

Effects of foraging by pink-footed geese on tundra vegetation in Svalbard: an assessment of extent and a proposal for a monitoring program

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Abstract

Increasing population sizes of some herbivorous Arctic breeding species have caused extensive damage to tundra vegetation, whose resilience to intensive herbivory is low, with very slow rates of plant recovery. Here we assess the impacts of the feeding activities of a rapidly growing population of pink-footed geese *Anser brachyrhynchus* on the Svalbard tundra at both spring pre-breeding staging sites and summer nesting grounds over a seven year period in four different sites in Isfjorden. From 2006 to 2013 the population of Svalbard pink-footed geese increased from 52,000 to 81,500 individuals. Over the same period there was an increase in goose use of less favoured, but much more abundant, drier habitat at the expense of less abundant but preferred wetter tundra at pre-breeding staging sites. Spring snowmelt occurs first in drier areas with prolonged snow cover in wetter parts and we observed a positive correlation between the extent of spring snow cover and use of drier habitats. Hence, both an increasing population size and late spring snowmelt are likely to lead to extensive use of drier habitats. Drier areas are less resilient to disturbance and take longer to recover from damage than wetter habitats, thus it is now likely that pink-footed geese are causing long-term vegetation changes at pre-breeding sites. Pink-footed goose foraging choices appear somewhat different at their nesting grounds. Here, they fed in previously disturbed wet habitat in close proximity to their nests. Presumably this allowed them to quickly return to the nest if predators were spotted, while also feeding in locations where the rooting structures of forage plants have been disturbed, making extraction from the soil easier. Long-term damage to tundra vegetation therefore seems more likely to occur at pre-breeding sites where habitat availability can be restricted by snow cover and an increasing population size.

Based on our sampling protocol and transect design, we propose an adaptive monitoring program which incorporates gradients in wetness of habitats and snow cover in four sites in Isfjorden. Ideally the monitoring should be carried out at 3-year intervals to be coordinated

with the reporting from the AEWA international adaptive management plan for the Svalbard population of the pink-footed goose.

Effekter av fødesøkende kortnebbgjess på Svalbardtundraen: en vurdering av omfang og et forslag til et overvåkingsprogram

Sammendrag

Økende bestander av herbivore arter i arktis forårsaker betydelige skader på tundra-vegetasjonen. Dette er en habitattype som i liten grad tåler intensivt beite og bruker lang tid på å gjenvinne planteveksten. I dette studiet vurderer vi beiteaktiviteten på Svalbardtundraen til en raskt voksende bestand av kortnebbgås *Anser brachyrhynchus*. Registreringene på Svalbard er gjennomført over en syvårsperiode i fire lokaliteter i Isfjorden, både i områder som gjessene bruker før de etablerer reir og i hekkekoloniene i selve reirperioden. Fra 2006 til 2013 har den Svalbardhekkende bestanden av kortnebbgjess økt fra 52 000 til 81 500 individer. Resultater fra registreringene på Svalbard viser at det, i lokalitetene som brukes før reiretablering, over samme tidsperiode har vært en økning i bruken av de tørre og mindre gunstige, men vanlige, habitatene. Dette har vært på bekostning av de mindre vanlige, men fuktige og mer foretrukne tundrahabitatene. Om våren smelter snøen først i de tørre områdene, mens snøen ligger lengre i de fuktige partriene på tundraen. Det forventes derfor at den økende bestanden av kortnebbgjess og en sen snøsmelting om våren medfører en mer intensiv bruk av de tørre habitatene. Slike habitater tåler imidlertid beitetrykket dårligere og det vil ta lengre tid å gjenvinne tilstanden i motsetning til i de fuktige habitatene. Det er derfor sannsynlig at kortnebbgjessene kan påføre vegetasjonen langtidsendringer i slike habitater.

Kortnebbgjessene beiter noe annerledes i hekkekoloniene. Her beites det på våtmarkshabitater i nærheten av reiret, en habitattype som vi i dag ser er betydelig nedbeitet flere steder og viser tidligere påførte skader. Fødesøking i slike habitater gjør at gjessene raskt kan vende tilbake til reiret om det kommer en predator. En intensivt beitet tundra vil

også ha en ødelagt rotstruktur på plantene. Dette medfører at plantene blir mer tilgjengelige for gjessene ved at de er lettere å ekstrahere fra underlaget.

Basert på registreringer i dette og tidligere studier, antar vi at langtidsskader på tundravegetasjonen sannsynligvis vil øke med økende bestandsstørrelse av kortnebbgjess. Mest utsatt er lokalitetene som gjessene bruker før de etablerer reir i hekkekoloniene. Graden av skade vil imidlertid begrenses av snødekke, og er således både sesong- og årsavhengig.

Basert på innsamlingsmetodene og utformingen av overvåkingstransektene gjennomført i dette studiet, foreslår vi et adaptivt overvåkingsprogram som inkorporerer gradienter i habitatenes grad av fuktighet og snødekke i fire kjerneområder for kortnebbgjess i Isfjorden. Det optimale vil være om overvåkingen gjennomføres i treårs intervaller slik at datainnsamlingen koordineres med de treårige prosessene i den adaptive og internasjonale forvaltningsplanen for Svalbardbestanden av kortnebbgås (AEWA).

Introduction

Although herbivores are known to feed on a wide range of different plant species, they can also show preferences for specific plants and plant communities. Preferential feeding on any one plant community or habitat does not generally perturb the balance of an ecosystem. However, when the population of a herbivore that has specific feeding preferences increases significantly over a short time-scale, it can cause extensive damage to individual plants and/or plant communities and habitats. In temperate or tropical regions, regrowth may be relatively quick and any damage caused rectified within one or two growing seasons. Conversely, in the Arctic vegetation damage can be very long lasting and take many years to recover due to the slow growth rate of Arctic plants.

The vegetation at La Perouse Bay has suffered significant damage from the many thousands of snow geese which nest in the area. Snow geese feed by grubbing for the nutritious below-ground rhizomes and storage organs of Arctic tundra plants, causing disruption to the plant communities. Such feeding activities by a rapidly increasing goose population have led to changes in hydrology, with extensive areas now devoid of vegetation, geese moving further and further away from their original nesting grounds and associated impacts on the wider ecosystem. In the European Arctic, numbers of pink-footed geese have risen substantially over the recent decade due to improved winter survival and conservation policies which have protected the birds from hunting. The Svalbard population has increased from less than 20,000 in the early 1970's to a current count of more than 80,000 individuals (Madsen and Williams 2012). Pink-footed geese are now the most numerous and widespread migratory herbivore on Svalbard (Tombre et al 2011; Wisz et al 2008), hence it is of great ecological importance that we now understand the impacts that such a large population may have on the Arctic tundra in an effort to prevent events such as those observed with snow geese at LPB.

Here we have assessed pink-footed goose grubbing on the central Svalbard tundra from 2006 to 2013, when the population increased rapidly from 52,000 to 81,500 individuals (Madsen and Williams 2012, Madsen et al 2013). We investigated changes in grubbing activity/intensity and patterns of reutilisation of grubbing patches during both the spring pre-breeding period and the early nesting period across a range of different vegetation types and under different snow cover conditions. We tested the following predictions: i) when spring snowmelt was late and the pink-footed goose population size was high, less preferred habitat was utilised to a higher degree during the pre-breeding period than when the goose population was lower and spring snowmelt was early; ii) nesting pink-footed geese grubbed in previously used parts of the tundra which were closer to their nests rather than in undisturbed vegetation located further away from the nest. Additionally, to understand the mechanisms behind reutilisation of previously grubbed tundra, we also quantified the mechanical effort required to extract below-ground plant material from previously grubbed and undisturbed areas of the tundra.

