

Disturbance, recovery and tundra vegetation change

Final report project 17/92 - to Svalbard Environmental Protection Fund

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Plate 1. Goose-driven dominance of the sedge *Carex subspathacea*, replacing the former dominant marsh graminoids *Dupontia* spp. and *Eriophorum scheuchzeri* with yet unknown ecosystem effects. Photo: Helen Anderson.

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Foreword

During the last 20 years, Svalbard's climate has grown warmer, Svalbard reindeer almost doubled in population size, and Svalbard pink-footed geese increased dramatically in both number and spatial extent. All three factors can strongly influence tundra vegetation, but sufficiently long-term and spatially extensive studies on Svalbard's vegetation are lacking, preventing us to appraise the impact of changes in climate and herbivore densities.

Svalbards miljøvernfond allowed us to move away from this position, by providing funding for a new programme of work to trace, literally, earlier steps made. Since 1997, as part of a long-term study of the reindeer population (Albon et al. 2017), vegetation work commenced in one of Svalbard's most productive area, the Colesdalen-Reindalen valley system. Part of this work took place in a relatively confined area (Semmeldalen), revealing - among other aspects - a great sensitivity of tundra plant production to current summer's temperature conditions (Van der Wal and Stien 2014). Other parts covered the 'reindeer study area', with vegetation transects walked in most of its valley. About 10 years on, when realising the scale and potential impact on the vegetation by the expanding pink-footed goose population, we also started to investigate their disruption of tundra vegetation and recovery thereof, through the initiation of a short-term experimental vegetation disturbance experiment in Adventdalen (Speed et al. 2010). Svalbards miljøvernfond provided us with the opportunity to capitalise on these two unique and by now historical research efforts, and embark, in 2018 and 2019, on a mission to reveal valley-wide vegetation change over a 20-year period and the drivers thereof, the findings of which we report here.



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Plate 2 Reindeer summer grazing on dry Ridge vegetation, disturbing the vegetation little unlike the situation –in places - during winter. Photo: René van der Wal

Most important findings

Despite a warming climate, increases in reindeer numbers and a strong increase in the pink-footed goose population over the last 20 years in the Colesdalen-Semmeldalen-Reindalen area, much of the re-surveyed tundra remained relatively unchanged. In several valleys the vegetation became somewhat wetter, yet in others no difference in the prevalence of difference vegetation types was observed. Disturbance to the tundra was very widespread, and mostly due to geese. However, this had limited impact on the vegetation because most grubbing takes place in wet tundra where recovery is rapid. While the relative abundance of vegetation types remained remarkably similar, the character of a considerable part of notably wet marshes changed. Here, disturbance by geese has allowed the sedge *Carex subspathacea* to replace formerly abundant graminoids (such as *Dupontia* spp. and *Eriophorum scheuchzeri*). From its stronghold in wetter areas, the sedge is now moving into drier parts of the tundra, creating a vegetation type not observed in the past. Similarly, depletion of favoured graminoids by geese in wetter areas has also contributed to an increase in horsetail (*Equisetum* spp.) in respective communities. Reindeer had greater impacts on the vegetation than expected, with their activities often resulting in bare soil. However, dissimilar to goose driven disturbance, little vegetation change resulted from reindeer activities. An unexpected finding was that many gaps in the vegetation created by reindeer higher up on ridges were subsequently used, and often extended, by geese – a form of interaction not documented before. Human disturbance of the tundra was extremely rarely encountered, and thus negligible compared to both goose and reindeer-driven disturbance. Thus, whilst it is evident that humans can degrade tundra vegetation, notably near settlement areas and points of tourist attraction, we did not witness this in our – spatially extensive – investigation.

Environmental benefit

This study has shown that 13 years after (simulated) goose disturbance to tundra vegetation, such disturbances remain clearly visible in drier habitats (*Dryas* ridge and *Cassiope* communities). However, in wetter vegetation types (*Dupontia* and other marsh communities) these disturbances were no longer detectable. In mesic (Wet moss tundra) and *Dupontia* communities, re-grubbing of experimental plots by geese kept some open. In most cases, however, it was not exposed soil or decomposing moss that identified our experimental plots, but vegetation changes such as the loss of specific graminoids favoured by geese (notably *Dupontia* spp.) and increases in horsetail (*Equisetum* spp.) and the sedge *Carex subspathacea*. Thus, although goose grubbing is the most common form of disturbance across the tundra, the impact in terms of creating large areas of bare unvegetated soil is limited. A greater impact of goose disturbance may be a change in plant species composition in wetter vegetation types. Both of these findings should be taken into account when assessing the adaptive management plan for pink-footed geese.

Although disturbance to tundra vegetation by reindeer is lower than that of goose driven disturbance, the potential for reindeer activities to generate bare soil is greater than that for geese. This should be noted when considering the recently published findings on the size and spatial extent of the reindeer population in Svalbard.

Suggestions for action

1. Investigate the spatial extent (both within wetter plant communities and in drier habitats) and broader ecological consequences of *Carex subspathacea* expansion.
2. Integrate the findings on the extent and resilience of the tundra to goose herbivory into the adaptive pink-footed goose management plan.
3. Determine the ecological interactions between goose and reindeer that lead to co-occurrence of disturbance in particular areas of the tundra.

Relevance for environmental management

Our findings show that goose grubbing does little to damage tundra in the longer term, as the most heavily impacted parts – wetlands – recover quickly. Their impacts in terms of plant species change are considerable and widespread, however, and the consequences of this for other species and wider ecosystem functioning should be investigated. The areas where both reindeer and geese cause longer-term disturbance to the tundra are the vegetated ridges. Here, they appear to work in concert – a principle not observed before and worthy of more in-depth investigation. Understanding what the rather dramatic vegetation change in wet tundra, from *Dupontia* spp. and *Eriophorum scheuchzeri* dominated to *Carex subspathacea* dominant, and the subsequent encroachment of this species into drier tundra, means for the functioning of the tundra more widely is clearly a priority.



Plate 3 Reindeer disturbance to Ridge vegetation due to winter grazing, with the openings subsequently used and enlarged by spring-grubbing pink-footed geese. Photo: René van der Wal

Summary

The Svalbard pink-footed goose population has rapidly increased during the last 20 years. In spring, their feeding on belowground plant parts (so-called grubbing) disrupts the moss mat in valleys across Svalbard. Grubbing is particularly common in wet tundra and can result in 'vegetation-free craters' of several square meters. In late snow-melt years geese are pushed into feeding in drier areas, thereby leaving the whole tundra vegetation demonstrably scarred. Indeed, goose grubbing may well be the strongest driver of vegetation change in warmer parts of the archipelago, but long-term recovery and large-scale vegetation change studies to determine this are lacking. Therefore, we capitalised on three unique and separate historical studies to determine: a) long-term vegetation recovery from grubbing disturbance over a 12-year period (in six habitats ranging from dry to wet); and b) valley-wide vegetation change over a 20-year period and drivers thereof.

Our findings show that much of the tundra vegetation remained relatively unchanged. Despite widespread disturbance to the vegetation, by herbivores and environmental pressures, there was limited long-term change in the relative abundance of plant communities across valleys. There was some movement, however, for communities of intermediate wetness that signalled an overall increase in moisture levels (e.g. *Luzula* heath becoming *Luzula-Alopecurus* heath; *Luzula-Alopecurus* heath becoming Wet moss community), plausibly related to a deepening of the active layer. But this trend did not occur in all valleys and most remained relatively stable in terms of plant community abundance over 20 years.

Yet, changes in plant species composition within plant communities clearly occurred, with the cover of shrubs declining in drier communities, forbs increasing on Graminoid slopes, and grasses increasing in marshes. In fact, quite dramatic vegetation change did take place in wetter parts of the tundra. Here, cover of the horsetail *Equisetum arvense* and the sedge *Carex subspatacea* increased significantly, while graminoids such as *Dupontia* spp. and

Eriophorum scheuchzeri (both favoured by pink-footed geese) decreased. Such changes are to the extent that food web or wider ecosystem consequences are likely.

The recording of disturbance to tundra vegetation during our surveys in 2018 and 2019 revealed that goose grubbing was omnipresent across all valleys investigated (Fardalen, Colesdalen, Bodalen, Skifferdalen, Semmeldalen, Istjorndalen, Passdalen, Kalfdalen, Reindalen and Adventdalen), and was by far the greatest cause of disturbance of tundra vegetation. Such disturbance-driven activity by geese lead to the exposure of very little bare soil and in the longer-term appeared to result in the specific vegetation changes detailed above in wetter parts of the tundra.

Resurveying plots that had been subject to experimental disturbance of the vegetation (in the forms of turf stripping and simulated goose grubbing at different intensities) in Adventdalen 13 years ago revealed that such disturbances remain clearly visible in drier parts of the tundra (*Dryas* ridge and *Cassiope* communities). By contrast, such disturbances were no longer detectable in wetter parts of the tundra (*Dupontia* and mire communities). In mesic (Wet moss) and *Dupontia* communities geese continued to grub at the sites of the experimental plots. In most cases, however, this did not lead to the presence of exposed soil or decomposing moss, but to vegetation change of the kind observed in the transect and plot surveys in the Colesdalen-Reindalen-Semmeldalen area (see below).

Due to the habitat preference of pink-footed geese for (mostly) wetter areas, across valleys grubbing had limited impact in most places. The exception was in wetter parts of tundra, which are used for concentrated foraging early in the year when snow melt is progressing. Here, the extensive grubbing, walking and selective grazing of pink-footed geese disfavoured formerly dominant marsh grasses and rushes (notably *Dupontia* spp. and *Eriophorum scheuchzeri*) and lowered the moss mat - thereby changing the hydrological and possibly snowmelt conditions experienced by plants, allowing other species to colonise. The

most prominent species taking advantage of the extensive engineering of wetland vegetation by geese was the sedge *Carex subspathacea*. Twenty years ago, we found this species almost exclusively along the coast in Colesdalen, where in select locations it formed mats of floating vegetation. In 2018/19 the species was found in many wet parts of the tundra across much of the surveyed area, and dominant in part. The species also moved into drier areas, creating a vegetation type not observed in the past. Understanding what this rather dramatic vegetation change means for the functioning of the tundra is a priority.

Reindeer were the second most widespread agent of disturbance, with their impacts greater than expected. Unlike goose driven disturbance, reindeer activities often lead to bare soil, although the overall extent of reindeer impacts on the vegetation was limited. Only parts accessible in winter and early spring, i.e. vegetation on higher-up ridges and protruding humps lower down in valleys, were often disturbed. In these areas, bare soil was exposed, due to winter grazing, scraping and walking. One notable finding was that many gaps in the vegetation created by reindeer high up on ridges were subsequently used, and often extended, by geese. This form of interaction between reindeer and geese has not been documented before, and warrants further investigation.

