Yield reductions in agricultural grasslands in Norway after springtime grazing by pink-footed geese

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Summary

1. A large population increase of the Svalbard-breeding pink-footed goose *Anser brachyrhynchus* over recent decades has intensified the conflict with agriculture at the spring-staging sites in Norway. Knowledge of the yield loss caused by goose grazing in these northern areas is lacking, and the motivation behind the study was to quantify a relationship between grazing pressure and yield loss of agricultural grasslands and corresponding changes in vegetation composition.
2. Field trials were established on agricultural grasslands at four sites in central Norway. Eight plots were established at each site; four with exclosures to exclude or reduce grazing from geese and four with access for the geese. The exact same plots were followed for 2–4 years. Dropping density, used as a measure of grazing pressure, and compressed sward height (CSH) were recorded throughout the goose staging periods, and dry matter yield was determined at first and second harvests. Plant samples from first harvests were analysed for vegetation composition.
3. Grazing pressure varied between both years and sites. Exclosures reduced grazing pressure by 75–78 % during high-pressure grazing periods and increased first harvest yields by up to 31 %. At lower grazing pressure, exclosures prevented grazing completely. Grazing pressure was inversely correlated with dry matter yield at first harvest, but second harvest yields were unaffected.
4. The fraction of sown species declined while the fraction of weeds increased during the study both in open plots and exclosures, but level of grazing pressure did not have any significant influence on the overall fraction of sown species, or in any specific year.
5. *Synthesis and applications.* As the same plots were measured over several years, it was possible to quantify goose-grazing effects beyond one season. In the context of the wildlife-agriculture conflict, the results demonstrate that some farmers always

suffer disproportionately with yearly variations. The relationship between grazing pressure and yield loss may provide knowledge to a regional goose grazing subsidy scheme in the study area, identifying the most affected areas and distribute the subsidies correspondingly. However, the seasonal variations in grazing pressure demonstrate the difficulty of targeting exact areas on a yearly basis. On the other hand, the observed variations may promote another management tool in the form of delayed ploughing of stubble fields before spring sowing, as stubble fields may attract more geese, reducing the grazing pressure on agricultural grasslands and hence the overall conflicts with agricultural interests.

Keywords: *Anser brachyrhynchus*, agricultural conflict, exclosures, grazing pressure, yield loss, crop damage, growth conditions, vegetation analysis, wildlife management

Introduction

Throughout Europe, expanding populations of migratory geese have led to an intensified conflict with agriculture as they forage on pastures and arable land (Van Roomen & Madsen 1992; Madsen, Cracknell & Fox 1999; Fox *et al*. 2005; Fox *et al*. 2016). In this respect, one population, the Svalbard-breeding pink-footed goose *Anser brachyrhynchus*, has been a challenge for farmers and county administrative managers in Norway, as the geese feed intensively on crops in spring stopover sites (Bjerke *et al*. 2014; Madsen, Bjerrum & Tombre 2014). The pink-footed goose population spends the winter and early spring in Belgium, the Netherlands, and Denmark. In spring, they migrate through two specific staging sites in Norway: Nord-Trøndelag in central Norway and Vesterålen in north Norway (Tombre *et al*. 2008). The population has increased over recent decades, and in 2012, an international flyway management plan under the auspices of the African-Eurasian Waterbird Agreement was adopted (Madsen & Williams 2012). Reducing conflicts with agriculture is one of the main objectives in the plan, and because it is assumed that the number of geese relates to level of grazing damages and conflicts, a population target has been set. The current population level (74 000 geese in 2016) is above the population target of 60 000 geese (Madsen *et al.* 2016), which implies a need to reduce the goose population. Although the population size has been somewhat reduced the last couple of years as more geese have been shot during the traditional autumn hunting in Denmark and Norway (Madsen *et al.* 2015, 2016), significant conflicts with agriculture and dissatisfaction among local farmers remains (Eythórsson, Tombre & Madsen 2017).

Northern grasslands are not only critical to geese, but also to farmers in terms of the significantly reduced length of growing season at these latitudes (Volden 2002; Uleberg *et al*. 2014). Hence, there has been a growing conflict between spring-staging geese and agriculture at stopover sites in Norway (Tombre, Eythórsson & Madsen 2013; Madsen, Bjerrum & Tombre 2014). The yields of agricultural grasslands are critical in order to ensure enough winter fodder for cattle, and sheep farms also need the grasslands for grazing for newly released lambs. As a consequence of the farmers' complaints, a subsidy scheme funded by the Norwegian agricultural authority was implemented in 2006 (Tombre, Eythórsson & Madsen 2013). However, knowledge of the exact yield loss and costs for the farmers is lacking, making a fair distribution of subsidies challenging. An estimation of real losses will therefore be useful for the authorities managing the subsidy scheme, both in terms of the distribution of the subsidy and for quantifying the potential gap between the costs of real losses and subsidies available, the latter being an issue for political pressure. Yield losses due to winter- and early spring-staging geese have been studied in the Netherlands (Groot Bruinderink 1989), Germany (Mooij 1998), Belgium (Van Gils *et al*. 2012), Denmark (Lorenzen & Madsen 1986) and the United Kingdom (Patton & Frame 1981; Summers & Stansfield 1991; MacMillan, Hanley & Daw 2004), as summarized in Fox *et al*. (2016). In these studies, yield losses varied from only a few percentages to more than 70 %, depending on goose species, grazing pressure, time of grazing (time of season), sward productivity, and weather conditions. Overall, these case studies suggest that some farmlands always suffer disproportionately as some fields attract more geese than others due to differences in crop type, topography or distance to roosting sites, forests, roads and buildings.