Based on our field work and analyses we propose a program for monitoring the future impacts of goose grubbing in Svalbard. Since the interactions between goose grubbing intensity, goose population size and snow conditions are not yet fully understood, the program has to be adaptive. The monitoring program should ideally be tightly coordinated with the processes and reporting cycles of the adaptive international management plan which has been implemented for the Svalbard population of the pink-footed goose under the auspices of the African-Eurasian Waterbird Agreement (AEWA).

Methods

Study areas and population

Geese are the dominant herbivores of the Arctic (Van der Wal 2005), with the pink-footed goose the most numerous on Svalbard (Tombre et al. 2011; www.goosemap.no). The

population of this species has increased rapidly in recent decades and now stands at 81,500 individuals (Fig. 1; Madsen and Williams 2012, Madsen et al 2013). The species overwinters along the north-sea coasts of the low countries of Europe, migrating through Norway to arrive in Svalbard in mid-May (Madsen 2001, Fox et al 2006). Birds then spend approximately 3 weeks at pre-breeding staging sites on Svalbard feeding (Fox et al 2006, Glahder et al 2006). Towards the end of May geese move to their breeding grounds to initiate nesting when snowmelt allows access to their nest sites (Madsen et al 2007). During the 26-27 day incubation period the adult birds remain on or at the nest, taking short recess periods to feed when necessary (Løvenskiold 1964, Inglis 1977).

Grubbing by pink-footed geese was surveyed in four different locations in central Svalbard: Adventdalen, Bohemannflya, Colesdalen and Sassendalen. Adventdalen, Colesdalen and Sassendalen are broad U-shaped former glaciated valleys containing a central, wide braided river system and open tundra dominated by marsh, ridge and heath vegetation. Bohemannflya has similar vegetation types but is a flat, open tundra coastal plain. All sites are either pink-footed goose spring staging areas, used when the birds first arrive in Svalbard in mid-May, and/or breeding areas used from late May/early June onwards (Anderson et al 2012).

Grubbing at pre-breeding staging sites

Pink-footed goose grubbing activity carried out during the pre-breeding period was surveyed in Colesdalen, Adventdalen and Bohemannflya and Sassendalen (Fig. 1; Appendix 1).

Transects were assessed at the larger spatial scale (median length = 1.1 km, quartiles = 0.7, 1.5 km). Transects were surveyed during 2006 or 2007, when the goose population numbered 52,000 and in 2013 when the population had risen to 81,500 (Fig. 1). For logistic reasons, identical transects were not re-surveyed, however transects were located within same area.

Grubbing was assessed using the same method in both 2006/7 and 2013. 5 × 5 m plots were located along each transect surveyed. Plots were spaced at 30 m intervals and represented typical patches of tundra habitat. Previous observations of feeding geese revealed that individual goose feeding stations were discrete and characteristically 0.35 × 0.35 m in size. Therefore, grubbing intensity was assessed in a 0.35 × 0.35 m frame, which was located within each 5 × 5 m plot. The first measure of grubbing intensity was the average grubbing utilisation, which was determined as the average grubbing within the 0.35 m frame that was centrally placed within the 5 × 5 m plot. The second measure of grubbing intensity was the peak grubbing utilisation, which was the maximum intensity of grubbing within the 5 × 5 m plot and also assessed over a scale of 0.35 × 0.35 m. The realised grubbing utilisation was the ratio between the average and peak grubbing utilisation. In 2013 a third measure of grubbing intensity was recorded, the grubbing extent, which was the coverage of grubbing within the 5 × 5 m habitat patch. Grubbing is expressed as the proportion of the frame or patch which was grubbed, to the nearest 10%.

Grubbing at nesting sites

Eight small spatial scale transects (10 m - 27 m) were set up in Sassendalen in 2010 (Fig. 1) to determine the probability of grubbing intensity adjacent to pink-footed goose nest sites. Sassendalen is one of the main pink-footed goose breeding areas in Svalbard (Jepsen et al 2002) and transects were located in wet fens, the preferred foraging habitat (Speed et al 2009), and adjacent (10 - 250 m) to clusters of nests (range 3 – 30). The initial selection of sites for grubbing analysis was determined by the presence of previous grubbing activity, fresh droppings and, since pink-footed geese become central place foragers during the incubation period to defend nests against predators (Fox et al 2007), proximity to nests. The presence or absence of grubbing was recorded along the line of each transect at 1 cm intervals in 2010 and repeated in in 2012 and 2013. All transects started at locations closest to nest sites (east) and ran perpendicular to the river (west). Photo examples of two transects are shown in Appendix 2.

Below-ground forage extractability

To determine how difficult it was for geese to remove the edible below-ground parts of typical forage plants (*Alopecurus borealis*, *Dupontia* spp., *Eriophorum scheuchzeri*), an artificial clamping mechanism was used. This allowed the force required to extract individual plants from the ground to be measured (see Anderson et al 2012). Sampling was conducted during the spring (mid- to end-May) pre-breeding period in Adventdalen (2010). Locations were selected by observing where groups of geese were feeding and had formed noticeably grubbed patches in the tundra vegetation. Individual shoots of forage plants located at the outer edge of such grubbing patches were selected for extraction. The same forage species were also extracted from similar habitats of the tundra that had been undisturbed by goose grubbing to allow comparisons between plants growing in grubbed and undisturbed tundra. Repeated sampling of the same areas and sampling of damaged shoots were avoided. The artificial clamping mechanism gripped an individual plant at the junction between the above- and below-ground parts and, when pulled directly vertically upwards, registered an extraction value in kg on a hanging balance. Many of the plant samples snapped at the junction of above- and below-ground parts, therefore only wholly intact samples were included in the analysis and, hence, sample sizes were limited (*A. borealis*, n = 17, *Dupontia* spp., n = 27, *E. scheuchzeri*, n = 23). Each sample was split into above- and below-ground components at the point at which live green tissue was observed. Samples were washed and oven dried at 70°C until a stable weight was obtained and then recorded. Below-ground biomass extraction values were calculated as the reading recorded from the hanging balance (in kg) divided by the dry mass (in g) of the below ground part of the plant removed from the soil. This accounted for differences in sizes of below-ground plant parts and allowed comparisons among species to be made.

Snow cover analysis

Cloud-free MODIS satellite images (spectral bands 1 (620-670 nm) and 2 (841-876 nm), resolution 250m) were used to determine snow cover in Adventdalen, Bohemannflya, Colesdalen and Sassendalen during late May (the pre-breeding period for pink-footed geese) for 2006, 2007, 2012 and 2013. It proved impossible to obtain cloud-free images for exactly the same date in each year, hence images used for analysis dated from 23 to 26 May. No atmospheric correction was applied and the MODIS Swath Reprojection Tool (https://lpdaac.usgs.gov/tools/modis_reprojection_tool_swath) was used to geo-reference each image. Snow cover estimates for each image were estimated by using visual training points and a maximum likelihood classification to generate a two class (snow, no snow) standard confusion matrix, with no less than 50 points identified for each class. We did not find any correlation between the date of image capture (day of year) and snow cover estimate at any of the survey locations (Adventdalen: $r = 0.14$, $n = 4$, $p = 0.86$; Bohemannflya: $r = 0.24$, $n = 4$, $p = 0.76$; Colesdalen: $r = -0.16$, $n = 4$, $p = 0.85$; Sassendalen: $r = 0.2$, $n = 4$, $p = 0.80$). Hence, we have assumed that the prevailing low temperatures (at or below freezing), minimal precipitation and the late onset of snowmelt in the days prior to and after image acquisition caused minimal error in our estimates of annual snow cover and that the images were representative of snow conditions at the same date from year to year and are therefore comparable.

