 1, 2.5, and 4 m because of lack of plant material to collect. The two last samples collected around this carcass (at 2.5 and 4 m) were from mosses growing on bones and have been treated as replicates of the sample collected at 0 m. The plant samples were dried at 30°C for 2–3 nights and stored in paper bags. Samples were later dried again at

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TABLE 1. Characteristics (geographic location, date found, vegetation type, and most abundant plant species present around the carcass) of four muskox carcasses investigated in a study of nitrogen concentration in tundra vegetation. The numbering of sites follows the site manual of the Swedish Tundra Northwest Expedition 1999.

Muskox #	Site (site #) Latitude, Longitude Altitude	Date	Vegetation type	Plant species[1]
2.1 and 2.2	Banks Island N (12), 73° 37′N, 115° 52′W 10 m a.s.l.	11 August 1999	Transition zone between mesic sedge meadow and sedge-dwarf shrub heath	*Alopecurus borealis*, *Arctagrostis latifolia*, *Hierochloë pauciflora*, *Carex bigelowii*, *C. misandra*, *Eriophorum* spp., *Dryas integrifolia*, *Saxifraga hirculus*, *Silene uralensis* ssp. *apetala*, *Bistorta vivipara*, *Salix arctica*
3	Melville Island (13), 75° 06′N, 107° 39′W, 100 m a.s.l.	14 August 1999	Cryptogam-herb heath	*Alopecurus borealis*, *Poa abbreviata*, *Saxifraga cernua*, *Papaver dahlianum*, *Stellaria longipes*, *Oxyria digyna*
4	Ellef Ringnes Island (14), 79° 01′N, 105° 15′W, 15 m a.s.l.	20 August 1999	Polar desert	*Pohlia drummondi*

[1] Nomenclature follows Porsild and Cody (1980) and Elven and Elvebakk (1996).

40°C to constant mass, milled, and analyzed for total N and carbon (C) (as percent of dry mass) on a CHN analyzer (Perkin Elmer 2400 CHN Elementar Analyzer, Perkin Elmer, Norwalk, Connecticut, USA).

Data (values relative to 1 m) were analyzed by one-way ANOVA, with distance from carcass as the independent factor. Where significant effect of distance was found, the Tukey HSD post hoc test was applied to recognize significant contrasts. All data met the assumption of normal distribution (Kolomogorov-Smirnov test) and homogeneity of variances (Levene's test). Calculations were performed using the Statistica software (StatSoft, 1997).

RESULTS

The effect of carcasses on the surrounding vegetation was dramatic (Fig. 1) as they had created patches of fertilized plant micro-communities that were visible from a great distance. For the muskoxen found on Banks and Melville Islands, N concentration in the plants significantly declined from 1 to 2 m distance, then remained at the same level further away (Table 2). The muskox carcass from Ellef Ringnes Island was somewhat atypical because it was found in a polar desert. Still, the N concentration in the moss cover showed a similar trend, declining with increasing distance from the carcass (Table 2). The nitrogen values (percent of dry mass) ranged from 1.2 to 4.0 for vascular plants and from 0.7 to 1.2 for mosses. Concentration of C in vascular plants (40.6% to 46.8% of dry mass) did not change with increasing distance from the carcass ($F_{6,14} = 0.42, p = 0.85$). Again, the moss cover result was similar to that of the vascular plants, with concentration of C ranging from 40.2% to 46.5% of dry mass). The C:N ratio was highest close to the carcass (at 1–3 m distance) and then decreased farther away (Table 2).

DISCUSSION

The effect of the carcasses on plant nitrogen content was significant only at 1 m distance from the carcass. The nitrogen concentrations we found in plants collected over 1 m from the muskox carcasses correspond well with average N concentrations reported for tundra plants (Chapin, 1980; Maessen et al., 1983) and for tundra mosses (Chapin et al., 1980). Our carcasses were thus found in habitats with nitrogen levels typical of the tundra, and our results, although based on a small sample size, may have a general value.