The Svalbard-breeding pink-footed geese primarily stay in the Netherlands and Belgium during the agriculturally non-productive winter season, but their passage through Norway coincides with the early spring growth of agricultural grasslands (Madsen 2001; Tombre *et al*. 2008). Yield-loss data from snow-free wintering sites are not necessarily comparable to the spring situation at more northerly sites which are normally covered by snow in winter.

Moreover, the habitats are different both in terms of topography and species composition. Per capita grazing pressure for geese will also differ between winter and spring, because whilst overwintering geese forage for maintenance and survival, their food intake in spring increases considerably in order to build up body reserves for the flight to Svalbard and for breeding (Black, Deerenberg & Owen 1991; Prop & Black 1998; Drent *et al*. 2003). Chudzińska *et al*. (2016) found that, although net energy intake obtained per hour of actual foraging did not differ between foraging sites in Denmark and central Norway, the increase in daylength and hence time available for foraging in Norway made the net energy intake per day 50 % higher in spring.

Studies estimating yield loss caused by foraging geese in Norway are scarce (Hatten *et al*. 2006; Bjerke *et al*. 2014), and the motivation behind the present study was hence to improve our knowledge of the consequences of goose grazing on perennial leys. Most of the affected farmers in the study area produce grass for silage as winter forage for cattle. The most common species sown in Norwegian perennial leys is timothy *Phleum pratense*. Fox et al. (1998) found that repeated removal of the youngest timothy leaf led to an increased regrowth rate of the youngest leaf, however at cost both to the leaf elongation of older leaves and number of new leaves generated. Hence, in the longer term, the plants will be weakened, and due to a slow rate of tillering and recovery, timothy is known to have a rather low tolerance to frequent defoliation regimes or grazing (Østrem & Øyen 1985; Stevens et al. 1993), especially if vegetative tiller apices are removed (Höglind, Schapendonk & Van Oijen 2001). The present study was an experiment in which vegetation and yields were compared between exclosure plots, where the aim was to prevent or reduce goose grazing, and control plots open to goose grazing at four different perennial leys in central Norway. The main aim was to measure any impacts on dry matter yield under different goose grazing pressures and assess a dose-response relationship between grazing pressure and yield loss. However, as the farmers argue that intensive goose grazing does not only cause yield losses, but also increases the need for reseeding, the effects on vegetation composition were also quantified. Measurements were conducted over a period of 2-4 years. Except for a two-year study of goose grazing during winter and early spring in temperate grasslands by Percival & Houston (1992), there are, to our knowledge, no other studies where vegetation responses after goose grazing have been followed at the same fields and the same plots within the fields over several seasons.

Materials and methods

Study area

The study area is a patchwork of forests and agricultural fields mainly dominated by agricultural grasslands (i.e. perennial leys), spring cereals (barley and oats) and potatoes. There are also several lakes in the area and, along with the Trondheimsfjorden coastal shoreline, these are important roosting sites for geese. The perennial leys were selected based on a set of criteria: each field should be known to be visited by geese (cf. Jensen, Wisz & Madsen 2008; Bjerrum *et al*. 2011) and the sample should be representative of the regional variation in goose densities. That is, we did not only choose the fields with the highest goose densities, but tried to capture the variability in grazing impacts in the area with our data sampling providing a dose response curve between goose densities and impacts on the plots. Additionally, the field should have been sown the previous summer and not used by livestock (i.e. they produce forage for use as winter feed), and farmers should not actively chase geese off their fields. Based on these criteria, and the willingness of the farmers to be involved in such an experiment, four sites were selected (Fig. 1, Table 1). The chosen fields were all located in the inner part of Trondheimsfjorden (see Fig. 1), which is favoured by spring-staging pink-footed geese. Here, almost the entire population stops from around mid-April to mid-May (Madsen, Cracknell & Fox 1999, Tombre *et al*. 2008). The field trials were conducted over three years (2011-2013), but at one site (Site 1, Fig. 1) the trial was continued into a fourth year (2014). At Site 4, the experiment was only carried out in two years (2013-2014).

Experimental design

We originally designed this experiment with the aim of excluding all goose grazing using exclosures to exclude geese from entering (Bjerke *et al.* 2014). However, during the first year, geese intruded into the exclosure plots at some sites. Grazing was still much lower in exclosures than in open ‘control’ plots. In fact, we considered the low grazing pressure in exclosures as an improvement of the experimental design, as it provided a better tool to evaluate dose-response relationships, i.e. instead of having multiple data points at dose 0 (no grazing), we got a better spread of doses, from negligible to low grazing pressure in exclosures and from moderate to massive grazing pressure in open plots. Hence, it rendered a better dataset to answer our research questions. Our design was, hence, as follows.

Four plots, exclosures of 5 m x 2 m, were set up at each site before the geese arrived and shortly after snow melt and soil thaw (late-March to early-April). Wooden poles were placed in the corners as well as at the middle on each long side. In the two first years, we nailed white Poly ropes (5 mm diameter with an inner 0.4 mm wide core of stainless steel) to the poles and wrapped them along the sides at 5, 15, 25 and 40 cm from the ground and, also, in a crisscross arrangement between the tops of the poles. In later years, the ropes were changed for netting. Temperature loggers (Hobo Pendant UA-002-64; Onset Computer Corp., Bourne, MA, USA) were placed on the ground and at 30 cm above ground, the latter shielded from direct solar radiation, inside and outside one of the four exclosures at every site to test for ambient-exclosure temperature deviations, and hence the “cage effect” (Vickery 1972; Groot Bruinderink 1989). The differences in temperature regimes inside and outside the exclosures were within the accuracy level of the loggers (± 0.53 °C), confirming there was no cage effect of this experimental design.