Disturbance of the vegetation by environmental agents proved more difficult to assess than for geese and reindeer. However, most disturbances attributed to environmental factors tended to be limited in frequency but with considerable impact when it did occur. The most common forms of disturbances were erosion due to meltwater action in spring, disrupting river bank vegetation, and frost boils. There was evidence for quite a number of cases where there was an interplay between environmental disturbance and disturbance caused by reindeer and/or geese, including situations where either alone would not have noticeably disrupted the vegetation. This was particularly noticeable with respect of frost boils, with deer breaking open the thin layer of vegetation covering the frost boils while walking over them.

Human impacts were limited to some snow scooter tracks on the upper parts of small vegetation mounds lower down in valleys (due to late spring travel when snow cover is low), and a few footsteps. Such human driven disturbance of the tundra was encountered extremely rarely, and was negligible compared to both goose and reindeer-driven disturbance. Thus, whilst it is evident that humans can degrade tundra vegetation, notably in reasonably confined areas near settlements and points of tourist attraction, we did not witness this in our – spatially extensive – investigation.



Plate 4 Vegetation on small wet frost boils walked open (and lightly grubbed) by pink-footed geese during spring or early summer– a common form of disturbance where soils are soft and the moss mat thin vegetation layer. Photo: René van der Wal.

Introduction

Long-term changes in the quality and quantity of vegetation in grasslands and arable lands have, together with reductions in hunting practice and the formation of nature reserves, driven down over-winter mortality of waterfowl (Van Eerden et al. 2005). This has led to particularly dramatic population expansions of arctic-breeding geese (Fox and Abraham 2017). The impact of such expanding goose populations on their arctic breeding grounds has been well studied in and around La Pérouse Bay, Hudson Bay area, subarctic Canada. Here, the dramatic increase in the number of breeding and spring-staging birds foraging on below-ground plant parts has caused vegetation cover decline and soil exposure, leading to the development of hypersaline topsoil, which has in turn killed off extant vegetation (Srivastava and Jefferies 1996) and reduced plant recovery potential (Handa et al. 2002). This resulted in exceptionally large-scale denudation of, notably, saltmarsh habitat, and to a lesser extent also freshwater habitat, in and around snow goose colonies along the 2000 km-long Hudson Bay coastline (Jefferies et al. 2006). Since vegetation recovery is slow (freshwater marsh) or absent (saltmarsh; Peterson et al. 2013), the lack of vegetation causes geese to move away and establish colonies elsewhere, resulting in further goose impacts across the region. Similar long-lasting, and large-scale, disruptions of the vegetation can now be observed across the Canadian Arctic. For example, between 1988 and 2011, well north of the Hudson Bay in Nunavut, a five-fold increase in area of exposed peat habitat (269 to 1,373 km² in a 36,370 km² study area) and a 48% loss of wet sedge meadow have been observed (Conkin and Alisauskas 2016). Although goose impacts in large parts of the Canadian Arctic remain limited, goose numbers are very high, colonies numerous, and local grazing impacts strong and replicated over large areas.

Whilst Palearctic goose populations have expanded almost as dramatically, the impacts on their Arctic breeding grounds appears to be far less well pronounced, but also considerably less well studied. The best understanding of the impacts of an increasing population of colony-breeding geese we have is for barnacle geese breeding in Svalbard. These barnacle

geese have increased in population size (Matthews et al. 2019), but unlike larger goose species, are not sufficiently strong-billed to extract the belowground parts of many plants. As a result, barnacle geese largely graze plants above-ground, typically leading to a suppression of vascular plant and moss biomass (Kuijper et al. 2009). Although this thereby reduces the carbon sequestration ability of tundra, recovery, when grazing pressure is reduced, is rapid (Sjögersten et al. 2008, 2011).

The population size of the larger Svalbard pink-footed goose has also rapidly increased during the last 20 years (Madsen et al. 2017, AEWA 2019). As with the Canadian snow geese, pink-footed geese engage in extensive and destructive feeding on belowground plant parts in spring (so-called grubbing), which involves the removal of the moss mat to access the desired plant storage organs (Fox 2006, Anderson et al. 2012). Disruption of the vegetation can be considerable and is visible across large parts of Svalbard, although the impact has been greatest in the warmer areas of the archipelago, including Nordenskiöld Land (Speed et al. 2009). Much of the grubbing takes place in the wetter parts of the tundra, with repeated use by the birds leading to 'vegetation-free craters' of several square meters. Grubbing may appear to have a less dramatic effect in drier parts of the tundra, but when snowmelt is late extensive grubbing also occurs here, thereby leaving all areas of the tundra subject to disturbance by pink-footed geese (Pedersen et al. 2013, Anderson et al. 2015a, 2016). We suspect that goose grubbing may be the greatest driver of vegetation change in the warmer parts of Svalbard, but the absence of long-term and large-scale vegetation studies prevents us from determining to what extent these birds shape tundra vegetation at the landscape scale and how that compares with other agents of disturbance.

Herbivores other than geese can disturb tundra vegetation. For instance, during winter, reindeer disturb patches of vegetation when cratering through the snow into the mineral soil in search of food plants (Svanson and Barker 1992, Hansen et al. 2010). Also, when soils are not frozen, reindeer can break through the vegetation when walking or running, with

such poaching being particularly prevalent in wet habitats and when densities of reindeer are high (Kitti et al. 2009). Where available, reindeer use branches of trees to rub their antlers on to aid in shedding velvet, with subsequent impacts on northern treelines (e.g. Tikhomirov 1962). In areas where trees or tall shrubs are absent, ground vegetation absorbs the impact of such antler wiping, which may lead to patches of exposed soil (Kightley and Smith 1976). On Svalbard, the reindeer population has returned to a high level after almost a century of strict hunting control (Le Moullec et al. 2019). The species is once again widespread and high densities of animals have been recorded in the most productive parts of the archipelago (Le Moullec et al. 2019). It is expected that the aforementioned impacts of reindeer activities (disturbance of the vegetation through cratering, walking and antler wiping) will be visible, but the extent of such disturbance and its impact on tundra vegetation is unknown.

Humans can also disturb tundra vegetation (Forbes et al. 2001, Tolvanen and Kangas 2016). On Svalbard this is particularly true in and around settlements and tourist hotspots, including landing sites (Hagen et al. 2012). The continual increase in the number of tourists has led to gradual and ongoing loss of vegetation cover on and around paths in well-visited places like Ny-Ålesund (Thuestad et al. 2015). Likewise, camping on the open tundra, be this by tourists or scientists, can leave its traces on the vegetation, although impacts may recover relatively swiftly (West and Maxted 2000). Snow scooter use, which has also increased considerably over the last few decades (Norwegian Environment Agency 2008) may also disturb vegetation when driven under conditions with too little snow (Norwegian Environment Agency 2008). All human impacts are a function of human density, and hence in places with relatively few visitors or temporary inhabitants (e.g. huts), human-driven disturbance of Svalbard's tundra is likely to be low.

Disturbance from mammalian herbivory is widely acknowledged as driver of tundra vegetation change (Van der Wal 2006, Olofsson et al. 2009, Ravolainen et al 2011). Also on Svalbard it has been reindeer, and not geese, to have been responsible for larger-scale

changes in plant community dynamics (Hansen et al. 2006) and longer-term vegetation change (i.e. disappearance of lichens, Van der Wal et al. 2001; promotion of graminoids, Van der Wal and Brooker 2004). Yet, the few studies from Svalbard reporting on contemporary vegetation change more broadly adhere to the sentiment that “Svalbard ecosystems are adapted to extreme fluctuations in climate on different temporal scales and can thus be regarded as rather robust” (Jónsdóttir 2005). Away from successional literature reporting on vegetation change over many centuries through deploying palynological (e.g. pollen or macro-fragment) analysis or space-for-time substitution (e.g. chronosequence) approach, we are aware of only two studies that report on findings from actual repeat visitations, and those do not take herbivory into account but couch their work in the context of observed climatic amelioration. The first one (Prach et al. 2010) concerned a strip of tundra (approximately 2 km x 0.5 km) near Brucebyen, Adolfbukta Bay, Billefjorden, West Spitsbergen. Remapping in 2008 did not reveal any vegetation changes on stabilised substrate since a previous study some 70 years prior. A second, more extensive and detailed study (Kapfer and Grytnes 2017) concerned the resurveying, in 2009, of three plant sociological studies up to 85 years before, using 186 resampled plots around Isfjorden, West Spitsbergen. They report that “the communities studied were relatively stable on a broad scale”, and interpret the changes in species presence and cover as “internal community restructuring”. Thus, from a botanical point of view, vegetation – at least in West Spitsbergen – has changed little during the last 70+ years. Yet, from a herbivory perspective, vegetation change should be expected, but so far has been focussed on reindeer whilst disturbance by geese now likely prevails.

To shed light on the long-term consequences of disturbance to tundra vegetation and to document any changes therein we made use of two historic datasets on (i) the abundances of plant communities and species across a large area of Nordenskiöld Land, and (ii) the potential of different plant communities and species to recover from experimentally simulated goose grubbing. This has enabled us to: (i) highlight longer-term (over a 20-year period)

changes in plant communities and species across central Svalbard, and to suggest the reasons for such changes; (ii) document the ability of tundra vegetation to recover from goose-driven disturbance after a 13-year period; and (iii) give current estimates of the extent and intensity of disturbance across Nordenskiöld Land attributable to geese, reindeer, environmental drivers and humans.

Methods

Study area description

This study was carried out in ten valleys located across Nordenskiöld Land in central Svalbard (Fig 1). Svalbard is located in the High Arctic zone with vegetation across the study area characterised by bryophyte (mostly mosses) carpets interspersed with vascular plants. The dwarf shrubs *Cassiope tetragona*, *Dryas octopetala* and *Salix polaris* are also present. Vegetation cover extends from the valley floor to an elevation of approximately 250 m.

