



Faeces deposition and numbers of vertebrate herbivores in the vicinity of planktivorous and piscivorous seabird colonies in Hornsund, Spitsbergen

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Abstract: Ornithogenic tundra developing near large seabird colonies with its dense vegetation creates sites for foraging, hiding and breeding of herbivores. Grazing, trampling and faeces deposition are considered as the most important ways that vertebrate herbivores influence the plants. Excrement deposition level informs us on the intensity of grazing *i.e.* foraging ground attractiveness. We have compared vertebrate herbivores' faeces deposition (biomass) in the vicinity of big colonies of piscivorous (kittiwake *Rissa tridactyla* and Brünnich's guillemot *Uria lomvia*) and planktivorous (little auk *Alle alle*) seabirds and the control area was in Hornsund, SW Spitsbergen. Much higher level of faeces deposition was recorded nearby seabird colonies as compared to the control area. These findings point out that vertebrate herbivores concentrate and feed more intensively on rich ornithogenic pastures. Number of herbivores and their faeces deposition level recorded nearby planktivorous seabird colony were greater as compared to those found nearby the colony of piscivores. The highest number of geese (*Branta bernicla* and *Anser brachyrhynchus*) and of their faeces biomass were found near the colony of planktivorous little auk, where distinct gradient in faeces deposition level along the colony-seashore axis was recorded. Reindeers *Rangifer tarandus* were observed in considerable numbers near the little auk colony, and were not recorded at all near cliff-nesting sites of kittiwakes and guillemots. Total deposition of excrements produced by geese was generally higher if compared to reindeers.

Key words: Arctic, Spitsbergen, faeces deposition, grazing, ornithogenic tundra.

Introduction

Low level of nitrogen limits plant growth over much of the biosphere and especially at high latitudes (Shaver and Chapin 1980; Maessen *et al.* 1983). In the Arctic, nitrogen availability is limited by abiotic factors, *e.g.* low temperatures, low precipitation, slow chemical weathering of bedrock and poor soil aeration. Seabirds, as amphibiotic animals, transport nitrogen from the sea where they forage, to

the land where they breed. Thus, large colonies of seabirds support nitrogen-rich “oases” in the generally nitrogen-poor landscape of the Arctic. They play a crucial role in initiating local concentrations of plants and animals and in ecosystem functioning. The ornithogenic soils near those colonies receive flushes of nutrients distributed by melting snow, streams and rainfalls, what maintains a typical steep nutrients gradient characterized by high levels at the colony base and lower concentrations downslope (Odasz 1994; Jónsdóttir 2005). The seabirds’ faeces concentration in the vicinity of their breeding places stimulates the increase of primary production resulting in higher richness of plant cover if compared to adjacent areas (Eurola and Hakala 1977; Remmert 1980; Klekowski and Opaliński 1986).

Such rich pastures attract herbivores, which graze and grub plants and deliver their own faeces to ornithogenic tundra, thus exerting the considerable influence on vegetation. Herbivores, despite their role in manuring tundra with faeces (containing high levels of soluble nitrogen; Bazely and Jefferies 1985), diminish per saldo its nutritional supply since they feed on autochthonous matter (Stempniewicz 1992). However, due to low rate of decomposition and mineralization of organic matter in polar ecosystems, homeothermic herbivores accelerate the turnover rate in the nutrient cycling by rapid transformation of organic compounds to the form of easy assimilable nutrients in their faeces (Remmert 1980). Herbivores’ faeces are used as an estimate of the grazing pressure (*e.g.* Eide *et al.* 2002; Fosaa *et al.* 2002), *i.e.* as foraging ground attractiveness. Herbivores may also reduce the moss cover and moss depth by grazing and trampling. This may change the physical properties of grazed sites and give more space for other plant species (Jónsdóttir 1991; van der Wal *et al.* 2000). Such disturbed micro-sites might be also invaded by nitrogen fixing cyanobacteria, improving conditions for plant production (Bazely and Jefferies 1989).

Studies from Spitsbergen (Eide *et al.* 2002) have shown that grazing and manuring affect various habitats in different ways. There was a positive relationship between droppings density and plant species richness in the mesic habitats. In dry habitats, however, where the weak negative correlation between droppings density and species richness was found, plants may be more vulnerable to damage and heavy grazing and thus may reduce plant diversity.

The main objective of this study was to compare faeces deposition level and numbers of vertebrate herbivores staying and feeding in the ornithogenic tundra developing in the vicinity of two different seabird colonies (piscivorous Brünnich’s guillemots *Uria lomvia* with kittiwakes *Rissa tridactyla* and planktivorous little auks *Alle alle*) and in a control area. We hypothesize that: (1) excrements deposition level (used also as an index of foraging intensity) is differentiated in consecutive vegetation zones along the colony-sea nitrogen gradient (Odasz 1994; Zmudczyńska *et al.* in preparation); (2) due to different area and distance between the colony and seashore, tundra related to planktivorous seabirds colonies favour herbivores staying there in higher number and leaving more faeces in comparison to tundra areas situated nearby cliff-nesting piscivorous seabirds (Stempniewicz *et al.* 2007).