In addition to the exclosures, four similar-sized ‘control plots’ were marked with small poles in the corners. Only the top 3 cm of the poles were visible. These areas were left open for grazing by geese. Exclosures and control plots are collectively termed ‘plots’ henceforth. At each site, all plots received the same kind and amount of fertiliser as used by the farmer on the rest of the field. This was in verbal agreement with the farmer before the experimental setup, and the fertiliser was mechanically spread across fields and fell naturally into the exclosures. The exclosures and open plots were placed along a transect across the ley to increase the farmers’ ability to achieve an even spread of fertiliser and to cover a goose grazing pressure gradient within the field, assuming lower intensities towards buildings, forests and roads (Madsen 1998). Fertilisation by droppings, as a supplementary source of plant nutrition, is assumed minimal as goose faeces take several weeks to break down (Larsen & Madsen 2000).

Non-invasive data collection

After the establishment of plots, sites were surveyed once a week during the goose-staging period from the beginning of April to the end of May. In all the plots, all goose droppings within an area of 3.14 m^2 (a circle of 2 m diameter) were counted at every visit. The circle centre was located at one metre’s distance from one of the plot’s short sides (i.e. the circles were located at one end of the plot), and the counting was performed within the same circles at every visit. There were no geese at the fields when droppings were counted. As geese have a high defecation rate, the number of droppings is generally accepted as a measure of grazing pressure (Groot Bruinderink 1989). Hence, dropping densities were used as a measure for goose density/grazing pressure (Ebbinge, Canters & Drent 1975; Ydenberg & Prins 1981). Droppings within the surveyed circles were removed after each visit to avoid double counting. Based on the dropping counts, the annual grazing pressure of each perennial ley was categorized as low (< 1 dropping m^{-2} y^{-1}) or high (>1 dropping m^{-2} y^{-1}). No other wildlife than geese grazed on the studied fields.

At every visit, the compressed sward height (CSH) was recorded with a rising plate meter which consists of a rounded polyethylene plate of 30 cm diameter, weighing 0.15 kg , that freely moves along a stick with a centimetre scale. Eight random measurements were taken per plot. As more biomass is needed to raise the plate, the CSH readings can be re-calculated as plant biomass using a regression line developed for the same type of grasslands (Mould 1992; Bakken *et al*. 2009).

Data collection during the first and second harvests

The harvests of experimental plots were performed at the same time as the farmer harvested the rest of the field, and after the geese had departed for their breeding grounds. Ideally, both control plots and exclosures would have been harvested at their optimal harvest time in terms of biomass accumulation and yield quality, as affected by plant growth. However, due to logistic and economic constraints, all plots within a field were harvested at the same time, when harvesting was most optimal for the control plots. Sites 2, 3 and 4 were harvested twice each year. The first harvest was between the 12th and 22nd June, and the second between the 15th and 23rd August. At Site 1, the farmer harvested the field three times each year, and hence both the first and the second harvest at this field occurred earlier than for the three other fields, between the 5th and 15th June and 20th and 31st August, respectively. The third harvest time was not included in this study. Swards in plots were harvested with a 1.4 m wide mower, hence excluding the edges of each plot. The fresh weight per area was measured in the field. One fresh sample (randomly selected) of ca. 2 kg from each plot was transported to the laboratory and dried at 60 °C for 48 h to establish a relationship between fresh and dry weights. For dose-response comparisons, the dry matter yields were converted into relative yield levels based on each field's yield potential without goose grazing (in terms of yield production in exclosures with no or minor grazing).

From the first harvest at each site, another fresh sample of ca. 2 kg was extracted from each plot and transported to the laboratory, semi-dried and frozen. These samples were later thawed and sorted according to species. After identification, samples of each plant species were placed in separate paper bags and dried at 80 °C for 48 h and weighed to nearest mg. These dry weights were then used to test for differences in vegetation composition between treatments. Species diversity was calculated thereafter using the Shannon diversity index (Magurran 1988), an index which in this context gives a value for sown species and weed. As the sites were sown with different mixtures of species (Table 1), they differed in species diversity. All sown species were therefore pooled and treated as one entity in the diversity analyses.

Linear modelling

Many non-experimental factors differed between plots. This includes inclination, microtopography, elevation, cardinal direction, sloping, soil quality, soil compaction, and distance to nearest roosting site, road, forest and house. To test the importance of these factors on harvested yields, we employed an automatic linear modelling procedure (SPSS Statistics Ver. 22, IBM Co., Armonk, NY, USA). This is an effective tool for linear modelling, compared to manual modelling procedures, accepting both categorical, ordinal and numerical data in a single analysis (Yang 2013). The automatic procedure uses a forward stepwise selection method based on Akaike's Information Criterion Corrected (AICC; Burnham & Anderson 2002) to select the best model. Soil quality was assessed based on observed growth in the field for each plot using a 3-level scale (low, average, good). Soil compaction was included as a dummy variable (0/1) based on our own observations of vehicle tracks crossing the plot when, in a few cases, the farmers had driven across plots. In the same modelling procedure, we also included additional aspects related to timing of goose grazing. This includes total number of droppings, number of droppings at first survey each year, the day of year (DOY) for first recorded goose grazing, DOY for maximum grazing pressure, and DOY for last recorded goose grazing, as well as grazing duration in number of days. Annual statistics on county level for compensation/subsidies paid to farmers for yield failure and winter-damage to agricultural farmlands were retrieved from the Norwegian Agriculture Agency. These data were used as information when interpreting potential non-treatment impacts.

Statistical analyses

Treatment effects were evaluated using Student's *t*-tests and repeated-measures analyses of variance (ANOVA) within the General Linear Model (GLM) procedure in SAS Statistical software (SAS Institute, Cory, NC, USA) and SPSS Statistics. Separate *t*-tests were applied for intra-annual differences if plot numbers differed between years, and the repeated-measures ANOVA only included plots with data from more than one year. For significant effects, a comparison between means was made using least significant difference (LSD) at a 0.05 probability level. In order to study the influence of different goose grazing pressures on post-grazing sward height and harvested dry matter yields, Pearson correlation coefficients were calculated for all fields and years with goose grazing in total, for each of the years separately, and for each of the fields within each year.