Statistical methods

All statistical analyses were carried out in R version 3.0.2. Grubbing during the pre-breeding period, conducted over the larger spatial scale, modelled average and peak utilisation using auto-logistic (logit link) generalised linear models (GLM), since grubbing intensity reflects the binomial process of grubbing or no-grubbing on any given sector of the frame. Realised grubbing utilisation was modelled after first removing 0 values (i.e. unsuitable habitat where peak utilisation = 0) as an arcsin-root transformed ratio within an auto-normal GLM. Spatial autocorrelation in grubbing was accounted for by using the unweighted average grubbing intensity within a neighbourhood of 500 m radius as an autocovariate (for consistency with

Speed et al. 2009). This approach accounts for habitat selection at an even larger spatial scale, reflecting the landscape-level habitat selection by the pink-footed goose (see Speed et al 2009). Model selection was based on likelihood ratio tests (Chi-squared test for the auto-logistic models, and F-test for the auto-normal model). To determine whether grubbing intensities varied with time, and whether this co-varied with habitat preference, we tested for an interaction between time period and habitat suitability, as well as for an effect of time period, habitat suitability and the spatial autocovariate in determining grubbing intensity.

The lme4 package for mixed models (Bates et al 2013) was used when modelling grubbing by pink-footed geese at the nesting grounds over a smaller spatial scale. This allowed us to test whether the presence of existing grubbing patches influenced the probability of subsequent grubbing and if geese preferentially grubbed closer to nest locations.

Generalised linear mixed models (GLMM) with binomial distribution and logit link function were used to determine relationships between i) distance from grubbing in year 1 (2010) and probability of grubbing in subsequent years (2012 and 2013), and ii) distance along transects and probability of grubbing. Fixed effects were distance from the nearest grubbing patch in the first model and distance along transect in the second model, with transect number as the random effect in both models.

A one-way ANOVA was used to determine differences in below-ground biomass extraction forces between forage species growing in previously grubbed areas. Student's t-tests were used to compare mean extraction forces required to remove the below-ground biomass of forage plants growing in previously grubbed areas with those growing in undisturbed areas of the tundra within the same habitat type.

Results

Grubbing at pre-breeding sites

At the large spatial scale, 1799 plots were assessed in 2006/7 and 539 in 2013. Both average and peak grubbing intensity were related to habitat preference across both time periods. Although average grubbing did not increase between 2006/7 and 2013 (Table 1), peak grubbing did increase, particularly in the less preferred habitat (Table 1). Peak grubbing increased from 0.09 in 2006/7 (proportion of vegetation grubbed, s.e. = 0.01) to 0.13 (0.03) in 2013 in the least selected habitat, but decreased from 0.25 (0.02) in 2006/7 to 0.18 (0.02) in 2013 in the most selected habitat (Fig. 3). Realised grubbing did not increase with time, nor was it related to habitat preference (Table 1). At the habitat patch scale, not only was grubbing irregular, but most grubbing also had low spatial coverage (Fig. 4), with the majority of observed grubbing covering less than 10% of the habitat patch. An example of an intensively grubbed wet fen area in Adventdalen is shown in Appendix 2.

Grubbing at nesting grounds

At the small spatial-scale, geese were significantly more likely to grub either within areas which had previously been used for grubbing or close to existing grubbed patches compared to undisturbed ground (2012: $z = -31.7$, $p < 0.001$, deviance = 724.83, 2013: $z = -24.1$, $p < 0.001$, deviance = 931.38; Fig. 2a and 2b). Approximately 30-40% of patches grubbed in 2010 were used again in 2012 and 2013, although patches over 2 m away from the nearest grubbed tundra in 2010 were almost never used for grubbing in 2012 or 2013. The probability of grubbing decreased significantly with increasing distance from nest sites (2010: $z = -14.6$, $p < 0.001$, deviance = 856.24, 2012: $z = -19.1$, $p < 0.001$, deviance = 694.68, 2013: $z = -8.74$, $p < 0.001$, deviance = 932.65; Fig 2c), with 23 to 35% of wet fens immediately adjacent to nests grubbed, but only 5 to 12% of wet fens at the maximum distance of 27 m away from nests sites grubbed.

Below-ground forage extractability

In areas of the tundra previously disturbed by grubbing there was no difference in the extraction forces required to remove the below-ground plant parts of different species (*A. borealis*: 39.2±13.2 kg per g, *Dupontia* spp.: 30.5±9.4 kg per g, *E. scheuchzeri*: 45.0±8.3 kg per g, $F_{2,64} = 0.62$, $p = 0.56$; Fig. 5). Although the extraction forces required to remove *A. borealis* from grubbed and undisturbed tundra were comparable ($t_{44} = 1.87$, $p = 0.12$; Fig. 5), *Dupontia* spp. and *E. scheuchzeri* were significantly easier to remove from previously grubbed areas than from undisturbed ground ($t_{61} = 3.52$, $p = 0.02$, $t_{62} = 2.84$, $p = 0.04$, respectively; Fig. 5).

Discussion

During the study period (2006 - 2013), the Svalbard-breeding pink-footed goose population has increased dramatically from 52,000 to 81,500 individuals (Madsen and Williams 2012, Madsen et al 2013). This increased productivity in the population has coincided with earlier spring temperatures in Svalbard (Jensen et al 2013) and has led to concerns that the Arctic tundra may be at increased risk of damage/destruction/change due to the foraging habits of this herbivorous species (Madsen and Williams 2012). By assessing the impact of pink-footed goose grubbing across different vegetation types and under the differing extents of spring snow cover experienced in Svalbard we are able to outline changes in the use of the tundra landscape by this species. The advantage of working at different spatial scales and covering different stages of the breeding cycle allows us to suggest reasoning for such changes as well as for patterns of reutilisation of previously exploited habitat.

Larger scale studies conducted over multiple habitat types identified that, between 2006/7 and 2013, geese increased their use of some areas of the landscape but not others during the spring pre-breeding period. Specifically, the intensity of grubbing utilisation increased in less preferred, drier habitats and decreased in preferred wetter parts of the tundra. This is

consistent with findings from a study covering 2007 - 2012, which also showed that pink-footed geese increased their use of drier, less preferred tundra habitat, while decreasing their use of predominantly wetter areas (Pedersen et al 2013a, Pedersen et al 2013b). This change in habitat use correlates with the observed increase in the size of the population, possibly hinting that the presence of more birds has led to the use of less preferred drier habitat. Since the more preferred wetter areas of the tundra tend to constitute a smaller proportion of the landscape (Anderson et al 2012), this may also support the prediction that a greater population forces geese to forage in less preferred drier habitat.