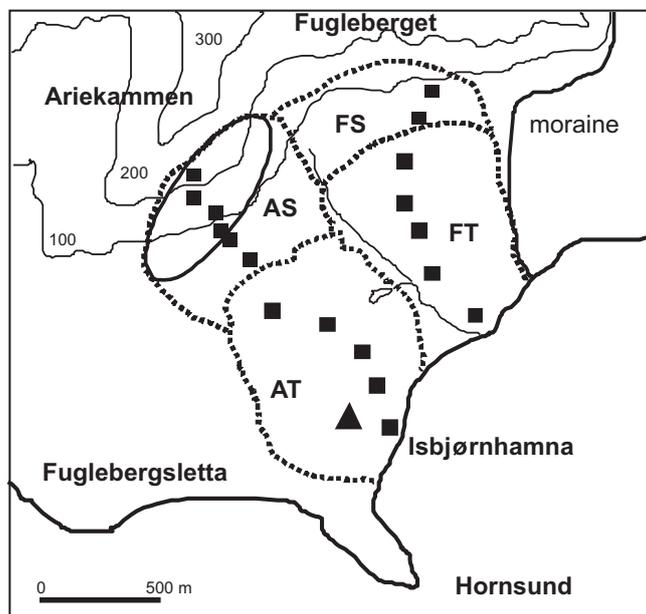


Fig. 1. Ariekammen and Fugleberget area map; black squares – plots for faeces collection, pointed lines – borders of areas, where herbivores were counted (AS – Ariekammen slopes, AT – Ariekammen tundra, FS – Fugleberget slopes, FT – Fugleberget tundra), black oval frame – colony of planktivorous little auks, black triangle – Polish Polar Station.

Methods

The study was conducted in 2005 and 2006 in Hornsund (SW Spitsbergen) in the vicinity of two seabird colonies: (1) planktivorous little auks (*c.* 15 000 breeding pairs) situated on Ariekammen slopes (77°00' N, 15°31' E), and (2) piscivorous kittiwake and Brünnich's guillemot of similar size situated in Gnålberget (77°01' N, 15°52' E). Tundra area with negligible ornithocoprophyllic influence situated beneath Fugleberget slopes (77°00' N, 15°32' E) was considered as a control area (Figs 1 and 2).

Faeces collection. — We collected all the geese (left by barnacle goose *Branta leucopsis* and pink-footed goose *Anser brachyrhynchus* combined, as we were not able to distinguish between them) and reindeers *Rangifer tarandus platyrhynchus* droppings found on plots 5×5 m or 10×10 m (size depended on local condition) established in three study areas (Ariekammen – 11 plots, Fugleberget – 7 plots, Gnålberget – 8 plots in 2005 and 10 plots in 2006; Table 1).

Plots were set in all studied sites with the same pattern, *i.e.* along the transects between the colony and the seashore (Table 1, Figs 1, 2). The distance between the first plot on the slope and the last plot on flat tundra was 1 km in Ariekammen and Fugleberget and 500 m in Gnålberget.

Table 1
 Characteristics of plots established for faeces collection. Plant community classification according to Wojtuń *et al.* (2007).

| Place | Zone (Codes) | Total area | Plant community |
|--|--|--|--|
| Ariekammen (colony of planktivorous seabirds) | colony slope (AS1-6) | 150 m ² | <i>Deschampsia alpina</i> – <i>Prasiola crispa</i> , <i>Cerastium arcticum</i> – <i>Chrysosplenium</i> <i>tetrandrum</i> |
| | flat tundra (AT1-5) | 500 m ² | <i>Sanionia uncinata</i> – <i>Straminergon stramineum</i> , <i>Saxifraga oppositifolia</i> – <i>Sanionia uncinata</i> |
| Fugleberget (colony) | slope (FS1-2) | 200 m ² | <i>Sanionia uncinata</i> – <i>Salix polaris</i> |
| | tundra (FT1-5) | 500 m ² | <i>Sanionia uncinata</i> – <i>Salix polaris</i> , <i>Saxifraga</i> <i>oppositifolia</i> – <i>Sanionia uncinata</i> |
| Gnålberget (colony of piscivorous seabirds) | beneath the colony (GS1-2) | 200 m ² | <i>Cochlearia groenlandica</i> – <i>Prasiola crispa</i> |
| | tundra (GT1-6) in 2005 (GT1-8) in 2006 | 600 m ² in 2005 800 m ² in 2006 | <i>Cochlearia groenlandica</i> – <i>Prasiola crispa</i> , <i>Cerastium arcticum</i> – <i>Poa alpina</i> , <i>Saxifraga</i> <i>oppositifolia</i> – <i>Sanionia uncinata</i> , <i>Sanionia</i> <i>uncinata</i> – <i>Straminergon stramineum</i> |

Table 2
 Dates of herbivore faeces collection in 2005–2006 (no of days between faeces collections).

| Plots localisation | Year | Cleaning | I collection | II collection |
|--------------------|------|----------|--------------|---------------|
| Ariekammen | 2005 | 11.07 | 25.07 (14) | 01.08 (7) |
| | 2006 | 08.07 | 02.08 (25) | 07.08 (5) |
| Fugleberget | 2005 | 11.07 | 26.07 (15) | 02.08 (7) |
| | 2006 | 08.07 | 02.08 (25) | 07.08 (5) |
| Gnålberget | 2005 | 04.07 | 17.07 (13) | 23.07 (6) |
| | 2006 | 03.06 | 24.07 (51) | 30.07 (6) |

At the beginning of the study initial plot cleaning from old droppings was performed. Subsequently, all faeces present on the plot were collected two times per season (after 14–51 days from the cleaning and then 5–7 days after previous collection; Table 2). All faeces taken during the first collection were counted, dried, measured and weighed. Faeces found during the next survey were only counted and collected. Their biomass was calculated on the base of the mean mass of one portion of faeces obtained from previous collection and was presented in grams of dry mass per day per 1 m².

In Ariekammen and Fugleberget all droppings were collected in the same plots in both studied seasons. Due to the damage of plot markings during the winter season 2005/2006, faeces in Gnålberget were collected in 2006 in a different, new established plots situated close to the previous ones.