Results

Treatment effects on grazing pressure and sward development

Grazing duration and pressure varied much between years and sites, with high levels in 2012 and 2014, intermediate in 2011 and low in 2013 (see Fig. S1 in Supporting Information). The dropping numbers demonstrate variable arrival dates but a relatively constant departure date in mid-May for all sites in all years (Fig. S1). Years with high grazing pressure were characterized by early goose arrival combined with geese gathering in large flocks, rather than being scattered in many smaller flocks (unpublished data). In 2013, the onset of spring growth was late due to low temperatures in March and April and a long-lasting ground frost (Fig. S2), and the geese also arrived later this year (Fig. S1). Moreover, the grain stubbles in the area were left unploughed and accessible as a food source for the geese for longer, giving a large reduction of goose grazing pressure on agricultural grasslands (Fig. S1).

Exclosures had a substantial effect on grazing pressure and development of the sward. For all years and sites, exclosures led to an average 75.9 % reduction of grazing pressure ($F = 25.54$, $P = 0.002$), ranging from 71.9 % in 2014 to 97.6 % in 2013 (Fig. 2a). CSH was reduced in open plots during the grazing period, while it increased in exclosures, except for in 2012 when CSH was also reduced in exclosures (Fig. 2b, $F = 43.76$, $P = 0.002$). At first survey after goose departure, i.e. ca. 7 days after the last geese left, CSH was on average 53.6 % higher in exclosures than in open plots; the difference being significant in all years (Fig. 2c, $F = 58.22$, $P < 0.001$).

Treatment effects on yield levels

The use of exclosures to reduce grazing pressure resulted in an overall 22.8 % increase in mean first harvest yields (Fig. 3a, treatment: $F = 28.73$, $P = 0.002$; time × treatment: $F =$

13.77, $P = 0.016$). At Site 1, which is the site with the longest data series and the highest grazing pressure, first harvest yields for the years 2012 to 2014 were 31 % higher in exclosures than in open plots (Fig. 3b, $F = 19.50$, $P = 0.002$). The year 2011 was excluded from this analysis, as two additional plots (one open and one exclosure) were established in 2012, but also in 2011 there were markedly higher yield levels in exclosures than in open fields, as reported previously (Bjerke *et al.* 2014). The two years of data from Sites 3 and 4 show that exclosures increased first harvest yields by 25-27 % in the year with the highest grazing pressure, while there were no significant treatment effect in the year with lowest grazing pressure (Fig. 3c-d, Site 3: $F = 5.83$, $P = 0.073$; Site 4: $F = 12.77$, $P = 0.012$). The low grazing pressure at Site 2 did not affect first or second harvest yield levels in any of the years 2011-2012 ($P > 0.518$, Table S4). Incidents with low temperature and ice-sheathing during the winter 2012/13 resulted in major winter damage of the grassland at this site, and the field was therefore not harvested in 2013.

Second harvest yield levels (Table S4) at Site 1 were not affected as a whole ($F = 0.002$, $P = 0.967$), or in any of the separate years ($P > 0.495$). At Site 4 in 2013, which is the sole year with second harvest yield values from this site, exclosures led to a 32 % increase in yield levels ($t = -2.6$, $P = 0.041$). At Site 3, second harvest yields were higher in exclosures in 2011 ($t = -4.6$, $P = 0.004$), but not in 2012 ($t = -0.3$, $P = 0.763$).

Relationship between yield level and grazing pressure

Overall, for all sites and years, there was a significant correlation between goose grazing pressure and dry matter yield at first harvest ($r = -0.28$, $P = 0.025$). However, the correlation was stronger ($r = -0.60$, $P < 0.001$) when analysing relative yield levels at only the eight field

× year combinations with a high grazing pressure (Fig. 4). The correlations were also stronger when analysing fields and years separately. At Site 1, there was a significant negative correlation for all years except 2013 when the goose grazing pressure was rather low (2011: $r = −0.95$, $P = 0.003$; 2012: $r = −0.85$, $P = 0.007$; 2014: $r = −0.80$, $P = 0.010$). At Site 3, dry matter yield was strongly correlated with recorded grazing pressure in 2012 ($r = −0.88$, $P = 0.004$), and at Site 4, there was a significant negative correlation in 2014 ($r = −0.86$, $P = 0.006$), but no correlation in 2013 when grazing pressure was low.

Increasing levels of grazing pressure were not correlated with dry matter yields of second harvest (2011: $r = −0.28$, $P = 0.361$; 2012: $r = 0.12$, $P = 0.660$; 2013: $r = −0.36$, $P = 0.167$; 2014: $r = −0.11$, $P = 0.781$).

Best linear yield models

Dry matter yields of first harvests were largely explained by treatment or grazing pressure (Table S1) and did therefore largely reflect the results of the significance analyses. However, the modelling procedure also provides explanations for cases when the relationship between treatment and response was less clear. In 2013, when grazing pressure was low, other factors than treatment better explain the variation in first harvest yields. At Site 1, microtopography is the most important factor, explaining 56 % of the variation in first harvest yields in the best model. This year, the lowest yield levels were in plots with a slightly concave microtopography. At Site 4, position at the north-south gradient is the only significant factor in the best model for 2013, explaining 50 % of the variation in yields. Position and yield are strongly correlated ($r = −0.757$, $P = 0.030$), indicating a trend towards higher yields at the southernmost, slightly higher-elevated plots.