An alternative explanation for the differences observed in habitat use by foraging geese may be related to the extent of spring snow cover at pre-breeding staging areas. Although the number of May thaw days in Svalbard has increased since 2000 (Jensen et al 2013) and have led to warmer spring temperatures, the High-Arctic still experiences extensive inter-annual variability in spring snow cover (Buus-Hinkler et al 2006, Rotschky et al 2012). Habitat use by foraging geese during the pre-breeding period is known to be influenced by patterns of snow cover in the landscape (Anderson et al 2012). Snow melts preferentially in drier areas, with more prolonged snow cover occurring in wetter tundra habitats (Anderson et al 2012). Thus, the use of less preferred drier habitat by pink-footed geese during the pre-breeding period may be a reflection of differing spring snow cover patterns. Indeed, when snowmelt during the pre-breeding period has been late geese have been observed to utilise the drier slopes and foot-hills when wetter habitats at lower elevations were still snow covered (own observations). The years in which our grubbing surveys have been carried out were classed as either having low spring snow cover (2006/7) or high snow cover (2012/13) (Table 2). Since the extent of spring snow cover at the pre-breeding sites calculated during our study also correlated positively with the pink-footed goose population size, we are currently unable to attribute any change in habitat use by foraging geese to one particular factor. Hence, further work, including population counts, transect resurveys for grubbing

intensity and spring snow analysis will be required to fully explain the changes observed in habitat utilisation by foraging geese.

We can be sure that, during the pre-breeding period, utilising drier areas offers the benefits of feeding in snow free tundra. In dry areas edible below-ground biomass may be lower than in wetter habitats (Anderson et al 2012) but forage plants commonly found in drier areas are easier to remove from the ground than species growing in undisturbed wetter parts of the tundra. Since the period when geese undertake grubbing, between arrival in Svalbard during mid-May to the early nesting phase during late-June, is limited and crucial in terms of gaining energy and maintaining body condition required for successful breeding (Hübner et al 2010), optimal foraging during this time is therefore critical. Using snow free areas of the tundra, where plant material is easily extractable, may provide geese with much needed feeding opportunities during this important period. However, in the long-term, such patterns of habitat use may be detrimental to the resilience and recovery of tundra vegetation. Higher intensity grubbing is more likely to shift the plant community towards a de-vegetated state (Speed et al 2010a). Drier plant communities have lower resilience and slower recovery rates from grubbing than wetter plant communities (Speed et al 2010a). Thus the increase in grubbing utilisation intensity of drier habitat suggests that these communities are at an increased risk of de-vegetation, particularly if the goose population continues to increase combined with late spring snowmelt years. However, since grubbing remained patchy at the habitat-patch scale, any de-vegetation is likely to be localised.

Small-scale surveys conducted immediately adjacent to nests at one of the main central Svalbard pink-footed goose breeding grounds revealed that previously grubbed wet tundra was more likely to be re-grubbed than undisturbed wet tundra. The probability of grubbing declined with increased distance from previously grubbed patches and geese were also more likely to forage in areas that were in close proximity to their nest sites. Feeding in such areas would allow adults to promptly return to the nest if approaching predators were

observed, hence aiding in nest defence. Additionally, geese probably fed in existing grubbed wet patches because the moss layer had already been removed and the extensive root structures of forage species loosened, disturbed and partly destroyed. Such changes to the root structure of forage species may explain why it appeared mechanically easier to remove below-ground biomass from the soil substrate in previously grubbed areas compared to 'pristine' undisturbed wet tundra. Thus, the changes to the mechanical properties of the below-ground biomass of forage species likely reduces the searching and handling time geese employ when feeding in previously disturbed areas. This would allow individuals time to ingest more material, which is advantageous for a species that has a poor digestion system and requires frequent feeding to maintain body condition.

Goose utilisation of pre-breeding staging sites varies between years, depending on snowmelt patterns (Anderson et al submitted), with the prevalence of grubbing also likely to vary with snowmelt timing. Thus, long-term monitoring, of both the extent of tundra usage by geese and the size of the goose population, is necessary if trends in disturbance caused by grubbing are to be identified, particularly if the pink-footed goose population continues its current rising growth trend. Our study suggests that there has been an increase in the intensity of grubbing by pink-footed geese concurrent with the population increase. However, any rate of vegetation change, its longer-term consequences and patterns of habitat use by an increasing population under different spring snowmelt conditions still remain to be demonstrated. This is of particular interest because the population increase has also been raised as a conservation concern in the international species management plan for the Svalbard population of pink-footed geese, implemented under the auspices of the African-Eurasian Waterbird Agreement (Madsen & Williams 2012; <http://pinkfootedgoose.aewa.info>), where a population target of 60,000 individuals has been agreed between the range states to avoid conflicts with agricultural interests in the staging and wintering areas as well as possible degradation of the Svalbard tundra vegetation.

Recommendations for future adaptive monitoring

The transect based sampling design has proved to provide reproducible data for monitoring extent and intensity of goose grubbing. The data suggest a coupling between goose grubbing and snow cover which needs better documentation. We hypothesise that in years with early snow melt the wet fen plots will be grubbed more intensively compared to late years, and vice versa for dryer habitats. In order to monitor future goose grubbing we propose a monitoring program based on the current methodology and study sites and including measures of timing of snow melt based on remote sensing (cameras or satellites). The monitoring program will have to be adjusted, hence adaptive, as the interactions between goose grubbing, population density and snow melt have been established. In order to feed effectively into the evaluation and reporting cycle of the international management plan for the pink-footed goose, we propose that the monitoring of grubbing is carried out at three-year intervals. However, to gain an understanding of the interactions more quickly, it would be beneficial to do some of the transects, e.g. in Adventdalen and Sassendalen, on an annual basis.

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Tables

Table 1. Likelihood ratio tests for selected models for average, peak and realised grubbing utilisation. Predictor variables for all models were habitat suitability (based on Speed et al. 2009), time period (2006/7 or 2013), the interaction between habitat suitability and time period, and the spatial autocovariate.

Average utilisation	Df	Deviance	Residual df	Residual deviance	p (χ^2)
Null	2333	482.6	-	-	-
Habitat suitability	1	65.04	2332	417.56	<0.001
Time period	-	-	-	-	-
Spatial autocovariate	1	41.49	2331	376.07	<0.001
Habitat suitability x Time period	-	-	-	-	-
Peak utilisation	Df	Deviance	Residual df	Residual deviance	p (χ^2)
Null	2333	954.16	-	-	-
Habitat suitability	1	114.73	2332	839.42	<0.001
Time period	1	0.06	2331	839.37	0.811
Spatial autocovariate	1	92.89	2330	746.48	<0.001
Habitat suitability x Time period	1	5.74	2329	740.73	0.017
Realised utilisation	Df	Deviance	Residual df	Residual deviance	p (F)
Null	579	54.91	-	-	-
Habitat suitability	-	-	-	-	-
Time period	-	-	-	-	-
Spatial autocovariate	1	1.45	578	53.45	<0.001
Habitat suitability x Time period	-	-	-	-	-

Table 2 Snow cover percentages for Adventdalen, Bohemannflya, Colesdalen and Sassendalen during May 2006, 2007, 2012 and 2013 derived from MODIS satellite images.