The presence of gradient in faeces deposition level along the colony-seashore axis (relationship between geese faeces biomass and the distance of each plot from

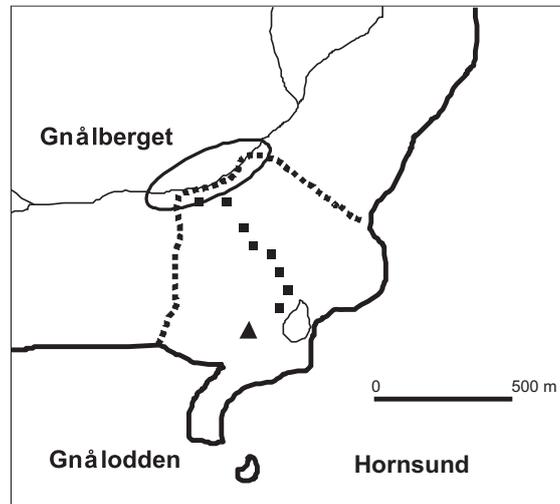


Fig. 2. Gnålberget area map; black squares – plots for faeces collection, pointed line – area, where herbivores were counted, black oval frame – colony of piscivorous kittiwakes and Brünnich's guillemots, black triangle – hut.

the highest plot situated in the slope or beneath the colony) was verified using Spearman's rank correlation coefficient. All χ^2 tests were performed with Yates' correction (Zar 1999).

Counts of herbivores. — Counts of two goose species (barnacle goose and pink-footed goose) and reindeers were performed at least three times per day in the periods 24 May – 3 August 2005 and 16 May – 7 August 2006 in Ariekammen and in Fugleberget. In Gnålberget herbivores were counted 6 times (4 July, 16–25 July) in the same season in 2005 and 11 times (3 June, 23–30 July) in 2006. All observed adult and juvenile geese were noted separately. All counts were conducted with a binocular from the place enabling good visibility of the whole study area. In Ariekammen and Fugleberget counting was performed separately on the slope (AS and FS) and in the flat tundra (AT and FT respectively). In Gnålberget counts comprised the whole area beneath the cliff colony (slope and flat tundra near the fiord shore; GS+GT) (Figs 1, 2). Numbers of animals observed in consecutive months were presented in five day periods (pentads).

Results

Faeces deposition. — In Ariekammen and Fugleberget total deposition of excrements produced by geese was generally higher if compared to reindeers (Table 3). In Gnålberget, due to the lack of reindeers, all collected faeces were produced by geese.

Table 3
 Percentage of faeces biomass produced by goose and reindeers with frequency comparison in Ariekammen and Fugleberget, in 2005–2006.

| Place | Plots | Percentage of faeces mass | | Total faeces dry mass [g] | Frequency comparison (χ^2 test) | |
|------------------|--------------|---------------------------|----------|---------------------------|---------------------------------------|--------|
| | | of reindeer | of geese | | χ^2 , df = 1 | P |
| Ariekammen 2005 | slope | 8 | 92 | 824 | 429.2 | <0.001 |
| | tundra | 47 | 53 | 1099 | 2.1 | 0.15 |
| | all combined | 30 | 70 | 1923 | 203.1 | <0.001 |
| Ariekammen 2006 | slope | 12 | 88 | 812 | 335.8 | <0.001 |
| | tundra | 39 | 61 | 766 | 23.1 | <0.001 |
| | all combined | 25 | 75 | 1578 | 265.1 | <0.001 |
| Fugleberget 2005 | slope | 9 | 91 | 106 | 48.5 | <0.001 |
| | tundra | 2 | 98 | 927 | 652.4 | <0.001 |
| | all combined | 3 | 97 | 1032 | 671.9 | <0.001 |

Biomass of collected goose faeces per day per square meter was similar in all the three studied places in 2005 (Kruskal-Wallis test: $H_{2,26} = 4.53$, $P = 0.10$). However, after exclusion of one plot in Fugleberget [FT5 – goose roosting place with significantly higher faeces concentration (0.33 g/day/m^2) in comparison with other plots there (less than 0.1 g/day/m^2)], significant differences among studied places were found ($H_{2,25} = 7.92$, $p = 0.02$). Deposition of goose droppings in control area in Fugleberget was significantly lower than near seabirds colonies in Ariekammen (Dunn test, $P < 0.001$) and Gnålberget (Dunn test, $P < 0.005$). In 2006 biomass of goose faeces collected in Ariekammen was significantly higher than in Gnålberget (Kruskal-Wallis test, $H_{2,28} = 9.84$, $p = 0.007$; Dunn test, $P < 0.001$) and than in Fugleberget (Dunn test, $P < 0.001$).

In the Ariekammen plots, total goose faeces deposition was estimated to $0.10\text{--}0.16 \text{ g}$ of dry mass per day per m^2 (Table 4). Biomass of droppings found on Ariekammen tundra plots was 4–5 lower compared to slope plots (Table 3; χ^2 test, 2005: $\chi^2_1 = 199.5$, $P < 0.001$, 2006: $\chi^2_1 = 235.6$, $P < 0.001$). The highest biomass of droppings was recorded in the highest slope plot (AS1) where the Alpine hair-grass *Deschampsia alpina* was considerably frequent. In other slope plots (AS2–5), dropping deposition was generally high. Only in AS6, situated in the dry lichenous tundra, recorded values were very low. In tundra plots, high droppings concentration was noted in wet tundra with moss and clusters of purple saxifrage *Saxifraga oppositifolia*, situated in the vicinity of small ponds (plots AT3 and AT5; Fig. 3). We have found clear gradient in the goose faeces deposition level along the colony-sea-shore axis in 2005 (Spearman rank correlation coefficient $r_s = -0.61$, $t_9 = -2.30$, $n = 11$, $P = 0.046$). In 2006 the droppings biomass and the distance from the colony were not correlated ($r_s = -0.43$, $n = 11$, $P = 0.19$).