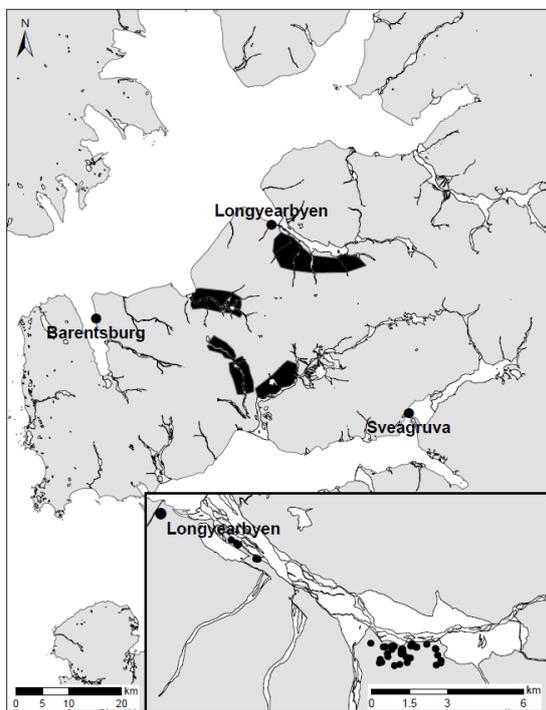


Figure 1 Map of central Svalbard showing locations of valleys in which an assessment of long-term vegetation change, the potential of tundra vegetation to recover from experimental goose disturbance and the extent of disturbance by pink-footed geese, reindeer, humans and environmental actions was made. Shaded areas in the main map indicate locations of the valleys used in the assessment of long-term vegetation change and in the extent of disturbance by geese, reindeer, humans and environmental actions. The inset map shows locations of the experimental grubbing plots used to assess the potential of tundra vegetation to recover from disturbance.

Valley transects

To determine change in the prevalence of vegetation types and the possible causes thereof, transects in nine valleys (Appendix Table 1) were surveyed in July/August 1997/98/99 and in

July/August 2018/19. A total of 39 different transects in these nine valleys were surveyed, covering a total distance of 59.1 km (Appendix Table 1). Vegetation was surveyed along straight transect lines running from the bottom of a valley (starting at the edge of a river) upslope to higher elevations until barren polar desert was encountered. The GPS co-ordinates of the start and end point of every transect were recorded, allowing these points to be relocated in 2018/19 to give comparable data for analyses. The error associated with the GPS co-ordinates was determined in the field as ± 8 m. Every 15 m a visual inspection of the vegetation in an area of 2 m x 2 m in front of the observer (1 m either side of the observer and 2 m in front) was made and recorded. The dominant plant community was determined, thereby differentiating between nine different ones (see Table 1 for communities and their main vascular plant species). These represent the common plant communities found across Nordenskiöld Land and are easily distinguishable in the field. In addition, data on bare or unvegetated ground was collected so that its frequency could be assessed. To determine long-term changes in the prevalence of plant communities among different valleys, a generalised linear mixed model with a Poisson distribution was used with year and valley as fixed factors and transect as the random factor. Tukey's HSD tests were applied to assess differences within valleys.

Table 1 Plant communities and their main vascular plant species used to assess long-term vegetation change in Svalbard.

Plant community	Main vascular plant species
Polar desert	<i>Papaver dahlianum</i>
<i>Dryas</i> ridge	<i>Dryas octopetala</i>
<i>Cassiope</i> heath	<i>Cassiope tetragona</i>
<i>Luzula</i> heath	<i>Luzula</i> spp.
<i>Luzula</i> heath with <i>Alopecurus</i>	<i>Luzula</i> spp. <i>Alopecurus borealis</i>
Graminoid sward	<i>Poa</i> spp.
<i>Alopecurus</i> / <i>Equisetum</i> /Wet moss	<i>Alopecurus borealis</i> <i>Equisetum arvense</i>
<i>Phippsia</i> snowbeds	<i>Phippsia</i> spp.
<i>Dupontia</i> / <i>Eriophorum</i> marsh	<i>Dupontia</i> spp. <i>Eriophorum scheuchzeri</i>

In 2018 data on disturbance to the tundra vegetation was also recorded. We recorded the presence/absence of disturbance, the agent that had caused the disturbance (geese, reindeer, humans, environmental factors such as landslips, frost boils, gravel dumping, etc.) (Plates 5 & 6), the area impacted by that disturbance (low [$< 5\%$ of plot], medium [6-25% of plot], high [26-50% of plot] or very high [$> 51\%$ of plot]) and the area of bare soil exposed (0, 10 x 10 cm, 35 x 35 cm, 50 x 50 cm or $> 50 \times 50$ cm) at every transect survey point.

Vegetation plots

To determine plant species' change within plant communities and places, vegetation plot surveys were undertaken in August 1997 and July/August 2018. In the original survey, plots were distributed across nine different plant communities (see Table 1 for communities and their main vascular plant species). These communities were the same as detailed for the Valley Transects. Plots were randomly placed within plant communities. Each plot measured 2 x 2 m and its GPS co-ordinates allowed it to be relocated in 2018. Plots that had been identified in 1997 as bare ground/gravel, polar desert or *Phippsia* snowbeds were not re-surveyed in 2018 due to their low sample numbers and time constraints. Of the 215 plots surveyed in 1997, 100 were located and resurveyed in 2018, allowing a paired comparison of 100 plots to be made.

In 1997 and 2018 the percentage cover of 65 different vascular plant species (Appendix Table 2) was estimated, alongside estimates of total moss cover and lichen cover. From these data, we calculated (i) vascular plant species richness (i.e. total number of vascular plant species), (ii) percentage cover of different plant functional groups (described below), and (iii) percentage cover of individual plant species in each of the nine plant communities in 1997 and 2018. For the assessment of changes in coverage of plant functional groups, we categorised species into six commonly used functional groups: bryophytes, evergreen shrubs, deciduous shrubs, forbs, graminoids and pteridophytes (see Appendix Table 1 for full list of plants in each functional group). Generalized linear models with a Poisson

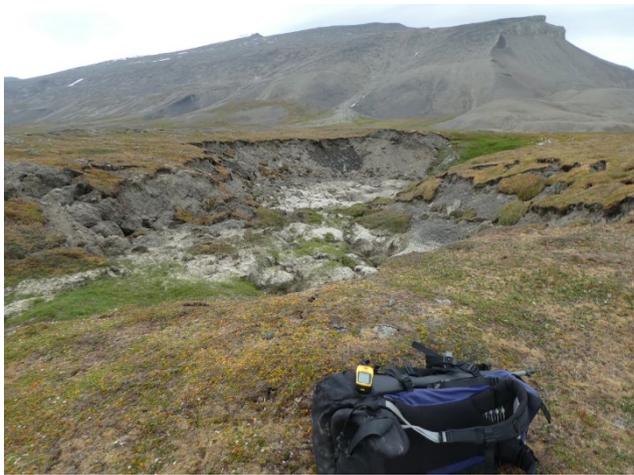


Plate 5 Environmental disturbances to the vegetation. From top left to bottom right: a) frost stripe creating bare soil (fairly commonly encountered along the transects); b) slope vegetation instability (regularly encountered); c) gravel deposition on tundra vegetation (commonly encountered); d) active layer deepening, leading to localised collapsing in of tundra soil and vegetation (sometimes encountered); and e) large collapse due to active layer deepening (rarely encountered). Photos: René van der Wal.

distribution were used to detect any significant change in (i) vascular plant species richness, (ii) percentage cover of plant functional groups, and (iii) percentage cover of individual plant species in each plant community between the two surveys. In 2018/19, disturbance data as outlined for the transects (presence/absence; disturbance agent; area impacted by that disturbance; area of bare soil exposed) was also recorded.

Grubbing recovery plots

In 2006 a short-term study (conducted over three years) was set up in Adventdalen to record the potential of plant species to recover from experimental pink-footed goose grubbing (Speed et al. 2010). The current project made use of this set-up to re-survey the vegetation and allow a longer-term (13 years) assessment of tundra vegetation recovery from disturbance to be made. The original study consisted of five replicate blocks of six different plant communities (see Table 2), occurring on an increasing gradient of soil moisture from dry ridge to mire. Disturbance treatments mimicked that of pink-footed goose grubbing and employed three different levels of intensity (low [31% of plot disturbed], medium [50% of plot disturbed] and high [100% of plot disturbed]). Control plots for each of the plant communities were identified within each block. For further details of the experimental set up see Speed et al. 2010. Each plot measured 35 cm x 35 cm and a gridded quadrat comprising of 25 individual cells (one cell = 7 cm x 7 cm) was used to count vascular plant shoots (at the species level) and percentage moss cover in each cell. Mean values for moss cover and vascular plant shoot density were calculated for each plot, and the data was expressed and analysed at the m² spatial scale to ease interpretation. To assess differences in both moss cover and shoot density between disturbance intensity treatments in different plant communities 13 years after experimental goose grubbing had been applied, two separate generalized linear mixed models, with plant community and disturbance intensity as the fixed factors and block as the random factor, were run. Tukey's HSD post-hoc tests were applied to assess differences within plant communities and intensity treatments.

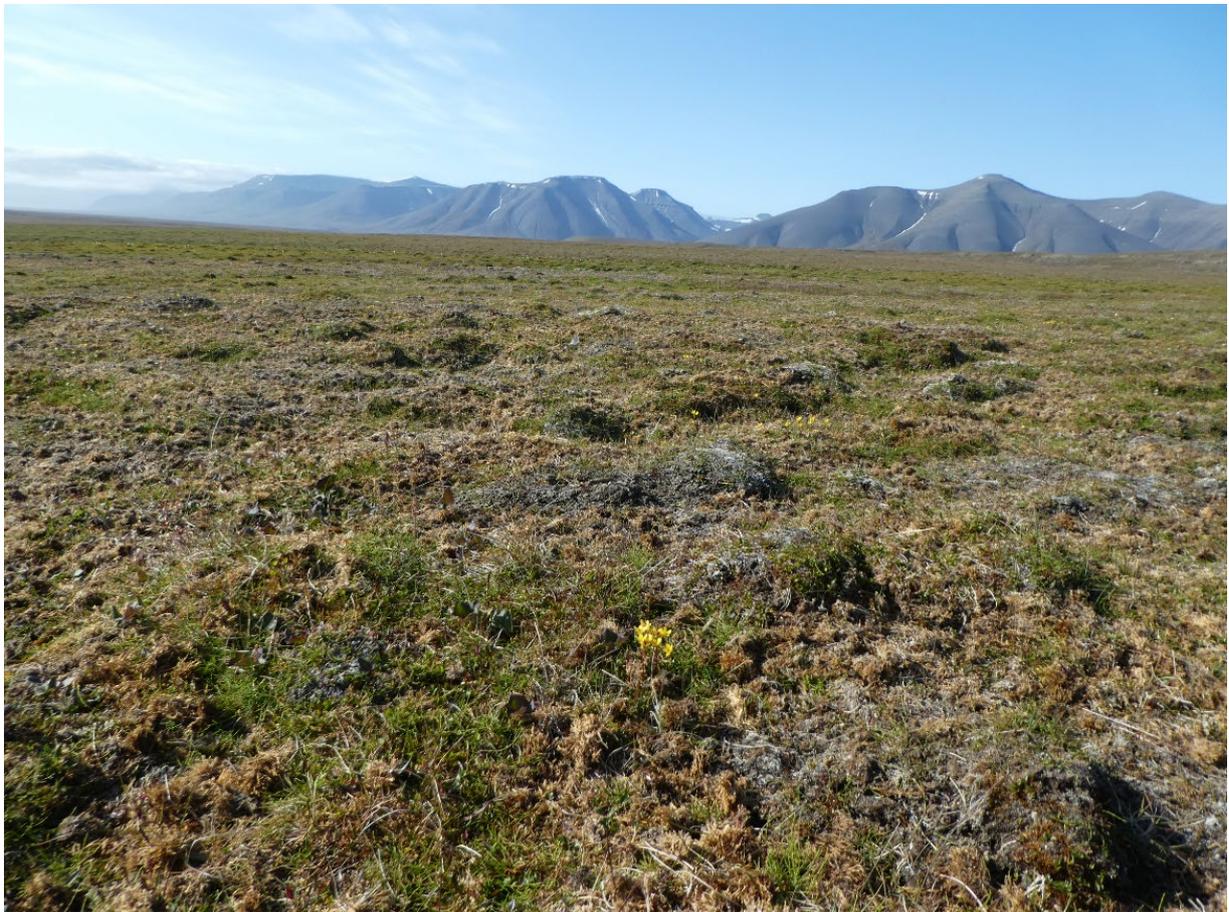


Plate 6 Commonly observed signs of pink-footed goose grubbing (from top left to bottom): a) around the lowest, and thus wettest and earliest thawed out, part of a well vegetated tundra hump; b) breaking through the shallow vegetation of a frost boil; and c) pulled out moss plugs and numerous holes created to pull out edible root systems in spring. Photos: René van der Wal.