Year	Adventdalen	Bohemannflya	Colesdalen	Sassendalen
2006	35%	22%	37%	49%
2007	38%	39%	33%	51%
2012	47%	47%	53%	61%
2013	48%	46%	50%	46%

Figures

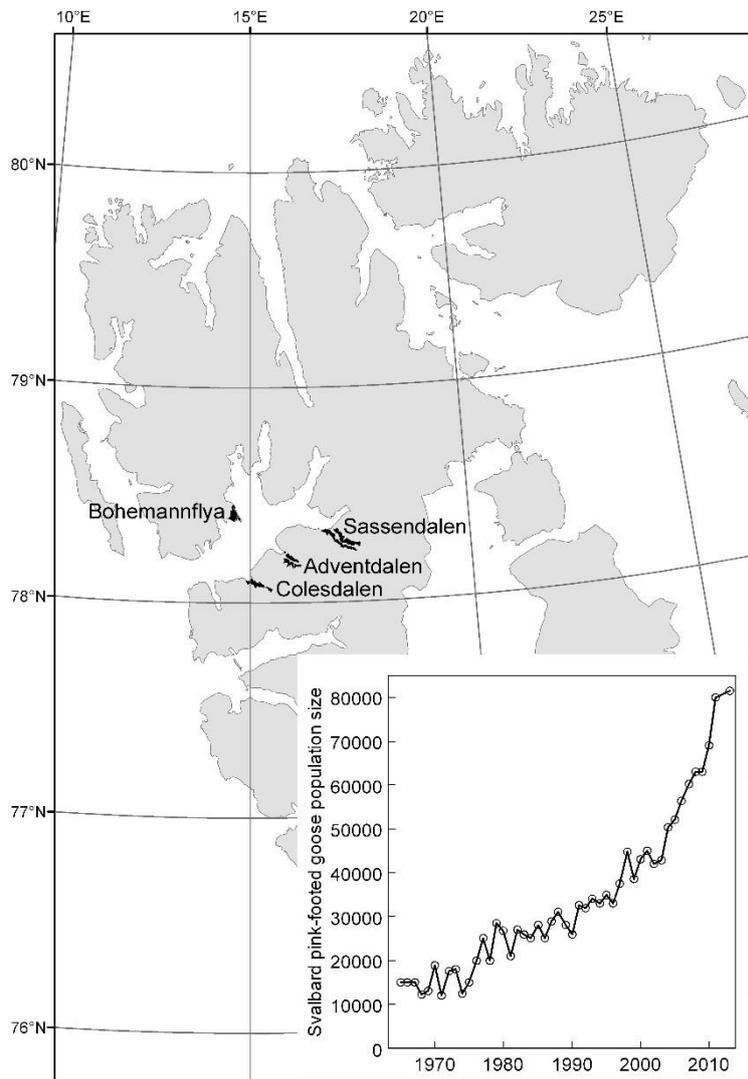


Figure 1. Locations of the four grubbing survey locations (indicated in black) in central Svalbard. The insert figure shows the population trend for Svalbard pink-footed geese. Population sizes were estimated during autumn/winter surveys in the overwintering area; data from Madsen and Williams (2012) and Madsen et al (2013).

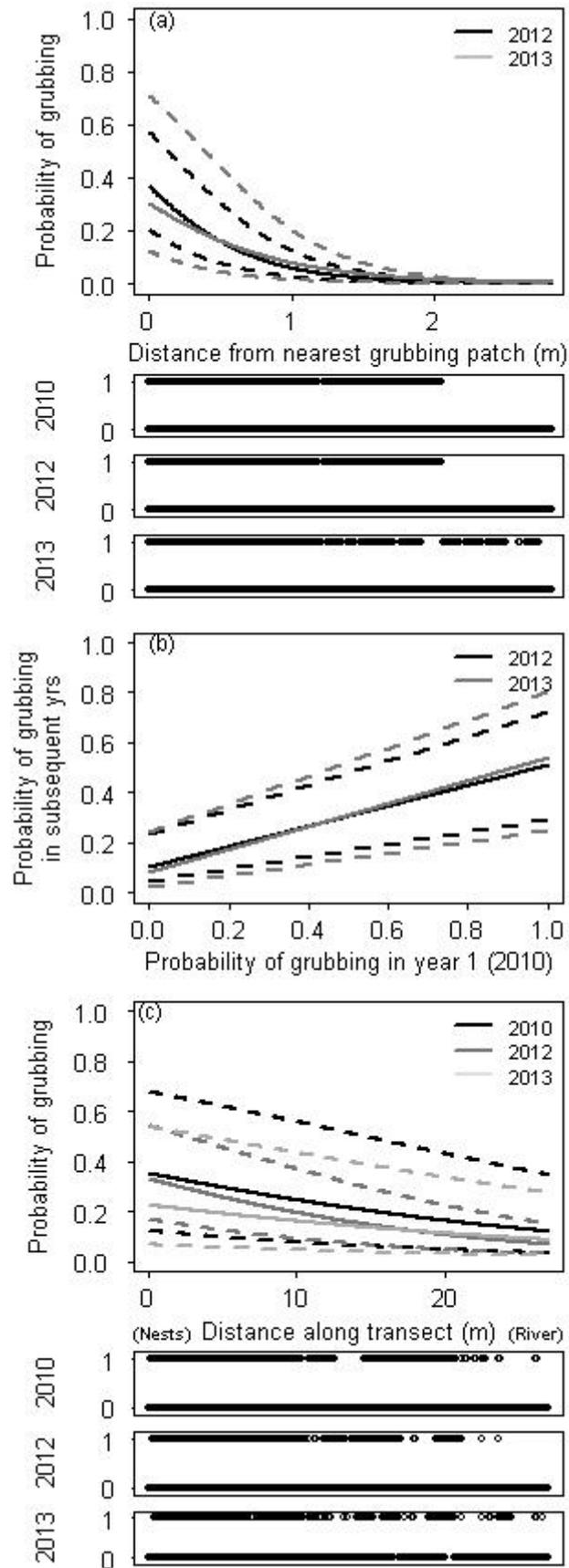


Figure 2. Probability of pink-footed goose grubbing at the small-scale in wet fen habitat in Sassendalen, Svalbard. (a) large panel: Probability of grubbing in 2012 and 2013 related to the distance (m) from nearest grubbing patches measured in the reference year 2010, small panels: presence (1) and absence (0) of grubbing in 2010, 2012 and 2013 related to the distance from the nearest grubbing patch; (b) probability of grubbing in 2012 and 2013 related to the probability of grubbing in the reference year 2010 and (c) large panel: probability of grubbing in 2010, 2012 and 2013 related to distances to nest sites, small panels: presence (1) and absence (0) or grubbing in 2010, 2012 and 2013 related to distances to nest sites. The 95% confidence intervals are shown as broken lines.