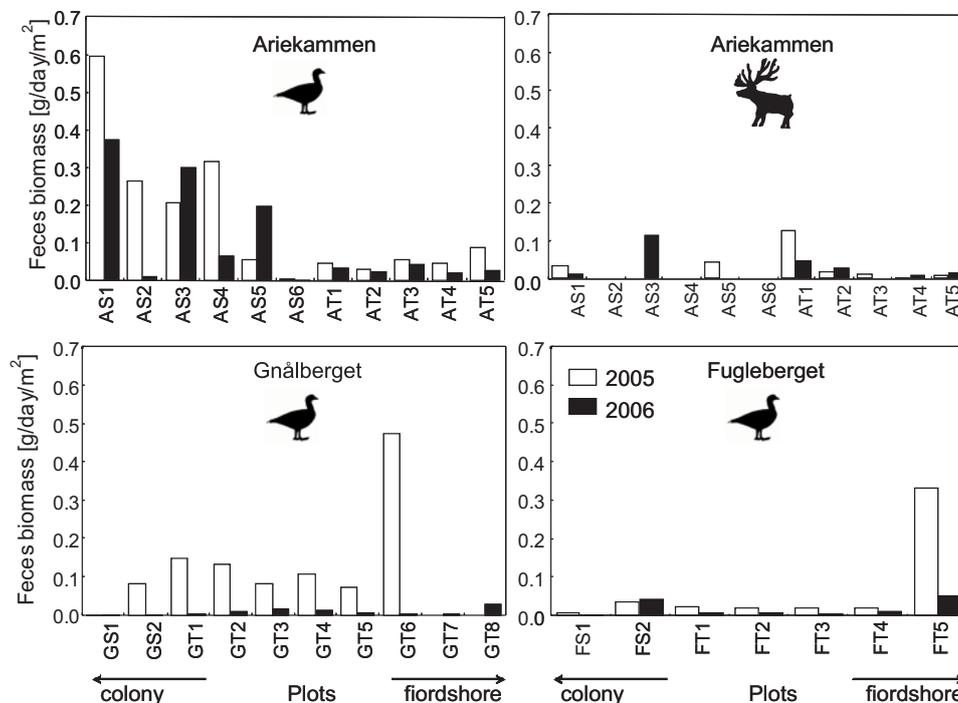


Fig. 3. Goose faeces deposition [g of dry mass/day/m²] in particular plots in Ariekammen, Fugleberget and Gnålberget and reindeer faeces deposition in Ariekammen in 2005–2006; note: localization of the plots in Gnålberget different in each season.

In the control area in Fugleberget geese deposited less than 0.1 g/day/m² in each season. Biomass of faeces found in tundra in 2005 was higher than in the slope plots ($\chi^2_1 = 101.9$, $P < 0.001$). After excluding plot FT5 from the analysis (see above), the values recorded in tundra and slope plots were similar ($\chi^2_1 = 0.36$, $P = 0.55$). In 2006 significantly higher amount of droppings was collected on the slope than in tundra ($\chi^2_1 = 6.2$, $P < 0.01$). Faeces deposition significantly higher than in the rest tundra plots combined (17 times in 2005, $\chi^2_1 = 491.8$, $P < 0.001$ and 7 times in 2006, $\chi^2_1 = 139.3$, $P < 0.001$) was recorded in the plot FT5 with wet moss tundra situated in the fiord shore near the small pond. On the slope considerable amount of faeces, was collected in the plot FS2 (Fig. 3) overgrown by a mixture of moss, lichens and vascular plants. We did not find any relationship between the goose droppings biomass and the distance from the highest slope plot (Spearman rank correlation coefficient, 2005: $r_s = 0.43$, $n = 7$, $P = 0.34$; 2006: $r_s = 0.50$, $n = 7$, $P = 0.25$).

Goose faeces deposition in Gnålberget varied considerably between seasons from 0.14 g/day/m² in 2005 to 0.01 g/day/m² in 2006 (Table 4). The droppings deposition was concentrated in tundra (in 2005 it was 4 times higher than on the slope; $\chi^2_1 = 159.1$, $P < 0.001$; in 2006 all faeces were found in tundra; Table 4). The highest geese faeces deposition was noted in the plot localized in the vicinity of the

Table 4
 Total biomass of goose and reindeer faeces (dry mass g/day/m²) collected in Ariekammen, Fugleberget and Gnålberget in 2005–2006.

| Herbivore | Place | Year | Slope plots | Tundra plots | All plots combined |
|-----------|-------------|------|-------------|---------------|--------------------|
| Geese | Ariekammen | 2005 | 0.24 | 0.06 | 0.16 |
| | | 2006 | 0.16 | 0.03 | 0.10 |
| | Fugleberget | 2005 | 0.02 | 0.08 (0.02*) | 0.07 (0.02*) |
| | | 2006 | 0.02 | 0.02 (0.008*) | 0.02 (0.01*) |
| | Gnålberget | 2005 | 0.04 | 0.17 | 0.14 |
| | | 2006 | 0.0 | 0.01 | 0.01 |
| Reindeer | Ariekammen | 2005 | 0.01 | 0.03 | 0.03 |
| | | 2006 | 0.02 | 0.02 | 0.02 |
| | Fugleberget | 2005 | 0.002 | 0.001 | 0.001 |
| | | 2006 | + | + | + |

* – data after excluding one plot with outstandingly high faeces concentration

+ – faeces were present, lack of biomass data

pond near the fiord shore (GT6 in 2005 and GT8 in 2006; Fig. 3) with green mossy tundra. Relatively high droppings deposition exceeding 0.02 g/day/m² was recorded in 2005 on flat tundra plots GT1–2 dominated by the scurvy grass, *Cochlearia groenlandica*. We did not find any clear gradient in goose faeces deposition level along the colony-seashore axis in this area (Spearman rank correlation coefficient, 2005: $r_s = 0.36$, $n = 8$, $P = 0.38$; 2006: $r_s = 0.47$, $n = 10$, $P = 0.17$).