Table 2 Plant communities and their main vascular plant species used to assess long-term recovery from disturbance in Svalbard.

Plant community	Main plant species	Moisture content
Dryas ridge	<i>Dryas octopetala</i> <i>Salix polaris</i>	Driest  Wettest
Cassiope heath	<i>Cassiope tetragona</i>	
Luzula heath	<i>Luzula arctica</i> <i>L. confusa</i> <i>S. polaris</i>	
Wet moss tundra	<i>Alopecurus borealis</i> <i>S. polaris</i> <i>Equisetum arvense</i>	
Dupontia wetland	<i>Dupontia fisheri</i> <i>E. arvense</i>	
Freshwater mire	<i>Eriophorum scheuchzeri</i> <i>Ranunculus hyperboreus</i>	

All statistical tests were carried out in programme R (R Core Team, 2019). The package lme4 (Bates et al. 2015) was used for both generalized linear models and generalized linear mixed models, with emmeans (Lenth 2020) used for Tukey's HSD post-hoc tests. All figures (except Fig 1) were produced using the ggplot2 package (Wickham 2016). Fig 1 was produced using ArcGIS 10.7(©1999-2018 Esri Inc.).

Results

Valley transects

In the 20-year period covered by this study there were rather modest changes in the relative abundance of the different main plant communities found within the nine valleys surveyed across the study area (Fig 2). Moreover, these changes were not consistent across valleys ($F_{1,8} = 8.6$, $p < 0.001$). There was a small but general shift in prevalence towards somewhat wetter plant communities in three valleys (Bodalen, Fardalen and Passdalen; Fig 2a,c,f). In the other six valleys, the proportions of plant communities either remained relatively similar to that documented previously (Colesdalen, Istjorndalen and Kalvdalen; Fig 2b,d,e) or exhibited very marginal shifts towards wetter communities (Reindalen, Semmeldalen and Skiferdalen; Fig 2g,h,i). Regardless of these modest shifts in plant community dominance,

every valley (except Bodalen and Skifferdalen) experienced an increase in the proportion of bare or unvegetated tundra (Fig 2).

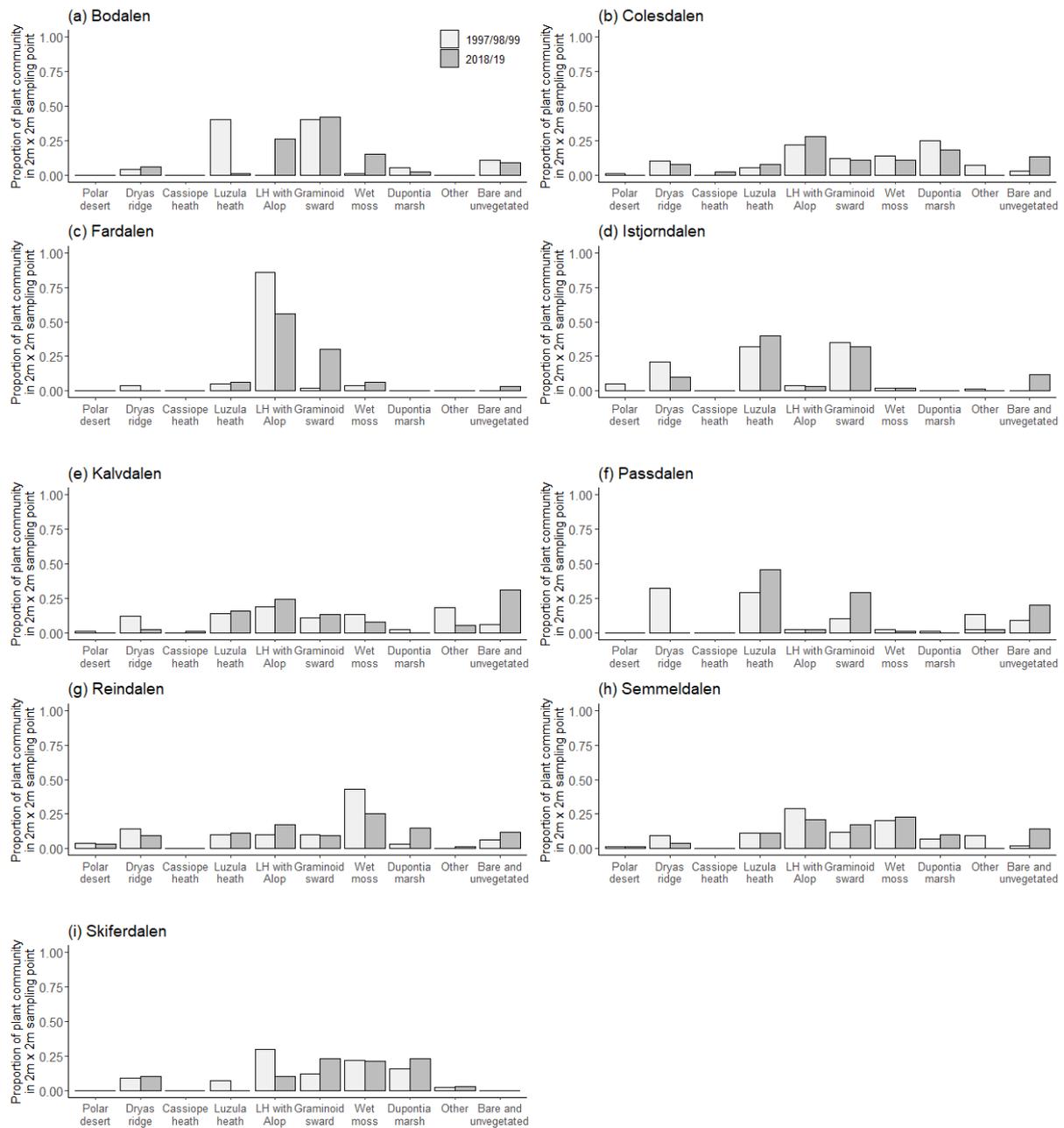


Figure 2 Proportional of plant communities and bare or unvegetated ground over a 20-year period in nine different valleys in central Svalbard. Results are based on transect surveys undertaken in 1997/98/99 and 2018/19. The category “Other” is comprised of *Phippsia* snowbeds and mire plant communities.

There were notable changes in the composition of the wettest plant community (*Dupontia* marsh) in Colesdalen, Reindalen and Semmeldalen (Table 3). In these three valleys, up to half the number of measurement points in *Dupontia* marshes were comprised of a

substantial proportion of the sedge *Carex subspathacea* (Table 3). This sedge was also present in drier plant communities in Reindalen, albeit at much lower frequencies (Table 3).

Table 3 Numbers of sampling points for *Dupontia* marshes in Colesdalen, Reindalen and Semmeldalen where the sedge *Carex subspathacea* was found within 3 different plant communities.

	<i>Luzula</i> heath with <i>Alopecurus</i>		Wet moss tundra		<i>Dupontia</i> marsh	
	Total no. sampling points with <i>C. subspathacea</i>	Total no. sampling points	Total no. sampling points with <i>C. subspathacea</i>	Total no. sampling points	Total no. sampling points with <i>C. subspathacea</i>	Total no. sampling points
Colesdalen	-	-	1 (1%)	85	47 (21%)	224
Reindalen	8 (7%)	121	11 (7%)	170	49 (46%)	106
Semmeldalen	-	-	-	-	28 (53%)	53

Resurveying the valley transects has shown that the overall change in plant community type dominance within any one valley has been small over a 20-year period. The most significant findings, however, have been marked change to the composition of wetter plant communities in the Colesdalen-Semmeldalen-Reindalen system and the almost universal increase in bare/unvegetated ground. The presence of a high proportion of bare or unvegetated ground is likely an indication that some kind of environmental disturbance to the vegetation has (possibly recently) occurred in almost all valleys. The sedge *C. subspathacea* has clearly benefited from disturbance in the form of goose grubbing in wetter areas, allowing it to spread to areas and plant communities outside its former coastal strongholds.

Disturbance to tundra vegetation was widespread across central Svalbard (Fig 3a), ranging from occurring in 61% of all sampling points along transects surveyed in Kalvdalen to 95% of those in Skiferdalen. The most common agent causing disturbance in all valleys were geese, whose activities led to 31-57% of the (occasions of) disturbance observed (Fig 3b).

Disturbance caused by reindeer (11-35%; Fig 3c) and environmental factors (3-11%; Fig 3d) generally occurred less frequently than that caused by geese. Disturbance caused by humans (foot prints and snow scooter tracks) occurred very rarely (< 1% in all valleys) and was considerably lower than that observed near settlements and tourist attractions where

disturbance can be substantial. Disturbance caused by more than one agent occurred in 14% (n = 383) of the sampling points. Reindeer and goose disturbance were found to occur together in 6% (n = 176) of the sampling points, with a third (n = 54) of those interactions occurring in dry *Luzula* heath. 3% of sampling locations experienced disturbance by both goose and environmental factors (n = 71) and 2% by reindeer and environmental factors (n = 61). Only 2% (n = 45) of sampling points had disturbance by all three of these agents.



Figure 3 Proportional area of sampling points along surveyed transects in 9 valleys that showed signs of disturbance; (a) in general, (b) by goose activities, (c) by reindeer activities, and (d) by environmental factors. Sampling points were 2 m x 2 m and located every 15 m along transects.