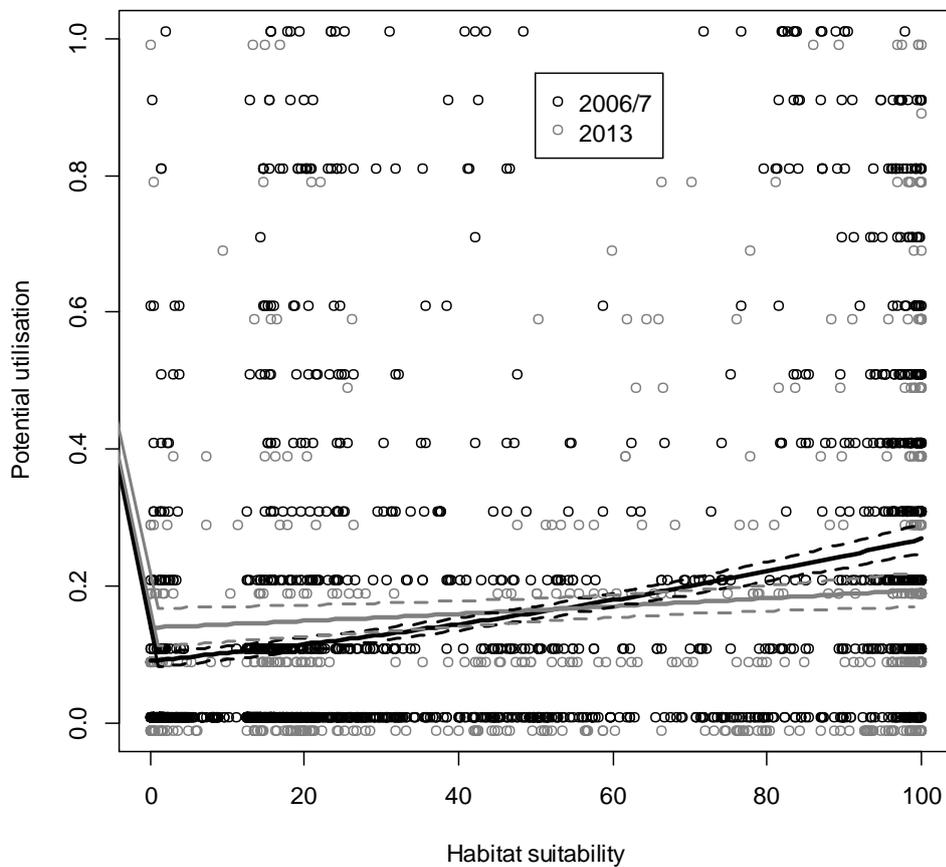


Figure 3. Peak grubbing utilisation (maximum intensity of disturbance at a scale of 35 × 35 cm feeding station within a 5 × 5 m habitat patch) plotted against habitat suitability (Speed et al. 2009) in 2006/7 and 2013. The auto-logistic regressions are shown with solid lines, with standard errors shown by dashed lines. Black symbols indicate 2006/7 data and grey symbols 2013 data.

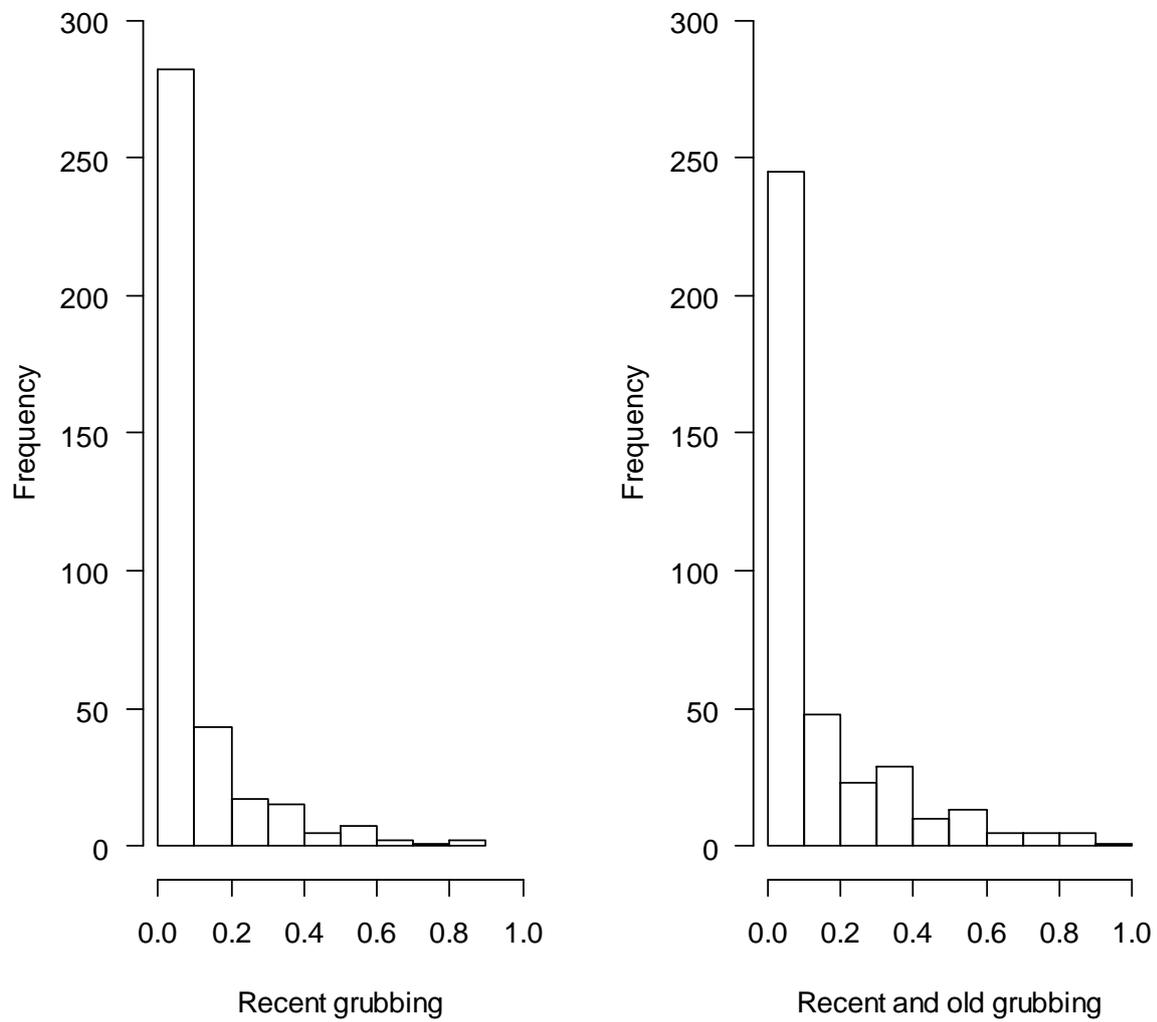


Figure 4. Distribution of intensities of grubbing cover in 2013. (a) Recent (current year's) grubbing and (b) recent and older grubbing in 2013. Grubbing is expressed as the proportion of a 5 × 5 m habitat patch covered by grubbing (habitat patches where grubbing was absent are not included).