Vegetation composition

The fraction of sown species, based on extracted samples from the first harvests, declined during the study at Site 1 (F = 20.4, P = 0.006). This was largely due to a 40 % decline from 2013 to 2014, i.e. from the third to the fourth year of goose grazing at the same plots (Fig. 5a, F = 0.08, P = 0.931). There was, however, no difference between open plots and exclosures, neither for the overall fraction of sown species or in any specific year (Fig. 5a). Biodiversity follows the same pattern (Fig. 5b), i.e. with a significant increase with time (F = 43.2, P = 0.001), but with no treatment effect (F = 0.93, P = 0.380). However, there was a significant negative correlation at Site 1 between the total grazing pressure, as summed up both for the current and the preceding years (overall dropping density for 2011-2013), and the fraction of sown species left in 2013 (r = −0.76, P = 0.017). As for the fraction of sown species left in 2014, there was no significant relationship with the total grazing pressure during 2011-2014 (r = −0.51, P = 0.157).

Site 3 showed the same general trend as Site 1 with an 8 % decline in the fraction of sown species from 2011 until 2013 and no treatment differences (time: F = 8.8, P = 0.025; treatment: F = 1.7, P = 0.246). There was no significant relationship between the fraction of sown species left in 2013 and the total grazing pressure during 2011-2013 at this site (r = −0. 48, P = 0.331). The single year (2013) with values from Site 4 showed no treatment effect (F = 1.3, P = 0.299).

Discussion

The differences in changes in CSH reflect the impacts of goose grazing, and demonstrate in the more heavily-grazed areas how geese effectively keep the plant biomass at a minimum level by continuously grazing any new leaf development. Sward development is also affected by differences in spring weather and growth conditions between years. Interannual differences in weather conditions also indirectly affected grass growth by influencing the timing of goose arrival, and hence, the length of the goose grazing period in the area. Goose arrival to the experimental field sites was five weeks earlier in the warm spring of 2014 than in the cold spring of 2013. These results are in line with the findings of Tombre *et al*. (2008), who found a significant relationship between the date of goose departure from staging sites in Denmark (heading towards central Norway) and the onset of spring, with the geese departing earlier in earlier springs. However, the dropping density data from the present study and statements from local farmers (T. Grande & H. Skei pers. comm.) suggest that the timing of departure from central Norway varies less between years. Hence, in years with an early spring in Denmark and central Norway, the geese stay for longer in central Norway than in years when spring is late. The potentially positive implications of an early spring for farm productivity (Skjelvåg 1998; Uleberg *et al.* 2014) may thus potentially be nullified, or even reversed, for grasslands where geese forage. Differences in weather conditions between years also influence the availability of grain stubble fields as forage areas for the geese. Geese mainly forage on grain stubble fields when they first arrive in central Norway, and the shift from feeding on grain stubble to grassland corresponds with a decrease in available stubble fields as these are ploughed and sown with spring cereals (Chudzińska *et al*. 2015). In years when spring is cold, delaying ploughing of stubble fields, as in 2013, the grain stubble will be available to the geese for a longer period, hence, alleviating the grazing pressure on grasslands. Delayed spring ploughing may indeed be a possible management tool in order to reduce grazing damage and corresponding conflicts. For this to be an effective tool, however, autumn staging or early spring staging geese must not already have depleted the fields for spilt grain. Regional managers may introduce an awareness campaign concerning the benefits of delayed ploughing in terms of reduced goose grazing pressure on grasslands and new-sown fields. A system for subsidising the farmers who follow this advice would facilitate this process (Baveco *et al*. 2017). Such a subsidy scheme would also need to take into consideration the potential negative impacts of a later development of spring cereals on grain yields and quality due to a later sowing time than optimal (Riley 2016).

In the current study, goose grazing mainly affected dry matter yield at first harvest. In a study of white-fronted geese *Anser albifrons* in The Netherlands, grazing during March to May was also found to cause significant yield reductions only at first harvest (Groot Bruinderink 1989). In Vesterålen (North Norway), however, which is the spring-staging site for pink-footed geese between central Norway and the breeding grounds in Svalbard, goose grazing did also affect dry matter yields at the second harvest (Tombre *et al*. 2015). This may be due to a generally shorter growing season in this sub-Arctic region and a shorter time span between the first and the second harvest, which renders less time for compensatory grass growth.

The observed difference between years, as related to the extent of yield reductions after goose grazing, reflects the additional impact of other yield-determining factors. The prevailing weather conditions during and after goose grazing affect the plants' ability to recover after grazing, and hence it is likely that the same grazing pressure may lead to variable yield reductions depending on spring growth conditions. Differences in yield potential between fields may also seem to have affected the extent of yield reduction at comparable levels of goose grazing. The results suggest that goose grazing had a greater impact at fields with poorer grass growth conditions (such as Site 1 in 2011 and 2014 and Site 4 in 2013) than at fields with more favourable growth conditions and higher yield potential. This is reasonable, because a high yield potential implies plants in good condition that will be more able than weaker plants to cope with stressful situations, such as grazing (Donaghy & Fulkerson 1997). However, as the sample size in the present study is rather small, this should be studied further in order to draw any conclusions.

The reduced opportunities of defoliated plants to fully exploit the long growth days of May and June at Norwegian latitudes (Skjelvåg 1998) for growth is most likely to be one of the reasons for the yield reductions caused by heavy goose grazing in this area. Overall, goose grazing did not seem to have any negative impact on dry matter yield until the summed grazing pressure exceeded a level of about 10 droppings m^{-2} across the grazing period, which is in line with the conclusions of Groot Bruinderink (1989). Studies of spring grazing by sheep have also given results comparable to the present study. Botnan (2002) found that low levels of sheep grazing did not reduce dry matter yields at the subsequent harvests, while higher levels of grazing caused significant yield reductions. In earlier studies, yield reductions were found to be larger when the goose-grazing period included March and April and not only covered the autumn and winter months (Patterson 1991). Similarly, Riesterer *et al*. (2000) concluded that defoliation at different times during fall and winter did not affect grass forage yields in May as long as it occurred before the onset of the plant’s spring growth. Their findings are confirmed in the present study where the geese graze on grasslands in early spring when plants are at their most vulnerable stage.