Although geese and reindeer were the most common causes of disturbance to tundra vegetation, the extent of that disturbance was predominantly low (< 5%; Fig 4a,b). However, there was a marked difference in how much bare ground was exposed by goose and reindeer activities: disturbance by geese predominantly led to very little or no exposed bare ground (Fig 5a), whereas reindeer activities tended to result in bare patches, albeit of relatively small sizes (Fig 5b). Environmental disturbance to tundra vegetation was usually

at a greater extent (Fig 4c), and resulted in larger patches of bare soil being exposed (Fig 5c) than by goose or reindeer activities.

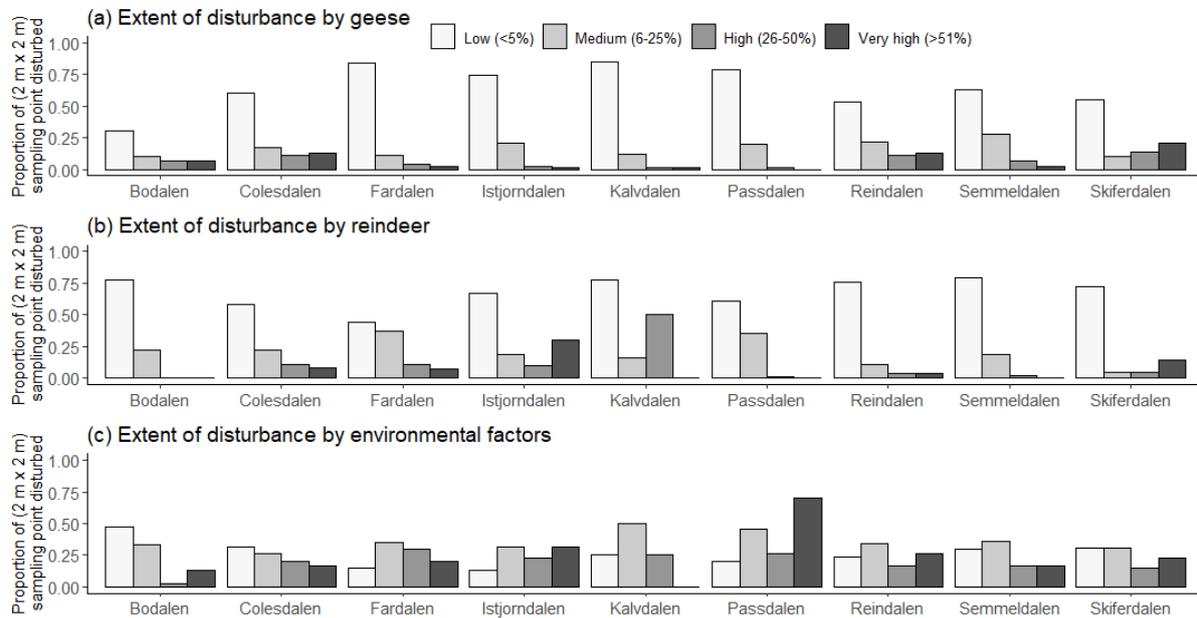


Figure 4 Proportions of sampling points along transects exhibiting disturbance at four different extents in nine valleys in central Svalbard. Mean values for low (<5%), medium (6-25%), high (26-50%) and very high (>51%) extents of disturbance caused by (a) geese, (b) reindeer, and (c) environmental factors. Sampling points were 2 m x 2 m, occurring every 15 m along transects.

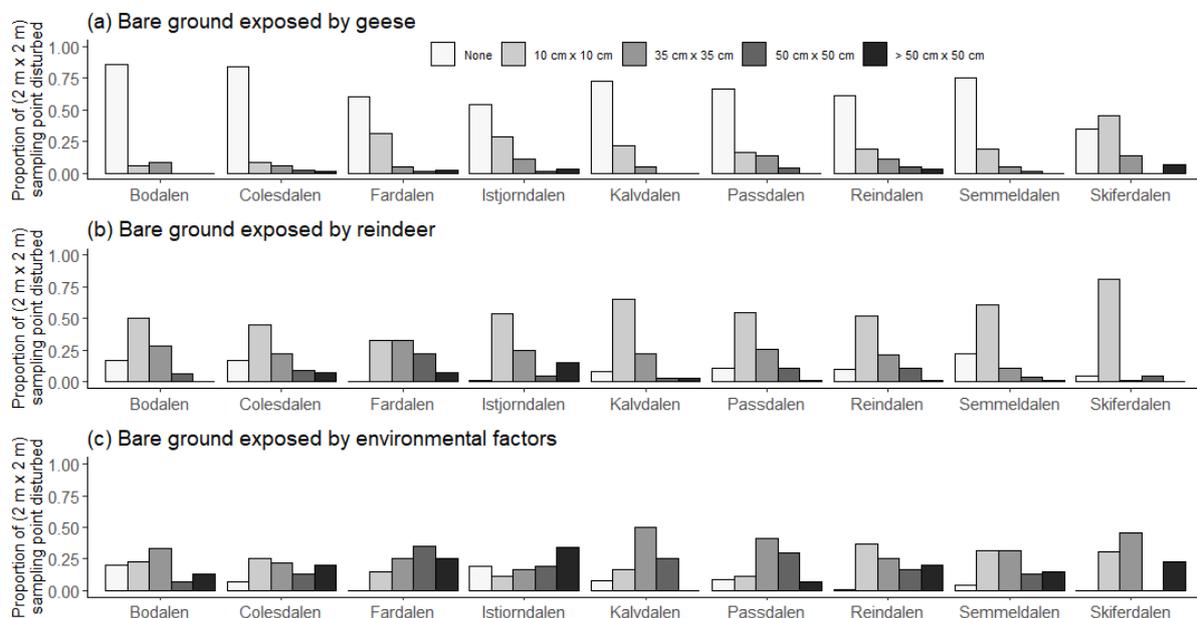


Figure 5 Proportion of bare ground exposed by disturbance in 2 m x 2 m sampling points in nine valleys in central Svalbard. Mean values are shown for bare ground of sizes none, 10 cm x 10 cm, 35 cm x 35 cm, 50 cm x 50 cm and in excess of 50 cm x 50 cm caused by (a) geese, (b) reindeer, and (c) environmental factors. Sampling points were 2 m x 2 m, occurring every 15 m along transects.

Thus, geese were the most common cause of disturbance to vegetation, but they generally only impacted a relatively small area and their activities tended not to result in the exposure of bare soil. Disturbance from reindeer and, notably, environmental factors were much more impactful on the vegetation and often resulted in the exposure of bare soil. However, these events occurred considerably less often than goose disturbance. Disturbance to tundra vegetation as a consequence of the interaction of goose and reindeer activities has not, to our knowledge, been documented before and may therefore lead to yet unknown changes to drier parts of the tundra.

Vegetation Plots

Most of the changes in abundance of plant functional groups occurred in wetter plant communities (Fig 6). The most noticeable change was the considerably greater cover of pteridophytes (horsetails, mostly *Equisetum arvense*), particularly in Wet moss and *Dupontia* marsh communities, where cover increased by 4% and over 2.5%, respectively (Fig 7a). Further changes were evident within *Dupontia* marshes, with an overall increase in coverage of graminoids by 2.8% (Fig 6e). Although most of this increase was attributable to the presence of more of the sedge *Carex subspathacea* (Fig 7b), there were notable losses of *Dupontia* spp. (Fig 7c) and *Eriophorum schuechzeri* (Fig 7d) from *Dupontia* marshes. There were small increases of forbs in the Graminoid sward (1%) and Wet moss (0.9%) communities (Fig 6f). These fluctuations in individual species, however, had no significant effect on species richness, with the average number of plant species found in each community remaining similar over time (Fig 6a).

Resurveying 100 2m x 2m plots therefore revealed that most changes occurred within wetter parts of the tundra, with a greater prevalence of horsetail and the sedge *C. subspathacea* but lower amounts of *Dupontia* spp and *E. scheuchzeri* (two species favoured by pink-footed geese) now compared to the past.

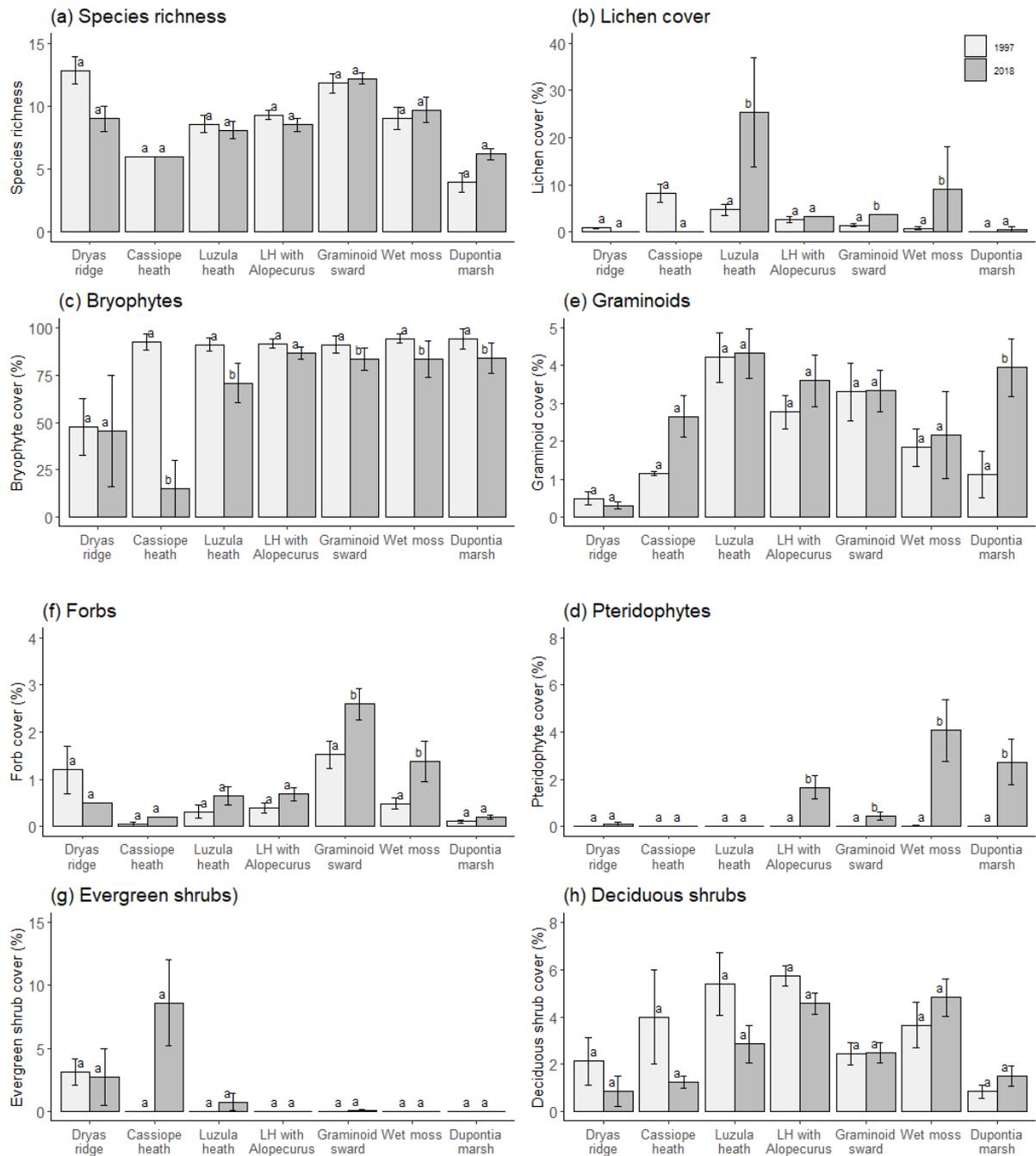


Figure 6 Species richness and plant functional group percentage cover in seven different plant communities measured in 2 m x 2 m plots in Svalbard in 1997 and 2018. Mean values are shown with error bars indicating the standard error of the mean. Species richness or plant functional groups with the same letter above the bars are not significantly different within a plant community at the $p = 0.05$ level (assessed using Tukey's HSD post-hoc tests).