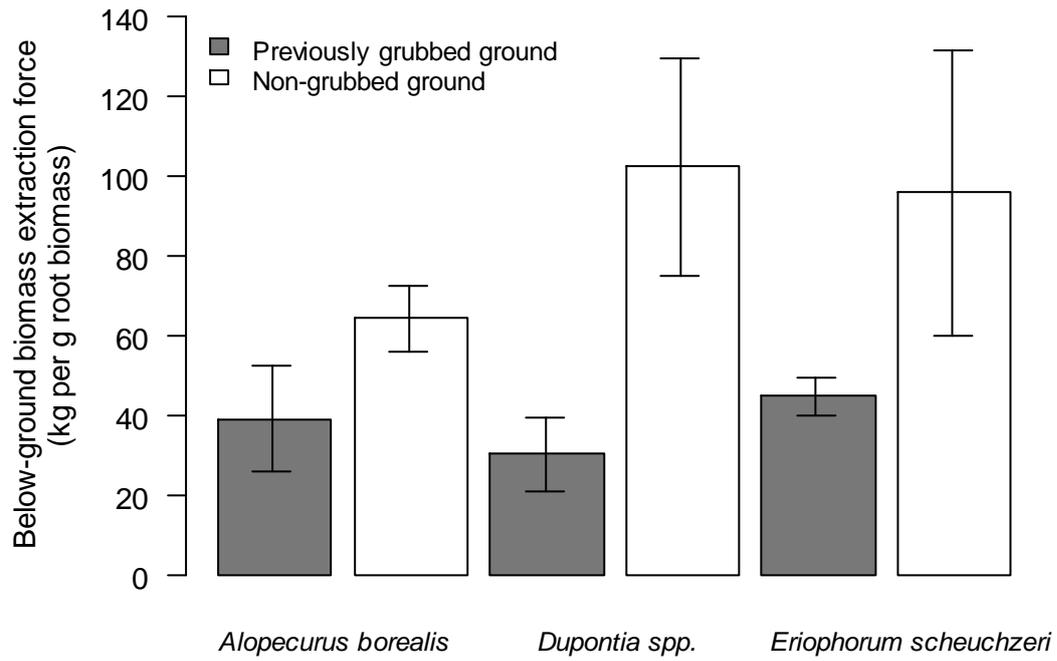
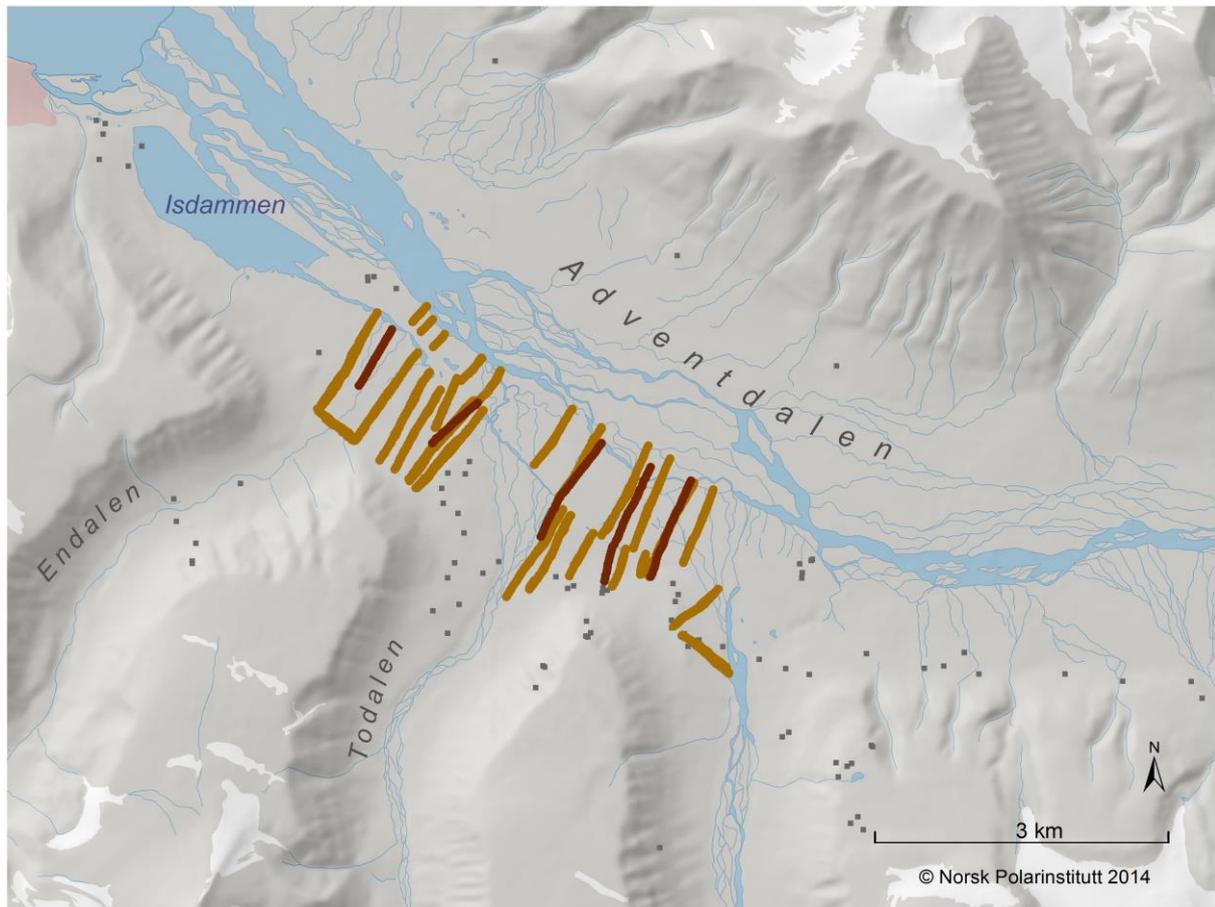
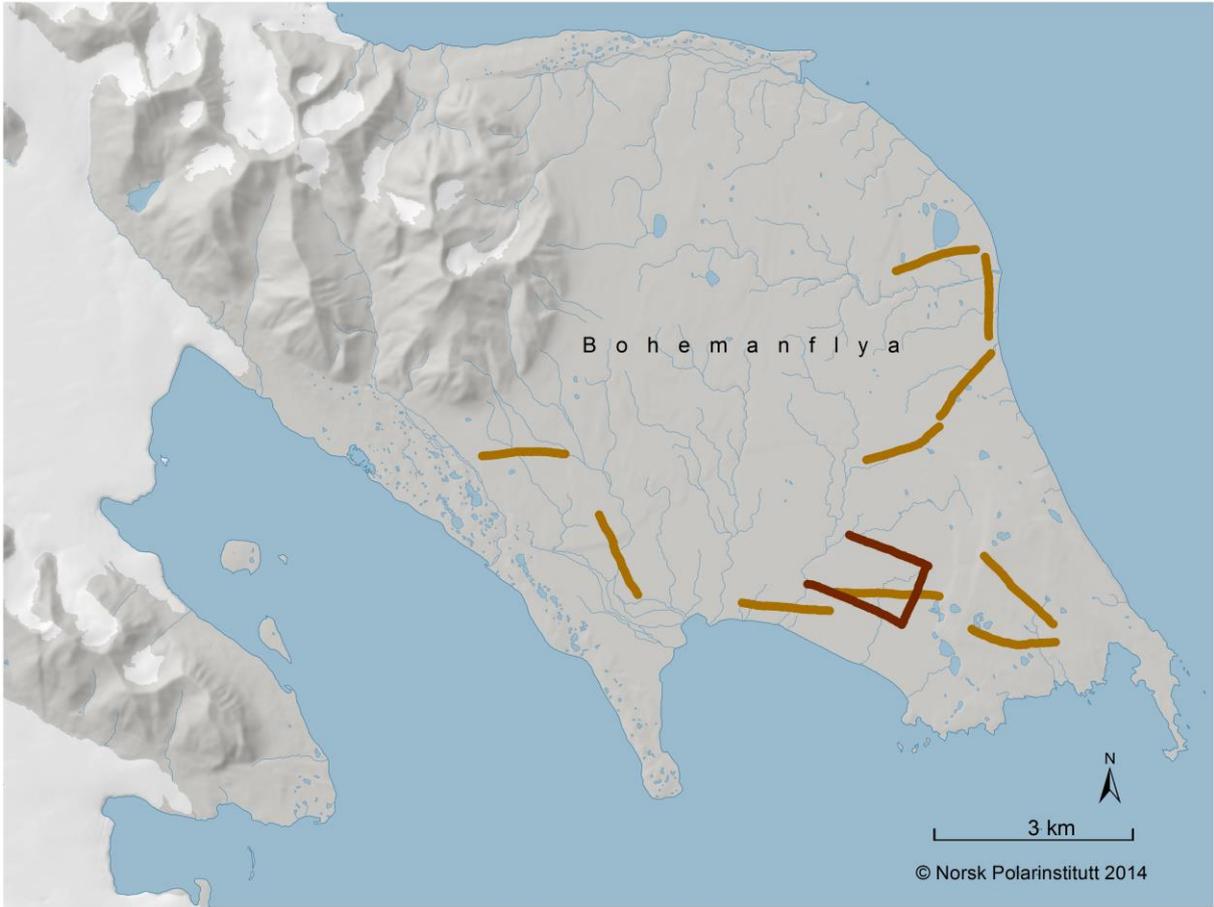