The linear modelling of first harvest yields shows that other factors than those related to goose grazing or treatment were the most important in 2013, when goose grazing pressure was low. The most important factors at sites 1 and 4 in 2013 were microtopography and position at the north-south gradient, respectively, which most likely reflects the impacts of an incidence of ice encasement that caused considerable plant damage regionally in central Norway at the end of the winter 2012/13 (information retrieved from the Norwegian Agriculture Agency). Ice encasement is known to be an important threat to northern agricultural grasslands (Gudleifsson & Larsen 1993; Bjerke *et al.* 2015), and the lowest yields at Site 1 and Site 4 were associated with those areas of the field which would be most prone for ice accumulation; concave microsites at Site 1 and the northernmost, slightly lower-elevated plots at Site 4.

Although goose grazing was not found to affect plant diversity in an earlier study of their overwintering sites (Groot Bruinderink 1989), many farmers in areas frequently used by geese report a need to reseed their grasslands more often (Groot Bruinderink 1989; MacMillan, Hanley & Daw 2004; Søreng 2008). By reducing the biomass of the sown plants, there is more space and light for weeds to establish (Frankow-Lindberg 2012). It has also been reported that goose droppings may bring in additional weed seeds (Ayers *et al*. 2010). These findings support the farmers' experience that goose grazing repeated over multiple years speeds up the grassland deterioration. In view of this, the lack of a significant treatment effect on the fraction of sown species at Site 1, the site with four consecutive experimental years, was unexpected. However, the large decline in fraction of sown species both in open plots and exclosures from 2013 to 2014 may have contributed to mask any possible effects of goose grazing. A general drop in the fraction of sown species between the third and the fourth year of harvest is not unusual at fields that are harvested three times per year (Østrem & Øyen 1985; Bakken *et al*. 2009), and the ice encasement incidence at the end of the winter 2012/13 may also have contributed to increase the rate of decline of sown species. The correlation found between the fraction of sown species at Site 1 in 2013 and the overall dropping density for 2011-2013, does indeed reflect a negative impact of goose grazing in terms of grassland deterioration.

Naturally, fields with high grazing pressures need a longer time to grow a harvestable yield than ungrazed fields. The consequences of postponed harvesting due to goose grazing are not estimated in the present study, nor are the economic consequences related to an increased need for reseeding of grasslands. Both factors should, however, be considered when assessing the total economic implications of grazing geese. An earlier study from Norway shows how dry matter yields at the second and third harvest time are reduced if the first harvest time is postponed (due either to unfavourable weather conditions or other reasons) and subsequently delays the second and third harvest, pushing regrowth and yield production into later summer times with less favourable growing conditions and shorter day lengths (Bakken *et al*. 2009). A complete cost assessment of goose grazing for the farmers should also include the economic costs of purchasing forage as a substitution for the forage lost by goose grazing. Although these factors are not taken into consideration in the present study, they illustrate the difficulties of calculating a specific economic loss. We have here demonstrated that level of yield loss appears to depend on many factors in addition to geese, like weather conditions, microtopography, and field and soil quality (the latter only briefly evaluated in the present study). These are all factors that complicate the evaluation of dose-response relationships, and their relative importance should therefore be studied in further detail. However, combined with a model predicting the distribution of pink-footed geese and their utilization and depletion of available farmland (Baveco *et al*. 2017), data from the current study may provide an overall assessment of costs (C. Simonsen *et al.*, *in prep*.). For managers, knowledge regarding effects of goose grazing and the losses for farmers is crucial for fine-tuning relevant management initiatives. The disproportionate distribution of damage among both farmers and seasons points out the challenges related to distributing subsidies.

Authors' contributions

All authors contributed to the planning of the experiment. A.K. Bergjord Olsen and J.W. Bjerke were responsible for the collection and analyses of data during and after the experiment. All authors contributed to the interpretation of data. Bergjord Olsen was the main author of the manuscript, but all authors contributed, and the final manuscript has been approved by all authors.

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Data accessibility

All data used for this paper may be found in the Supporting Information (Tables S2-S7).

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Fig. S1. Compressed sward height and goose grazing pressure during the geese' spring-staging period.

Fig. S2. Recorded soil temperature at 1 cm depth from April 1 to May 15 in 2011-2014.

Table S1. Best models from automatic linear modelling of dry matter yields.

Table S2. Field site and plot characteristics.

Table S3. Day of year for harvest times and last day of snow.

Table S4. Recorded yields at the first and second harvests.

Table S5. Shannon biodiversity index and fraction of sown species at Site 1.

Table S6. Recorded number of droppings m^{-2} during the geese' spring staging period.

Table S7. Recorded compressed sward height during the geese' spring staging period

Table 1. Location and field characteristics for the four grassland fields included in the study

Site no.	Location	Municipality	Experimental years	Farming practice	Dominant species*
1	Naust 63°55 N, 11°22 E; 4 m a.s.l.	Steinkjer	2011-2014	Conventional	Timothy (*Phleum pratense* L.)
2	Jystad 63°51 N, 11°09 E; 87 m a.s.l.	Inderøy	2011-2013	Organic	Half the field: Timothy The other half: An Italian ryegrass-tall fescue hybrid (*Lolium multiflorum* Lam.), tall fescue (*Festuca arundinacea* (Schreb.) Dumort) and red clover (*Trifolium pratense* L.)
3	Holte 63°40 N, 11°08 E; 32 m a.s.l.	Levanger	2011-2013	Organic	Timothy and meadow fescue (*Festuca pratensis* (Huds.) P.Beauv.)
4	Setran 63°44 N, 11°21 E; 45 m a.s.l.	Levanger	2013-2014	Conventional	Timothy