Increased availability of nitrogen in the soil may induce increased nitrogen uptake, reduced C:N ratios in plant shoots, and increased growth of tundra plants (Odasz, 1994; Saarinen, 1998). Our results support this theory, since C:N ratios were lowest close to the carcasses, where we also observed the most luscious growth (Fig. 1). Although this lush growth may be due to increased growth of the plant individuals already present, the seed bank and the

TABLE 2. Change in % nitrogen (N) and carbon to nitrogen (C:N) ratio (± 95% C.I.) in plants (aboveground biomass) collected at increasing distances from muskox carcasses in the Canadian Arctic. Distance has a significant effect on both change in %N (ANOVA $F_{6,14} = 11.41$, $p < 0.0001$) and C:N ratio (ANOVA $F_{6,14} = 6.54$, $p < 0.005$). Letters indicate post hoc differences at a-b $p < 0.05$. Change in %N and the C:N ratio at each distance is calculated as the change relative to the value at 1 m (for Banks and Melville Island) and at 0 m (for Ellef Ringnes Island). At Banks and Melville, values at 1 m were 3.24 ± 1.08 for N and 14.91 ± 5.52 for C:N ratios. At Ellef Ringnes, values at 0 m were 1.15 ± 0.11 for N and 35.57 ± 3.79 for C:N ratios.

Distance from carcass (m)	Banks and Melville Island		Ellef Ringnes Island	
	Change in %N (± 95% C.I.)	Change in C:N ratio (± 95% C.I.)	Change in %N	Change in C:N ratio
0			1.00	1.00
0.5			0.66	1.72
1	1.00 ± 0.00 a	1.00 ± 0.00 a	0.58	1.76
2	0.77 ± 0.13 b	1.33 ± 0.24 a,b		
3	0.65 ± 0.12 b	1.60 ± 0.24 b		
4	0.58 ± 0.02 b	1.69 ± 0.11 b		
5	0.57 ± 0.02 b	1.76 ± 0.10 b		
7.5	0.65 ± 0.11 b	1.56 ± 0.32 b		
10	0.67 ± 0.09 b	1.53 ± 0.19 b		

seed rain might also have contributed to new species (Molau and Larsson, 2000). Some of the seedlings of the new species may survive better on the more nutrient-rich patch and ultimately increase plant species richness, at least temporarily, close to the carcass.

Since vertebrate herbivores prefer to feed on fertilized plants (e.g., Miller, 1968; Behrend, 1973; Anderson et al., 1974; Löyttyniemi, 1981; Nams et al., 1996; Ball et al., 2000), vegetation should have been heavily grazed close to the carcasses. At Banks Island, the area where we found the two carcasses was heavily grazed by muskoxen. Surprisingly, we noted very few signs of grazing on the lush vegetation of grasses, sedges, and herbs surrounding the carcasses, although these plants are a normal part of the muskox diet (Schaefer et al., 1996). Animals may avoid grazing close to dead conspecifics in order to minimize the risk of parasite ingestion, as has been shown for faeces in domestic sheep studied in Scotland (Hutchings et al., 1999). Still, Arctic graminoids can compensate for biomass loss to herbivores (Hik et al., 1991; Wegener and Odasz, 1997; Raillard and Svoboda, 1999; Bråthen and Odasz, 2000), and it is thus difficult for us to conclude that there was no grazing activity at all.

The presence of a carcass may have many ecological impacts in the tundra. The released nutrients give better conditions for plant growth and stimulate flowering (Klokk and Rønning, 1987; Shaver and Chapin, 1995); hence, the carcass can create a recruitment oasis for seeds that can be spread to other parts of the tundra. Further, the carcass and increased plant cover may act as a trap for plant litter and soil particles blown by the wind, progressively building up a patch of soil and vegetation. This elevated patch may become a landmark and attract animals such as mammalian (Gray, 1993) and avian (Pielou, 1994) carnivores. The carnivore defecations may add to further buildup of nutrients. The death of a muskox can thus initiate a long chain of ecological processes in which soil nutrients, chemical composition of plants, animal parasites, herbivores, and predators may all play a role.

FIG. 1. A muskox carcass lying on the tundra, in a cryptogam-herb heath, on Melville Island, Canadian Arctic, 75°N. Although the muskox probably died over 10 years ago, its impact on the surrounding vegetation is still dramatic.

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