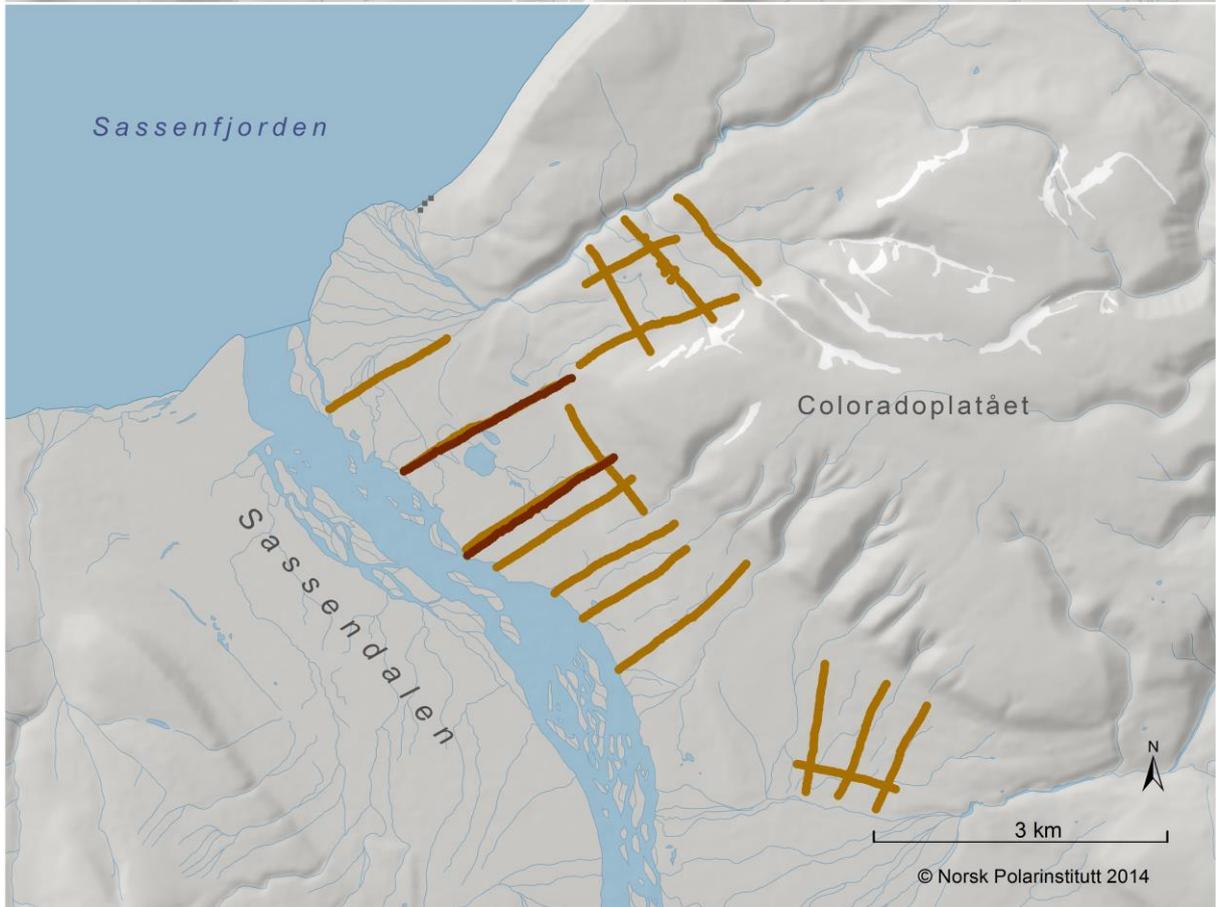
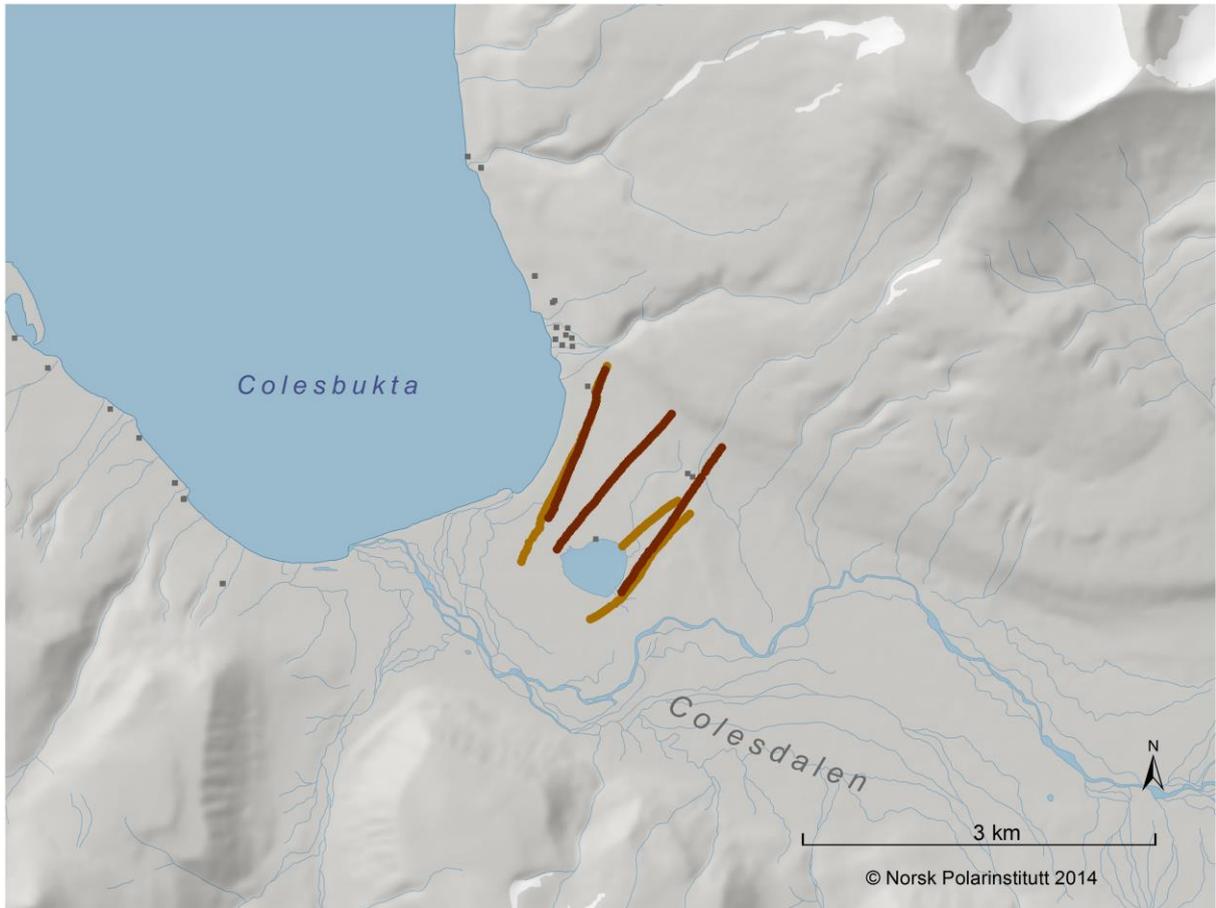
Figure 5. Below-ground biomass extraction forces per equivalent mass of root biomass for three pink-footed goose forage species. Bars indicate standard errors. Data for samples from “non-grubbed ground” from Anderson et al (2012).

Appendix 1

Detailed maps of transects in the four study areas: Adventdalen, Bohemannflya, Colesdalen and Sassendalen. Red lines: transects used in 2006/2007; black lines: transects used in 2013 (Norwegian Polar Institute).







Appendix 2

Photo examples of goose grubbed areas in Adventdalen (first photo) and Sassendalen
(photos: Jesper Madsen)