The reindeer excrements were found mainly in the Ariekammen area, only few were recorded in control area in Fugleberget, and none in Gnålberget (Table 4). In Ariekammen the reindeer droppings deposition in 2005 was significantly higher on the slope than in flat tundra ($\chi^2_1 = 32.2$, $P < 0.001$). In 2006, the faeces biomass was similar in both types of plots ($\chi^2_1 = 0.02$, $P = 0.90$). The highest concentrations of droppings in tundra were recorded in plots with high moss contribution (AT1–AT2) and on the slope in the plot AS1 with Alpine hair-grass and in AS3 with high contribution of moss and the Arctic mouse-ear *Cerastium arcticum* (Fig. 3).

In Fugleberget, the reindeer excrement deposition was very low in 2005 – similarly on the slope and in tundra ($\chi^2_1 = 0.11$, $P = 0.74$) (Table 4). Due to the lack of data on the droppings found in 2006 the deposition level in this season is unknown. In 2005 reindeer faeces were found only in the highest slope plot (FG1) and in one tundra plot (FT5, near the fiord shore). In 2006, the excrements were found in one slope (FT2) and in two tundra (FT1 and FT3) plots (Fig. 3).

Number of herbivores in the study areas. — Pink-footed geese were observed mainly in Ariekammen, within the little auk colony area. Almost all of recorded individuals (in 2005 all) were observed on the slopes (Fig. 4). Higher numbers of geese in this area were observed only during the spring migration period in May (max. 57 individuals in 2005 and 24 individuals in 2006; Fig. 4). In the con-

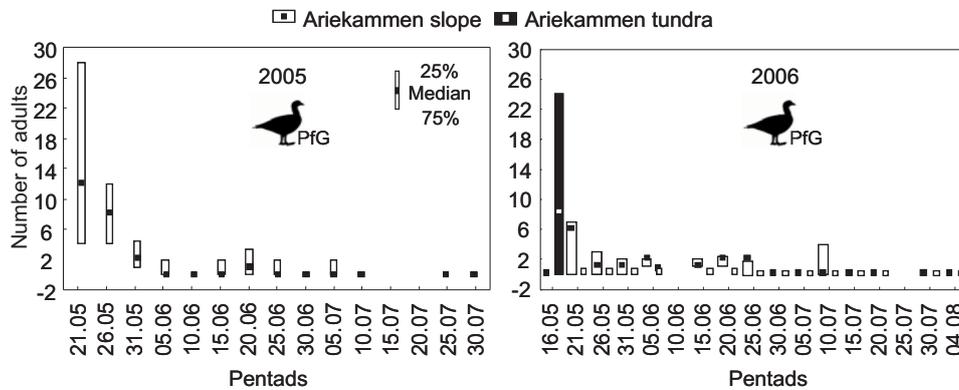


Fig. 4. Number of adult pink-footed geese observed in subsequent pentads on the slopes and in the Ariekammen tundra in 2005 and 2006; pentad dates are dates when the pentads begun.

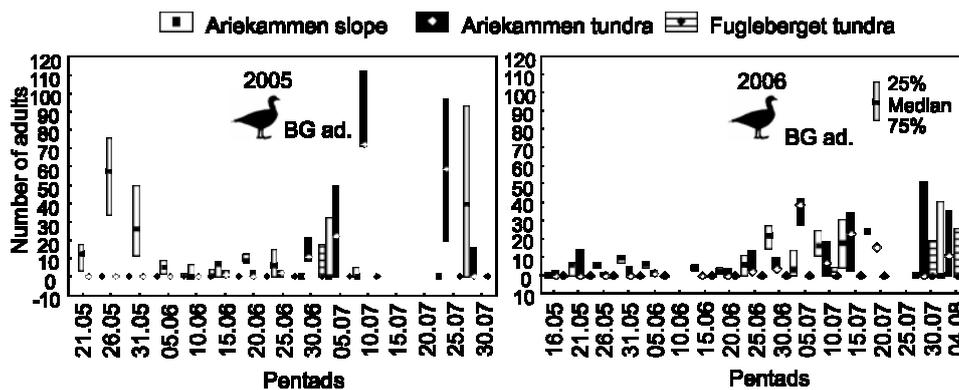


Fig. 5 Number of adult barnacle geese observed in subsequent pentads in Ariekammen and Fugleberget in 2005 and 2006; pentad dates are dates when the pentads begun.

trol area in Fugleberget we have recorded only 2 individuals in 2005. In Gnålberget area we have observed only 3 adult individuals in 2005 and 8 adults in 2006.

Barnacle geese were observed in all the studied areas. In Ariekammen, they were observed regularly in the slope and in tundra. Because flocks of migrating geese were observed at the end of May 2005 exclusively on the slope, the total number of adult barnacle geese found there in 2005 was significantly higher than in the flat tundra (U test, $Z_{148} = 2.62$, $P = 0.009$). In 2006, when such influx of migratory birds was not recorded, both values were similar (U test, $Z_{130} = 1.19$, $P = 0.23$). In June the number of birds was generally low and probably was built by local breeders. At the end of June families with goslings appeared from the neighbouring areas and the number of adult geese recorded in the study area increased (Fig. 5). Families were observed mainly in the flat tundra (Fig. 6). In Fugleberget geese were observed occasionally – six times in 2005 (2–40 adult individuals) and five times in 2006