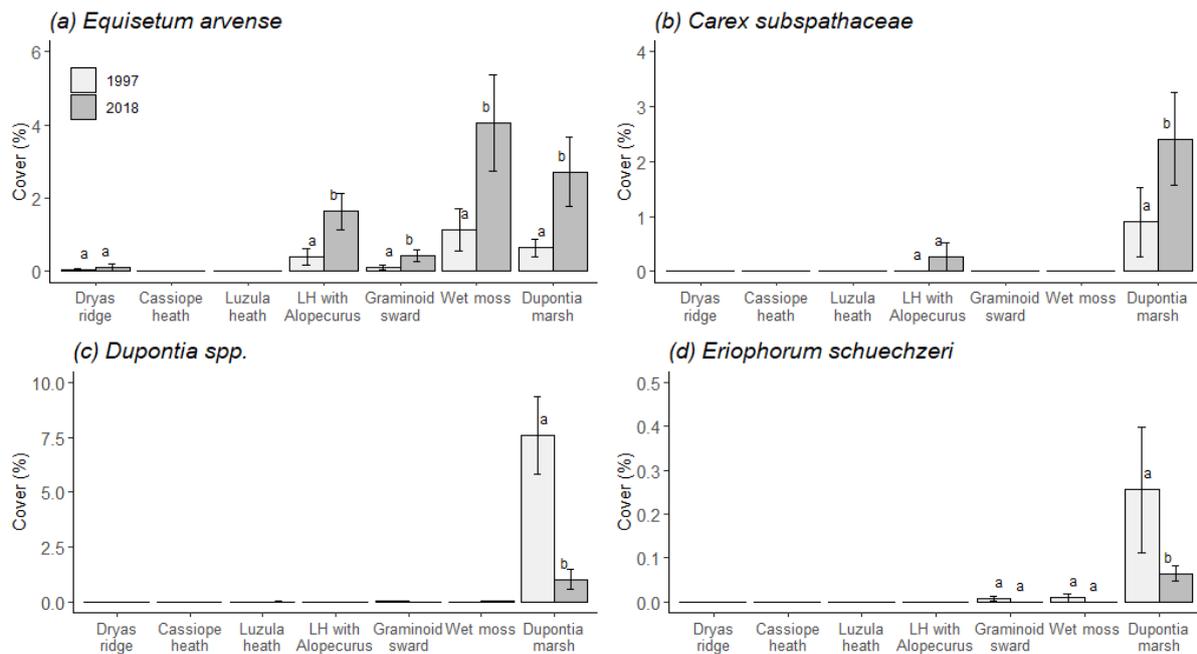


Figure 7 Percentage cover of four key plant species that experienced changes in abundance in seven different plant communities measured in 2 m x 2 m plots in Svalbard in 1997 and 2018. Mean values are shown with error bars indicating the standard error of the mean. Percentage cover with the same letter above the bars are not significantly different within a plant community at the $p = 0.05$ level (assessed using Tukey's HSD post-hoc tests).

As with the transects, disturbance of tundra vegetation in the plots was widespread, with 80% showing some kind of disruption. Goose grubbing was by far the most common cause of disturbance, occurring in almost two thirds of all plots ($n = 65$). Vegetation disturbance by reindeer ($n = 20$) and environmental factors ($n = 19$) were considerably lower, and evidence of disturbance by humans was not found in any of the plots. The number of plots in which disturbance was caused by more than one agent was low, with 10% of plots showing disturbance by geese and environmental factors, 7% by geese and reindeer, 2% by reindeer and environmental factors and only 1% of plots showing disturbance by all three agents. The extent of disturbance to tundra vegetation was predominantly low (< 5% of a plot) for both



Plate 7 Pink-footed goose induced expansion of the sedge *Carex subspathacea*. From top left to bottom: a) relatively recent grubbing caused the exposure of the moss decomposition layer, thus an effective lowering the point where vascular plants can grow; b) comparable previously grubbed area, but with *C. subspathacea* (soap-green) having colonised the denuded part; and c) dense *C. subspathacea* stand occupying previously grubbed area (yellowish green in the back), with in front heavily grubbed moss with few vascular plants left, and thinned out *Dupontia* vegetation in front (green-brown grasses), which likely will be dug out by the geese in the next few years now that the site can thaw out earlier due to a change in grubbing induced wetness and reduced (vascular plant and moss) layer depth. Photos: René van der Wal.

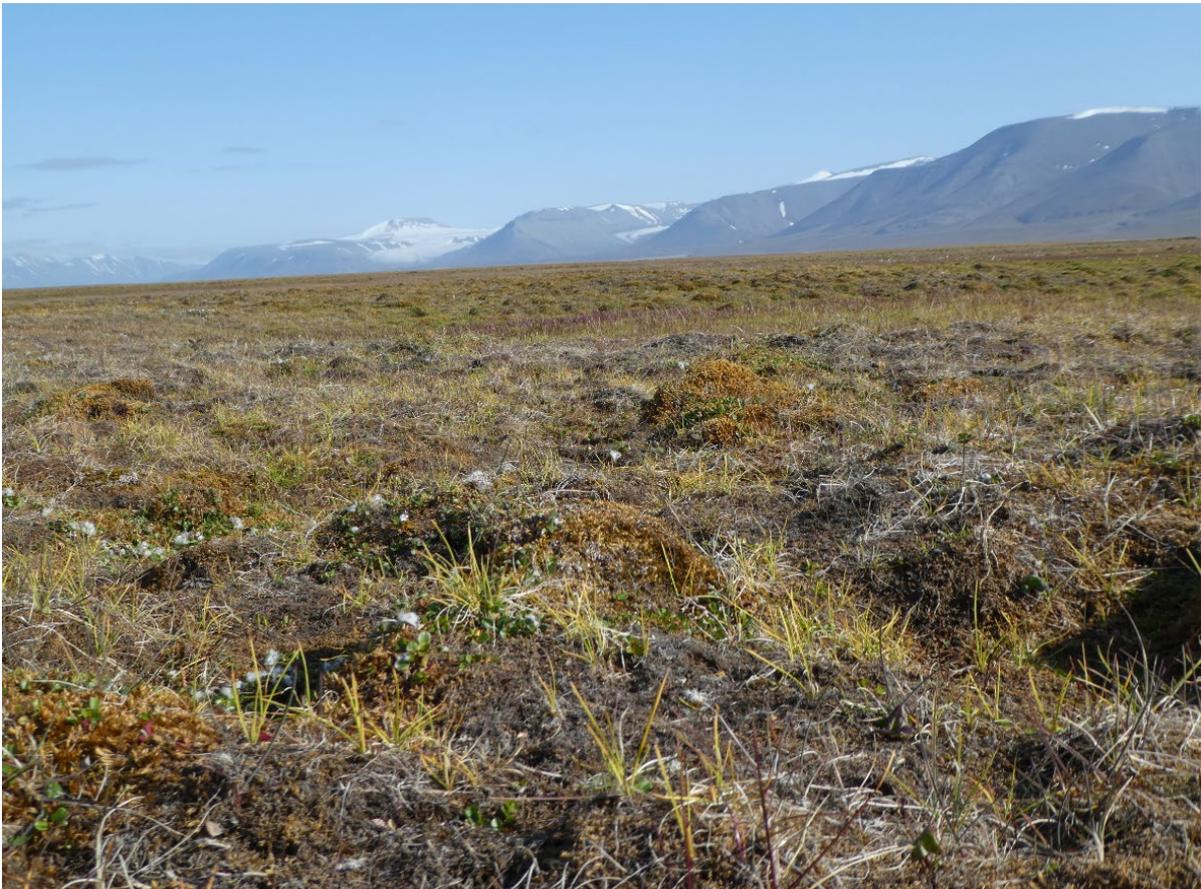
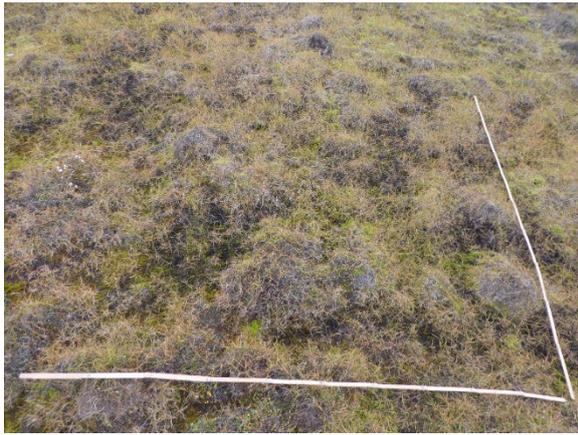


Plate 8 The arrival of a new vegetation type: *Carex subspathacea* spreading out from lower lying areas into slightly higher and drier tundra, growing alongside *Salix polaris* and *Alopecurus borealis* (and thus transforming wet moss vegetation). Photos: René van der Wal.