* There were also other forage plants sown in mixtures with the dominant species mentioned above, but they did not contribute much (< 2 %) to the total biomass

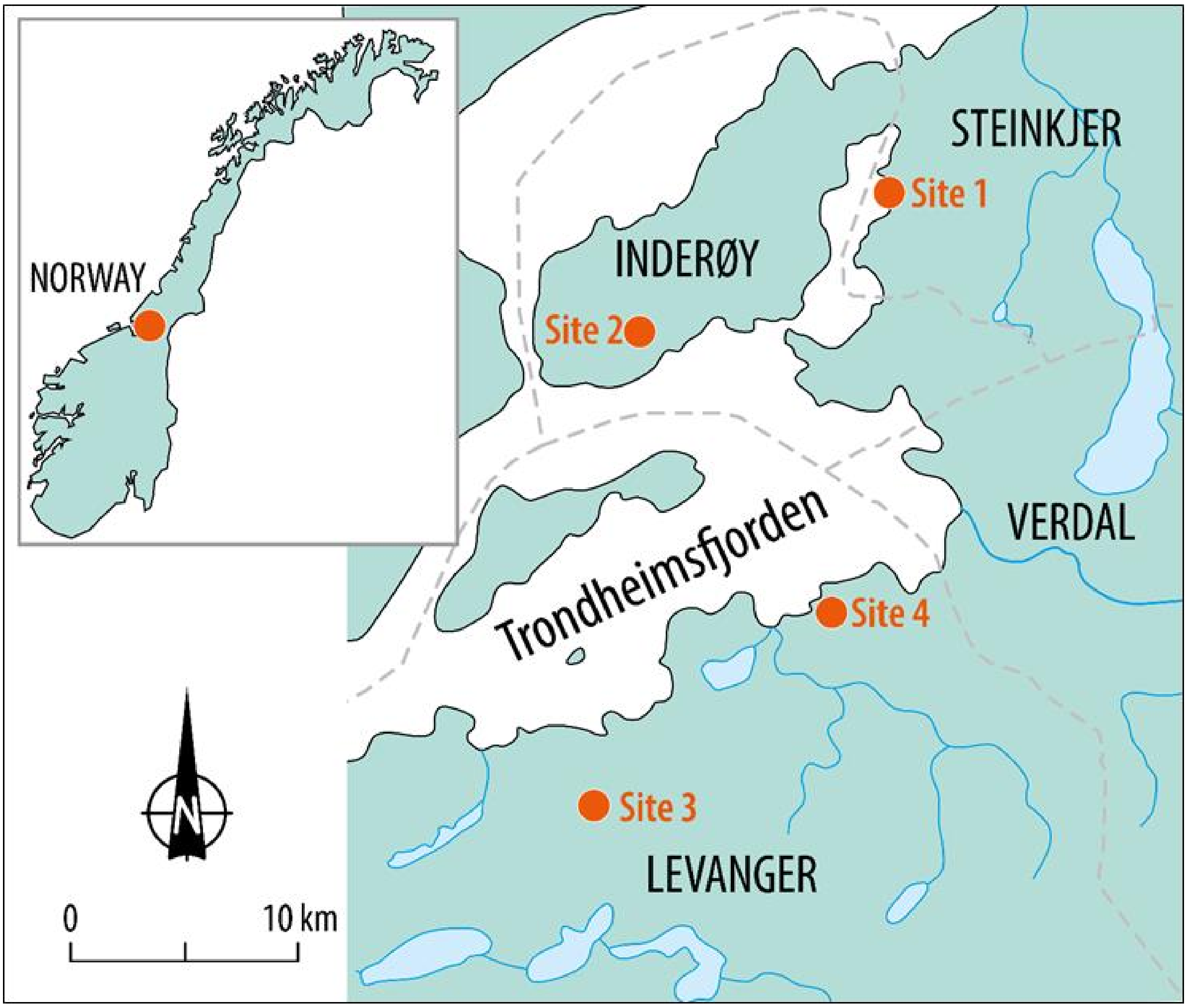


Figure 1. An overview of the four study sites (orange dots) where exclosures and open plots were established in the County of Nord-Trøndelag, central Norway.