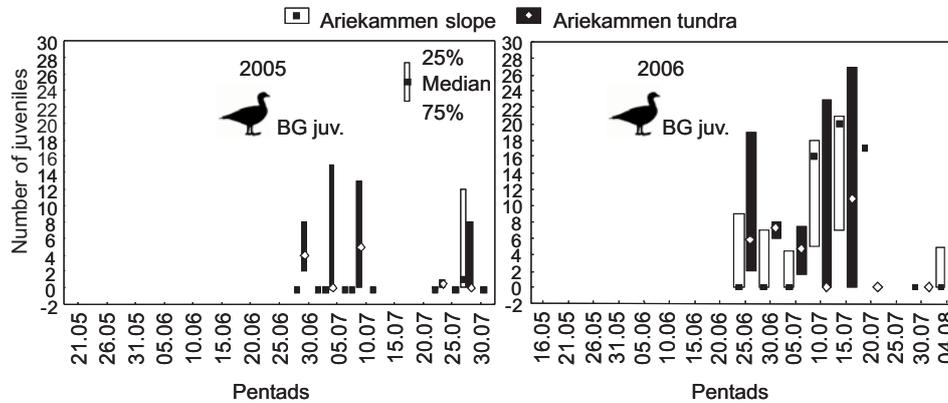


Fig. 6 Number of juvenile barnacle geese observed in subsequent pentads on the slopes and in the Ariekammen tundra in 2005 and 2006; pentad dates are dates when the pentads begun.

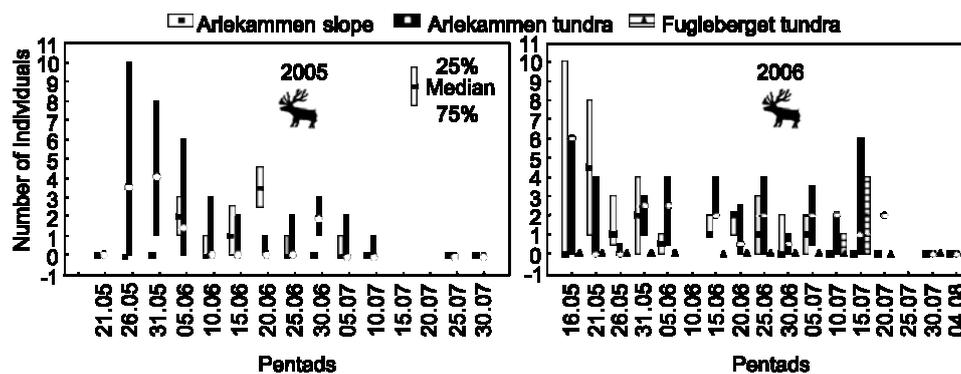


Fig. 7 Number of reindeers observed in subsequent pentads in the slopes and in the Ariekammen tundra in 2005 and 2006; pentad dates are dates when the pentads begun.

(2–50 adult individuals and 10 goslings), almost exclusively in the tundra zone. In Gnålberget we observed 10–125 (Median = 34.5) adults and 8 goslings in 2005 and 5–63 (Median = 14.5) adults with no goslings in 2006. Their numbers (adult and juveniles combined) were lower than near the colony of planktivores in Ariekammen in the same period (10 July – 3 August) in 2006 (U test, $Z_{17} = 2.68$, $P = 0.007$). In 2005, however, these values were similar (U test, $Z_{15} = 1.10$, $P = 0.27$).

The reindeers were observed frequently in the Ariekammen area, occasionally in the Fugleberget control area, and were not recorded in Gnålberget at all. In general, the number of reindeers staying in Ariekammen was highest in the spring (May) and then dropped gradually to single individuals in July (Fig. 7). The numbers of animals feeding on the slopes and in the flat tundra were similar in 2005 (U test, $Z_{148} = -1.44$, $P = 0.15$) and in 2006 (U test, $Z_{130} = -1.02$, $P = 0.30$). However, during first studied pentads in 2005, more reindeers were recorded in the slope zone than in the tundra (Fig. 7). In Fugleberget, the reindeers were recorded occasionally in the flat tundra.

Discussion

The highest deposition of herbivore excrements was recorded in the plots nearby the big colonies of seabirds, whereas the lowest values of deposition were recorded in the control area. These findings point out that the vertebrate herbivores indeed foraged most intensively in rich ornithogenic tundra pastures developing in the vicinity of seabird breeding colonies.

The level of faeces deposition near planktivorous little auk colony in Ariekammen was higher than that near the fish-eating seabird colony in Gnålberget. The main reason is the distinct difference in the surface area of tundra developing in the vicinity of these two colony types. Little auks breed far from the seashore and their colony is much more extensive. As a result birds flying to and from colony fertilize vast area of tundra, thus supporting higher numbers of herbivores. The opposite situation is in the case of kittiwakes and guillemots nesting on cliffs close to the sea. The much smaller area of ornithogenic tundra formed there could support smaller number of geese and no reindeers (Stempniewicz *et al.* 2007). Additionally the number of observed goose families was very low in Gnålberget compared to Ariekammen. Also, the differences in flora composition in both places, and especially in proportions of foraged plants might have some influence.

We have found a clear gradient in faeces deposition level along the colony-seashore axis (consistent with observed nitrogen gradient) only in Ariekammen in 2005. In 2006, this relationship was less distinct but still the higher faeces deposition was recorded on slope than in the flat tundra. The presence of dropping deposition gradient could also be expected in Gnålberget, based on nitrogen and plant biomass gradient recorded there. Lack of such pattern may be related to the steep slopes beneath the colony where steep cliff causes the goose droppings rolling down to the lower areas. Geese and their faeces distribution in flat tundra are related not only to food abundance but also to localization of tundra ponds and proximity of the seacoast making possible safe escape from the Arctic fox, *Alopex lagopus*, and from the polar bear, *Ursus maritimus*. This is most important during the rearing and moulting periods (Stempniewicz 1992, 2006).