Plate 9 Expansion of horsetail *Equisetum arvense*. One of the two species who currently reaches far greater cover than 20 years ago in wetter tundra. In part, this is due to pink-footed goose grubbing (as this species is often the only species left, as can be seen in the two photos on the top), but possibly environmental factors (such as a deepening active layer) may also play a part. Photos: René van der Wal.

geese (63%) and reindeer (70%). In most plots that showed signs of goose grubbing, no bare soil was exposed (61%). This is in contrast to vegetation disturbance caused by reindeer, where three-quarters of these plots had exposed bare soil. The area of bare soil exposed by both geese (27%) and reindeer (55%) was predominately small (10 x 10 cm). However, disturbance to tundra vegetation by environmental factors (58%) typically led to large areas (50 x 50 cm) of bare soil. Hence, the results of disturbance in the plots mirrored that found across the valley transects, with disruption to the vegetation being widespread and mostly attributable to geese. Although disturbance due to reindeer activities and environmental factors were less frequent, unlike for geese, these events were usually visible over a larger area and led to the exposure of bare soil.



Plate 8 Band of *Carex subspathacea* (yellowish brown) demarcating the low-lying area between two polygons, and allowing this plant to expand from the coastal mires into new areas, demonstrating it was not always just geese promoting this species but by times also environmental conditions. Photo: René van der Wal.

Grubbing recovery plots

All plant communities experienced an increase in moss cover to some extent 13 years after disturbance, and thus signs of recovery, but this change was not consistent across habitats. The lack of extensive moss regrowth in drier plant communities was particularly stark and noticeable. In *Dryas* ridge, *Cassiope* heath and *Luzula* heath, moss cover was considerably lower than that found in undisturbed tundra regardless of intensity of disturbance (Fig 8). This is in sharp contrast to moss regrowth in wetter communities (*Wet moss* tundra, *Dupontia* wetland and *Freshwater* marsh), where the extent of moss cover was virtually indistinguishable from that found in undisturbed tundra (Fig 9). Thus, in wetter parts of the tundra moss appears to have a greater potential for recovery from disturbance.

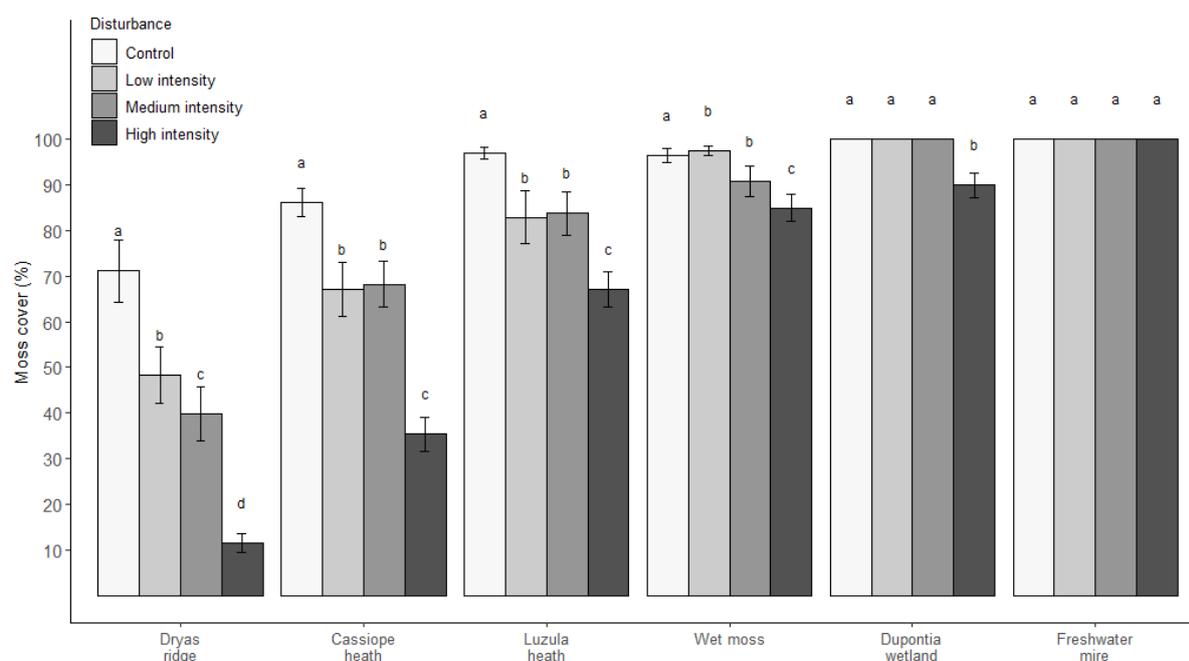


Figure 8 Percentage moss cover in six different plant communities in 2019, 13 years after being subjected to experimental goose grubbing. Mean values are shown with error bars indicating the standard error of the mean. Disturbance treatments with the same letter above the bar are not significantly different within a plant community at the $p = 0.05$ level (assessed using Tukey's HSD post-hoc tests).

Vascular plant shoot densities were also greater in all plant communities 13 years after disturbance, but this was not consistent across habitats or disturbance intensities. In drier plant communities (*Dryas* ridge, *Cassiope* heath and *Luzula* heath), the lack of plant

regrowth was particularly obvious, with scant coverage of vascular plants in many areas. Shoot densities in these drier communities failed to match that found in undisturbed tundra regardless of disturbance intensity (Fig 9). In wetter communities the picture was different, with shoot densities returning to (or marginally exceeding) that of undisturbed tundra when disturbance intensities were lower (Fig 9). However, in highly disturbed communities, shoot densities remained below that found in undisturbed tundra (Fig 9). Rather than a failure of plant growth to recover under a high intensity of disturbance, we suspect that low shoot densities here occurred due to a combination of highly disturbed parts of the tundra continuing to act as semi-permanent entry points for goose grubbing and changes to the species composition found within these wetter communities. Hence, although full recovery of vascular plant growth is possible in wetter habitats over 13 years, drier areas either may take much longer to recover or may not fully recover at all (Plate 9).

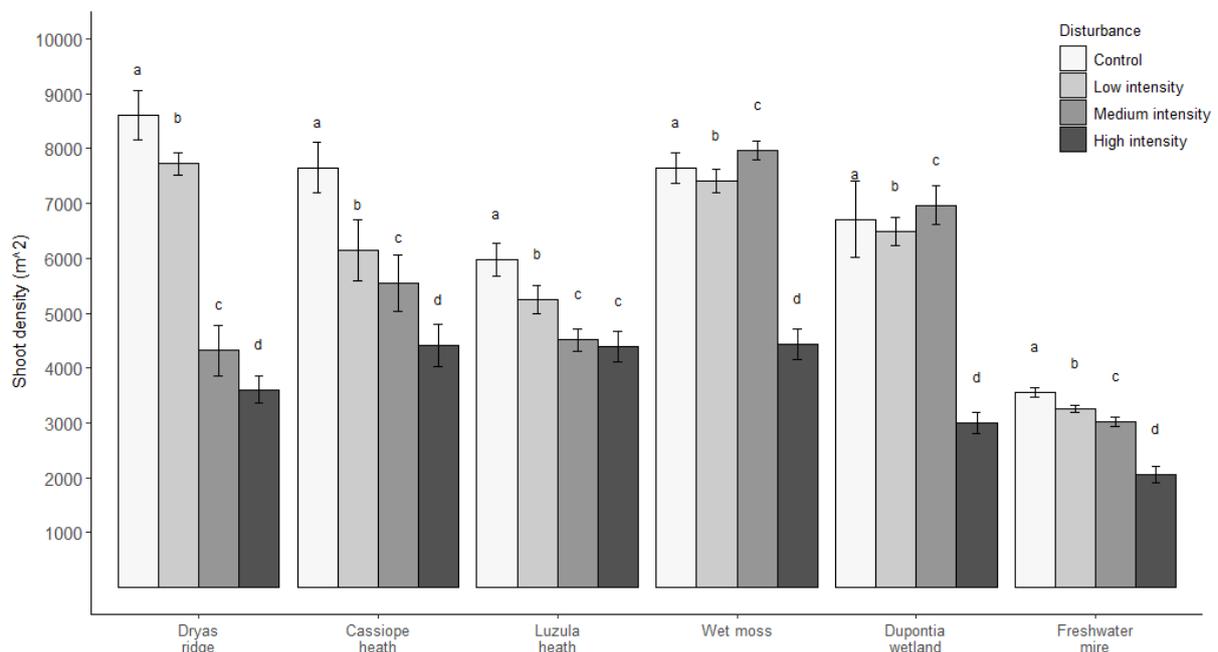


Figure 9 Vascular plant shoot density in six different plant communities in 2019, 13 years after being subjected to experimental goose grubbing. Mean values are shown with error bars indicating the standard error of the mean. Disturbance treatments with the same letter above the bar are not significantly different within a plant community at the $p = 0.05$ level (assessed using Tukey's HSD post-hoc tests).

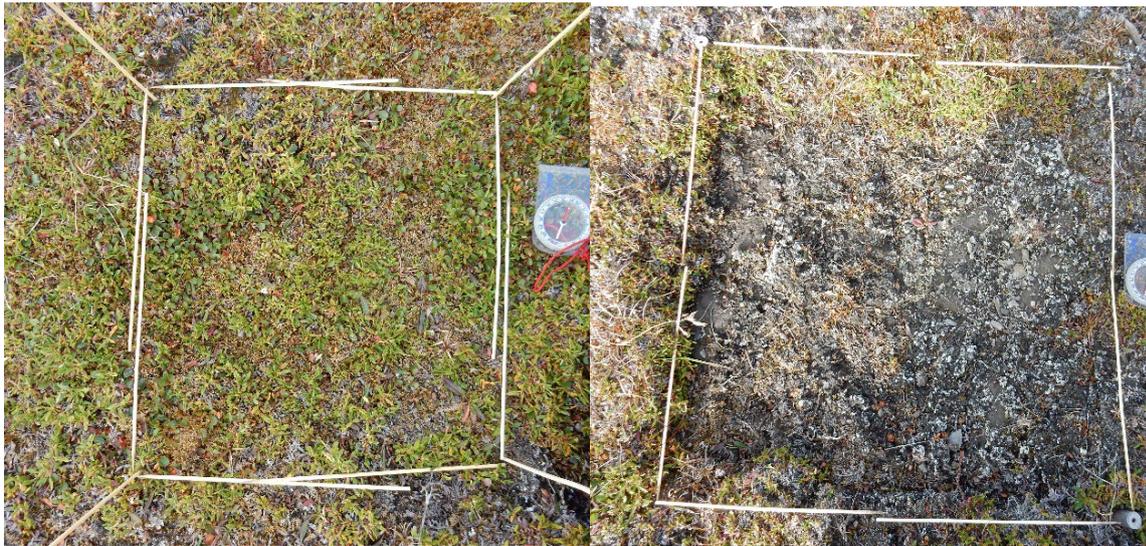


Plate 9 Example of limited disturbance recovery in a dry habitat - *Dryas* heath plant community. Image on the left shows undisturbed vegetation, while the image on the right shows the failure of vascular plants and moss to recolonize an area subjected to experimental goose grubbing 13-years previously (Photos: Helen Anderson).