The reindeer is a relatively new species in the Hornsund area (first records from 1990s, Fosaa *et al.* 2002). In the present study, reindeers contributed up to 30% biomass of all faeces deposited in the Ariekammen area and 3% in the Fugleberget area. Their manuring and trampling activity seems to have the greatest impact on local ecosystem leading to structural changes in both soil and plant communities (Cooper *et al.* 2001; van der Wal *et al.* 2004). Introduced reindeers in Ny-Ålesund area (north Spitsbergen) consumed and depleted fruticose lichens and then switched over to mosses (Staaland *et al.* 1993), subsequently they reduced moss height. This had a positive impact on the performance of vascular plants, as the soil temperature increased with the decreased moss layer (van der Wal *et al.*

2001, 2004). Similar scenario, especially in case if the reindeer population grows, may be expected in the Hornsund area.

The goose faeces depositions in Ariekammen tundra found in the present study (0.03–0.06 g/day/m²) and in 1980 (mean value 0.06 g/day/m²; calculated from Stempniewicz 1992) were generally similar. Also, in the control Fugleberget tundra, the deposition level was almost the same in the two periods and did not exceed 0.02 g/day/m². However, reindeers and their faeces deposition were not present in the studied area in 1980.

Migratory geese concentrate in time and space. Their impact through grazing, trampling and manuring can be much greater than that of reindeers at a single spot (Jónsdóttir 2005). Spring migrating geese of both species were observed mainly on Ariekammen slopes due to earlier terms of snow melting there compared to flat tundra. Higher concentration of reindeers in this zone early in the season can also be explained the same way.

Heavy grazing and faeces deposition by geese and reindeers influence plant communities at a local scale (*e.g.* Jefferies *et al.* 1994; Staaland and White 1991), but the effect on long-term plant communities diversity in the Arctic remains uncertain (Eide *et al.* 2002). The Arctic is currently undergoing a dramatic climate change (IPCC 2007) which may alter the relationship between herbivores and plants in the future. Predicted climate warming may cause the increase of piscivorous seabird populations. It is expected that large areas of ornithogenic tundra around the colonies of plaktivorous seabirds may disappear, while areas of tundra in the vicinity of piscivorous seabirds with low total production and supporting only few herbivores, will likely increase, but only tenuously. It may have negative consequences for tundra-dependent birds and mammals (Stempniewicz *et al.* 2007). On the other hand, predicted warming with earlier snowmelt and higher temperatures during the summer will favour reproductive success of most Arctic geese populations (Zöckler and Lysenko 2000), what may lead to their growth. Dramatic increase of lesser snow goose population recorded during the last few decades (Jefferies *et al.* 2004) resulted in the presence of large numbers of geese in the salt marshes along the coasts of Hudson Bay in Low Arctic Canada (Jefferies *et al.* 1995). It caused overgrazing and ecosystem damage (Jefferies 1988; Srivastava and Jefferies 1996; Walker *et al.* 2003). Also Spitsbergen populations of barnacle and pink-footed geese show an increasing trend during recent years (Owen and Black 1999; Madsen *et al.* 1999) but there are still no signs of over-exploitation or ecosystem degradation there. If goose populations continue to increase, the risk of damage potentially increases (Jónsdóttir 2005). In this context, the number of herbivores, faeces deposition (as an index of foraging intensity), and the impact on plant communities should be monitored.

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References

- BAZELY D.R. and JEFFERIES R.L. 1985. Goose faeces: a source of nitrogen for plant growth in grazed salt marsh. *Journal of Applied Ecology* 22: 693–703.
- BAZELY D.R. and JEFFERIES R.L. 1989. Lesser snow geese and the nitrogen economy of a grazed salt marsh. *Journal of Ecology* 77: 24–34.
- COOPER E.J., SMITH F.M. and WOOKEY P.A. 2001. Increased rainfall ameliorates the negative effect of trampling on the growth of High Arctic forage lichens. *Symbiosis* 31, 153–171.
- EIDE W., KLANDERUD K. and TOMMELSTAD R. 2002. Plant community diversity at different scales in six localities on Svalbard. In: I.S. Jónsdóttir (ed.) *Biodiversity in arctic plant communities*. UNIS Publication Series. AB-306 Reports 2001: 22–39.
- EUROLA S. and HAKALA A.V. 1977. The bird cliff vegetation of Svalbard. *Aquilo Series Botanics* 15: 1–18.
- FOSAA A.M., NYBAKKEN L. and OHT M. 2002. Vegetation and environmental relations along the western coast of Spitsbergen, Svalbard. In: I.S. Jónsdóttir (ed.) *Biodiversity in arctic plant communities*. UNIS Publication Series. AB-306 Reports 2001: 8–21.
- IPCC 2007. *Climate change 2007: the physical science basis. Summary for policy makers*. Contribution of Working Group I to the Fourth Assessment Report of the Inter-governmental Panel on Climate Change, Cambridge University Press, Cambridge.
- JEFFERIES R.L. 1988. Pattern and process in arctic coastal vegetation in response to foraging by lesser snow geese. In: M. Werger, P. van der Aart, H.J. During and J.T.A. Verhoeven (eds) *Plant form and vegetation structure, adaptation, plasticity and relationship to herbivory*. SPB Academic Publishing, the Hague: 281–300.
- JEFFERIES R.L., KLEIN D.R. and SHAVER G.L. 1994. Vertebrate Herbivores and Northern Plant Communities: Reciprocal Influences and Responses. *Oikos* 71, 193–206.
- JEFFERIES R.L., GADALLAH F.L., SRIVASTAVA D.S. and WILSON D.J. 1995. Desertification and trophic cascades in arctic coastal ecosystems: a potential climatic change scenario? In: T.V. Callaghan, U. Molau, M.J. Tyson, J.I. Holten, W.C. Oechel, T. Gilmanov, B. Maxwell and B. Sveinbjörnsson (eds) *Global Change and Arctic Terrestrial Systems: Ecosystem Research Report 10*. European Commission Directorate General XII, Brussels and Luxembourg: 201–205.
- JEFFERIES R.L., ROCKWELL R.F. and ABRAHAM K.E. 2004. Agricultural subsidies, migratory connectivity and large-scale disturbance in Arctic coastal systems: A case study. *Integrative and Comparative Biology* 44: 130–139.
- JÓNSDÓTTIR I.S. 1991. Effects on grazing on tiller size and population dynamics in a clonal sedge (*Carex bigelowii*). *Oikos* 62: 177–188.
- JÓNSDÓTTIR I.S. 2005. Terrestrial Ecosystems on Svalbard: Heterogeneity, Complexity and Fragility from an Arctic Island Perspective. *Biology and Environment: Proceedings of the Royal Irish Academy* 105B: 155–165.
- KLEKOWSKI R.Z. and OPALIŃSKI K.W. 1986. Matter and energy flow in Spitsbergen ornithogenic tundra. *Polar Research* 4: 187–197.
- MADSEN J., KUIJKEN E., MEIRE P., COTTAAR F., HAITJEMA T., NICOLAISEN P.I., BRNES T. and MEHLUM F. 1999. Pink-footed goose *Anser brachyrhynchus*: Svalbard. In: J. Madsen, G. Cracknell and T. Fox (eds) *Goose populations of the western Palaearctic: a review of status and distribution*. Wetland International Publication no. 48. National Environmental Research Institute, Denmark: 82–93.

- MAESSEN O., FREEDMAN B., NAMS L.N. and SVOBODA J. 1983. Resource allocation in high-arctic vascular plants of differing growth form. *Canadian Journal of Botany* 61: 1680–1691.
- ODASZ A.M. 1994. Nitrate Reductase Activity in Vegetation below an Arctic Bird Cliff, Svalbard, Norway. *Journal of Vegetation Science* 5: 913–920.
- OWEN M. and BLACK J.M. 1999. Barnacle goose *Branta leucopsis*: Svalbard. In: J. Madsen, G. Cracknell and T. Fox (eds) *Goose populations of the western Palaearctic: a review of status and distribution*. Wetland International Publication no. 48. National Environmental Research Institute, Denmark: 258–268.
- SHAVER G.R. and CHAPIN F.S. III 1980. Response to fertilization by various plant growth forms in an Alaskan tundra: Nutrient accumulation and growth. *Ecology* 61: 662–675.
- REMMERT H. 1980. *Arctic animal ecology*. Springer Verlag. Berlin, Heidelberg, New York.
- RUES R.W., HIK D.S. and JEFFERIES R.L. 1989. The role of lesser snow geese as nitrogen processors in a sub-arctic salt marsh. *Oecologia* 79: 23–29.
- SRIVASTAVA D.S. and JEFFERIES R.L. 1996. A positive feedback: herbivory, plant growth, salinity, and the desertification of an Arctic salt-marsh. *Journal of Ecology* 84: 31–42.
- STAALAND H. and WHITE R.G. 1991. Influence on foraging ecology on alimentary tract function of Svalbard reindeer. *Canadian Journal of Zoology* 69, 1326–1334.
- STAALAND H., SCHEIE J.O., GRØNDAHL F.A., PERSEN E., LEIFSETH A.B. and HOLAND O. 1993. The introduction of reindeer to Brøggerhalvøya, Svalbard: grazing preference and effect on vegetation. *Rangifer* 13: 15–19.
- STEMPNIEWICZ L. 1992. Manuring of tundra near a large colony of seabirds on Svalbard. In: K.W. Opaliński and R.Z. Klekowski (eds) *Landscape, Life World and Man in High Arctic*. Institute of Ecology, Polish Academy of Sciences, Warszawa: 255–269.
- STEMPNIEWICZ L. 2006. Polar Bear Predatory Behaviour toward Moulting Barnacle Geese and Nesting Glaucous Gulls on Spitsbergen. *Arctic* 59: 247–251.
- STEMPNIEWICZ L., BŁACHOWIAK-SAMOŁYK K. and WĘSŁAWSKI J.M. 2007. Impact of climate change on zooplankton communities, seabird populations and Arctic terrestrial ecosystem – a scenario. *Deep Sea Research II* 54: 2934–2945.
- WALKER N., HENRY H., WILSON D.J. and JEFFERIES R.L. 2003. The dynamics of nitrogen movement in an Arctic salt marsh in response to goose herbivory: a parameterized model with alternate stable states. *Journal of Ecology* 91: 637–650.
- WOJTUŃ B., MATUŁA J., STEMPNIEWICZ L., ZWOLICKI A., ZMUDCZYŃSKA K., ILISZKO L. and FRYDERYK S. 2007. Zróżnicowanie zbiorowisk roślinnych na gradientach ekologicznych badanych transektów. Materials of the conference „Udział doktorantów Uniwersytetu Gdańskiego w projektach Międzynarodowego Roku Polarnego”, Gdańsk, maj 2007.
- VAN DER WAL R., MADAN N., VAN LIESHOUT S., DORMANN C., LANGVATN R. and ALBON S.D. 2000. Trading forage quality for quantity? Plant phenology and patch choice by Svalbard reindeer. *Oecologia* 123: 108–115.
- VAN DER WAL R., VAN LIESHOUT S.M.S. and LOONEN M.J.J.E. 2001. Herbivore impact on moss depth, soil temperature and arctic plant growth. *Polar Biology* 24: 29–32.
- VAN DER WAL R., BARDGETT R.D., HARRISON K.A. and STIEN A. 2004. Vertebrate herbivores and ecosystem control: cascading effects of faeces on tundra ecosystems. *Ecography* 27: 242–252.
- ZAR J.H. 1999. *Biostatistical analysis*, 4th edition. Prentice Hall, Upper Saddle River, New York: 663 pp.
- ZÖCKLER C. and LYSENKO I. 2000. Water Birds on the Edge. First circumpolar assessment of climate change impact on Arctic breeding water birds. *WCMC Biodiversity Series No. 11*. World Conservation Monitoring Centre – World Conservation Press.

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