Plate 10 Example of good disturbance recovery in wet habitat - Wet moss tundra. Image on the left shows undisturbed vegetation and the image on the right shows regrowth of vascular plants and moss in an area subjected to experimental goose grubbing 13-years previously (Photos: Helen Anderson).

Discussion

The effects of long-term disturbance to tundra vegetation by increasingly large populations of herbivores have been a cause for concern across much of the North American Arctic (Jefferies et al. 2006). This study has revealed that such wide-scale denudation of tundra vegetation by an increasingly large pink-footed goose population in Svalbard has not occurred. What is apparent is that although disturbance by geese is widespread, the long-term effects are only noticeable in the form of changed plant community compositions of wetter tundra. Such herbivore-driven changes can be considered as 'ecosystem engineering', however, where this has been documented previously for geese it has led to the production of 'grazing lawns' of nutrient-rich forage plants (Drent and Van der Wal 1999 Person et al. 2003). This has not occurred in Svalbard, with abundances of favoured pink-footed goose forage plants (*Dupontia* spp. and *Eriophorum schuechzeri*) declining in marsh areas.

Pink-footed geese are known to return to feed in previously (experimentally) grubbed areas (Van der Wal et al. 2006). From a mechanistic point of view, this is likely because it is easier to remove under-ground plant material from parts of the vegetation-soil matrix that have already experienced disturbance (Anderson et al. 2016). The declines in favoured forage plants such as *Dupontia* spp. and *E. scheuchzeri* are therefore likely due to continued selective foraging for these plants by increasing numbers of geese. The concurrent higher abundances of horsetail (*Equisetum arvense*) and the sedge *Carex subspathacea* could be due to their ability to exploit gaps in the vegetation left by depletion of *Dupontia* spp. and *E. scheuchzeri* and/or a preference for growing in recently disturbed soil (see Chou et al. 1992 for details of *C. subspathacea* regrowth in goose-disturbed saltmarshes). We do not know whether continued lower abundances of favoured forage plants such as *Dupontia* spp. and *E. scheuchzeri* are due to sustained selective foraging by geese or are a result of being outcompeted by *C. subspathacea* and *E. arvense*. Higher abundances of *C. subspathacea*

(and to some extent *E. arvense*) may also reflect their apparent unpalatability to pink-footed geese. Although *C. subspathacea* is grazed intensely by geese in the Canadian Arctic (Gadallah and Jefferies 1995), it appears to be disfavoured by pink-footed geese in Svalbard and not grazed much by reindeer here either (Van der Wal, unpublished data). Further studies on the mechanisms and wider ecological impact of increasing abundances of the sedge *C. subspathacea* and horsetail (*E. arvense*) are clearly warranted.

Much of the focus on reindeer-driven disturbance to tundra vegetation has centred on 'cratering', where animals break through snow to reach forage plants (Hansen et al. 2010), and when vegetation is broken-up by animals walking across more fragile habitats (Kitti et al. 2009). The considerably greater current population size of Svalbard reindeer compared to two decades ago (Albon et al. 2017, Le Moullec et al. 2019) likely explains why we found evidence of such reindeer-driven disturbance. Co-occurrences of goose and reindeer disturbance were relatively low, but since these tended to happen in drier ridge areas and reindeer-driven disturbance generally resulted in bare patches of soil, this may give cause for some concern since drier areas of the tundra struggle to recover from disturbance.

Environmental disturbances of tundra vegetation were clearly on a different scale to that caused by herbivores. Although they were much less frequent than herbivore-driven disturbances, they have the potential to affect very large areas of the tundra. Environmental disturbances are intimately linked with changes in hydrology and permafrost and related to a warming climate (Vaughan et al. 2013). Such disturbances may not cause vegetation change directly, but warming of the active layer soils and changes to pH levels, already observed in Svalbard (Boike et al. 2018), could have knock-on effects on plant community abundances and assemblages. Indeed, one of the two earlier Svalbard vegetation change studies based found an increase in average soil pH from 6.4 to 6.8 within an 85-year period (Kapfer and Grytnes 2017). Yet, they conclude that plant species change has been rather limited. We agree with this finding with the exception of wet marsh communities. Species

cover change in Kapfer and Grytness (2017) study is somewhat difficult to appraise due to the use of classes, but was mostly non-existent or small (less than 3%); for only two species (the grasses *Trisetum spicatum* and *Alopecurus borealis*) was change in cover slightly greater (3-6%). Surprisingly, the species for which average cover in plots had increased strongest (1-3%), was *Dupontia fischeri* – a species for which we saw a 6% decline in cover in its main habitat: wet marshes. Moreover, no significant change in occurrence or cover of our ‘big winner’, *C. subspathacea*, was found. We suspect that these differences are due to their study having taken place just before the step-change increase in the number of breeding pink-footed geese in the area (Anderson et al. 2015b).

Occurrences of human disturbance were extremely low in this, spatially large, study. This does not, however, contradict previously published findings that the effect of human disturbance to the tundra can be substantial and extensive in Svalbard (Hagen et al. 2012). Our study highlights that disturbance to tundra vegetation by humans in Svalbard is not a universally extensive phenomena, but is confined to areas of high human population density, be that at settlements or at tourist locations.

Conclusions and recommendations

An increase in the pink-footed goose population size has led to widespread disturbance of tundra vegetation. However, this disturbance does not typically lead to large areas of exposed bare soil, but rather more subtle changes in the species composition of plant communities in wetter parts of the tundra where geese prefer to feed. Thus, although drier parts of the tundra may struggle to recover from goose-driven disturbance, wetter areas appear to be more resilient, coping with disturbance via plant species-specific changes in abundances. Where this creates greater occurrences of previously rare or unknown plant community assemblages, further investigation is required to determine the ecological impacts of such change on other plant species and on herbivores.

High densities of reindeer have also led to disturbance of tundra vegetation. Although this is at a lower extent than that caused by geese, reindeer activities do tend to generate bare patches of exposed soil. Given the current size of the reindeer population, further work on the impacts of reindeer-driven disturbance on plant community assemblages may be worth considering. This may be particularly relevant in drier ridge communities (which have difficulty in recovering from goose disturbance), where we found evidence, for the first time, of reindeer and goose disturbance happening together.

Although the climate on Svalbard has already changed considerably, we did not see this translate into noticeable vegetation change, with the possible exception of bare soil having increased in all surveyed valleys. We deem it prudent to investigate the spatial extent and causes of the latter, and to ask whether grazing impacts are in part realised because of wider environmental changes.

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Appendix Table 1 Valleys in central Svalbard in which transects were located for assessment of plant communities. The number of transects and samples recorded in 1997/98 and 2018/19 are stated.

Valley	Number of transects	Total length of transects (km)
Bodalen	2	2.6
Colesdalen	8	16.0
Fardalen	2	1.5
Istjorndalen	5	5.0
Kalvdalen	4	4.5
Passdalen	5	4.1
Reindalen	5	11.4
Semmeldalen	7	13.0
Skiferdalen	1	1.0
Total	39	59.1

Appendix Table 2 Plant species and their functional groups used to determine long-term vegetation change in Svalbard

Plant species or type	Functional group
Cup lichens	Lichen
Bush lichens	Lichen
Crust lichens	Lichen
All mosses	Bryophyte
<i>Alopecurus borealis</i>	Graminoid
<i>Calmagrostis stricta</i>	Graminoid
<i>Carex</i> spp.	Graminoid
<i>Carex lachenalii</i>	Graminoid
<i>Carex subspathacea</i>	Graminoid
<i>Deschampsia alpina</i>	Graminoid
<i>Deschampsia borealis</i>	Graminoid
<i>Dupontia</i> spp.	Graminoid
<i>Eriophorum scheuchzeri</i>	Graminoid
<i>Festuca cryophila</i>	Graminoid
<i>Festuca</i> spp.	Graminoid
<i>Festuca viviparoides</i>	Graminoid
<i>Juncus biglumis</i>	Graminoid
<i>Luzula arctica</i>	Graminoid
<i>Luzula confusa</i>	Graminoid
<i>Luzula wahlenbergii</i>	Graminoid
<i>Phippsia</i> spp.	Graminoid

<i>Poa abbreviata</i>	Graminoid
<i>Poa alpigna</i>	Graminoid
<i>Poa alpina</i>	Graminoid
<i>Poa arctica</i>	Graminoid
<i>Trisetum spicatum</i>	Graminoid
<i>Hierochloe alpina</i>	Graminoid
<i>Deschampsia</i> spp.	Graminoid
<i>Cardamine bellidifolia</i>	Forb
<i>Cardamine nymanii</i>	Forb
<i>Cerastium</i> spp.	Forb
<i>Cerastium regelii</i>	Forb
<i>Cochlearia groelandica</i>	Forb
<i>Draba</i> spp.	Forb
<i>Erigeron humilis</i>	Forb
<i>Koenigia islandica</i>	Forb
<i>Minuartia</i> spp.	Forb
<i>Oxyria digyna</i>	Forb
<i>Papaver dahlianum</i>	Forb
<i>Pedicularis hirsuta</i>	Forb
<i>Petasites frigidus</i>	Forb
<i>Polmonium boreale</i>	Forb
<i>Polygonum vivipara</i>	Forb
<i>Potentilla hyparctica</i>	Forb
<i>Ranunculus hyperboreus</i>	Forb
<i>Ranunculus nivalis</i>	Forb
<i>Ranuncula pygmaeus</i>	Forb
<i>Ranunculus spetsbergensis</i>	Forb
<i>Ranunculus sulphureus</i>	Forb
<i>Sagina nivalis</i>	Forb
<i>Saxifrage cernua</i>	Forb
<i>Saxifraga cespitosa</i>	Forb
<i>Saxifraga foliolosa</i>	Forb
<i>Saxifraga hieracifolia</i>	Forb
<i>Saxifraga hyperborea</i>	Forb
<i>Saxifraga nivalis</i>	Forb
<i>Saxifraga oppositifolia</i>	Forb
<i>Saxifraga rivularis</i>	Forb
<i>Saxifraga tenuis</i>	Forb
<i>Silene uralensis</i>	Forb
<i>Stellaria crassifolia</i>	Forb
<i>Taraxacum arcticum</i>	Forb
<i>Cassiope tetragona</i>	Evergreen shrub
<i>Dryas octopetala</i>	Evergreen shrub
<i>Salix polaris</i>	Deciduous shrub
<i>Equisetum arvense</i>	Pteridophyte
<i>Equisetum scirpoides</i>	Pteridophyte
<i>Equisetum variegatum</i>	Pteridophyte