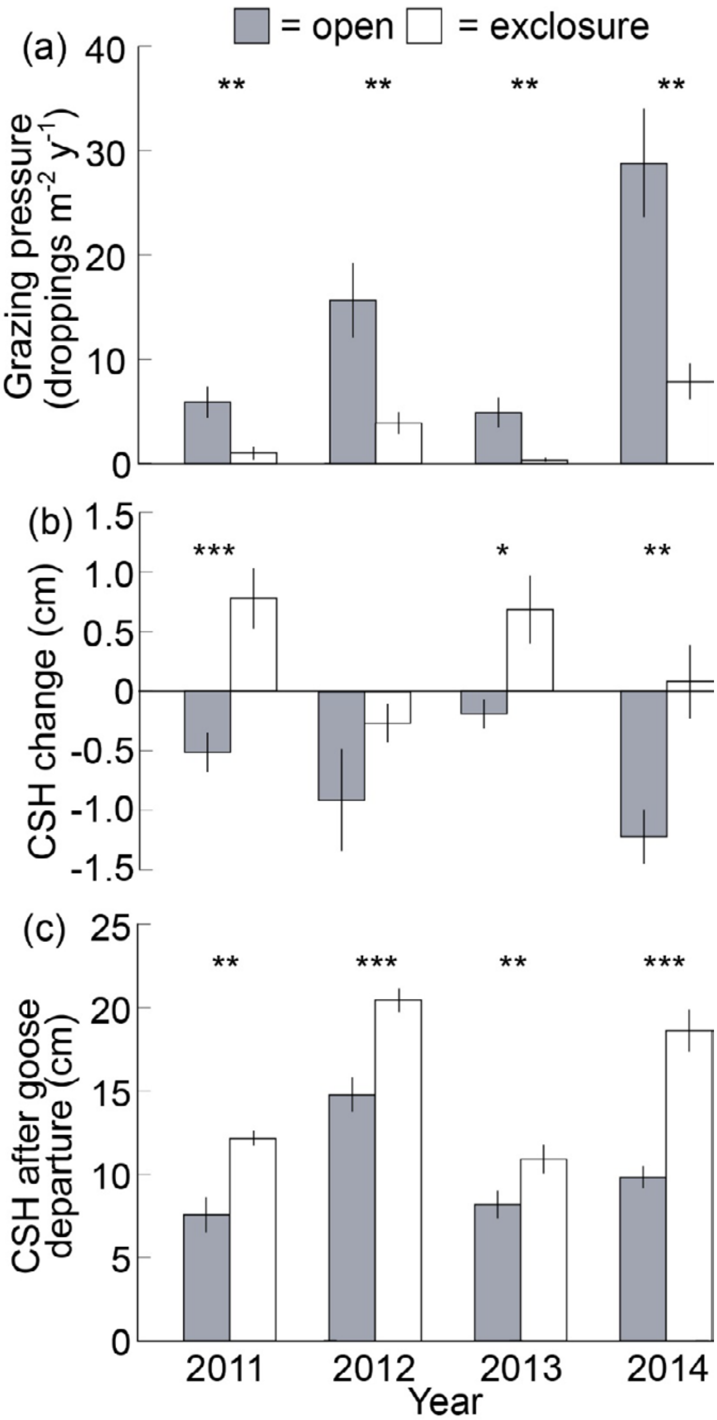


Figure 2. Treatment effects on (a) grazing pressure, (b) development of compressed sward height (CSH) from onset of spring until date for maximum grazing pressure, and (c) CSH at first survey after goose departure, i.e. ca. 7 d after the last geese left. Asterisks denote significant treatment differences within years. * = P < 0.05, ** = P < 0.01, *** = P < 0.001. Vertical lines indicate ± 1 S.E.

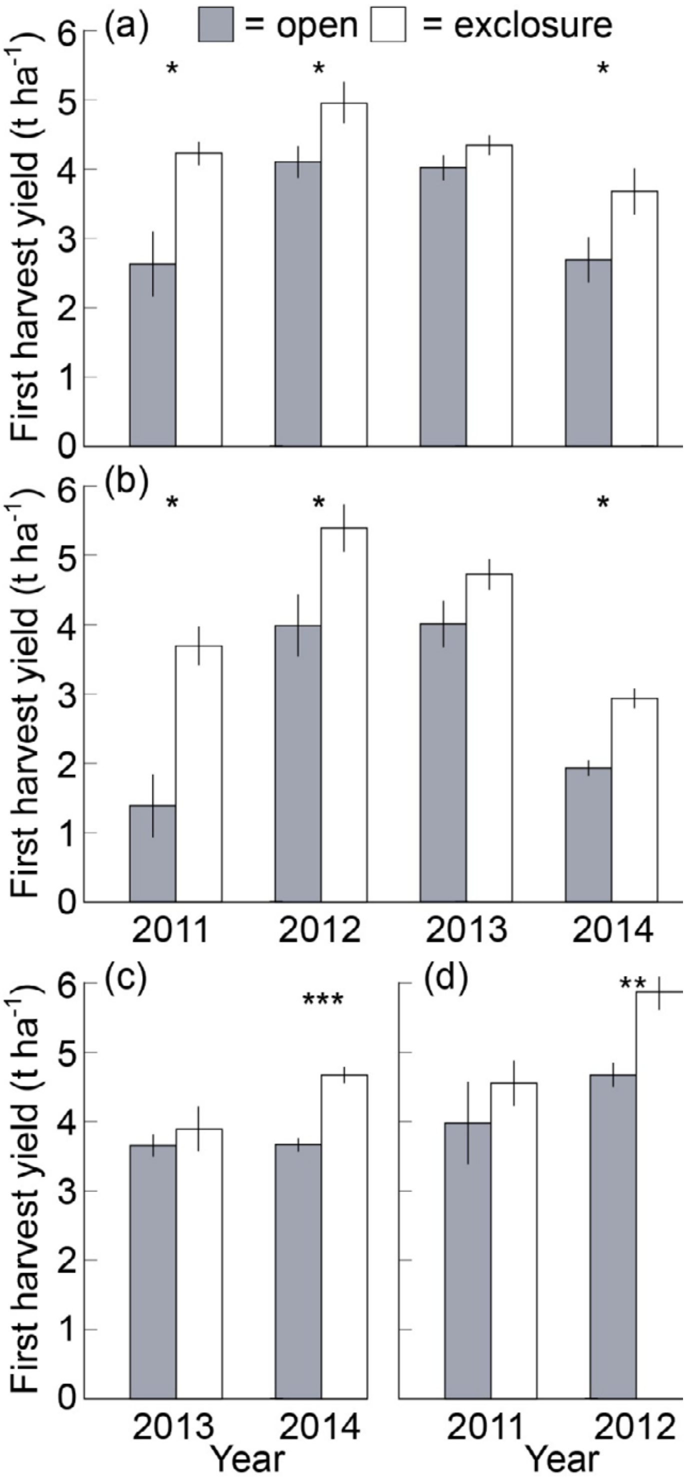


Figure 3: Treatment effects on first harvest yields at (a) All sites (3 sites in 2011-2013, and 2 sites in 2014), (b) Site 1, (c) Site 4, and (d) Site 3. Asterisks denote significant treatment differences within years. * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$. Vertical lines indicate ± 1 S.E.

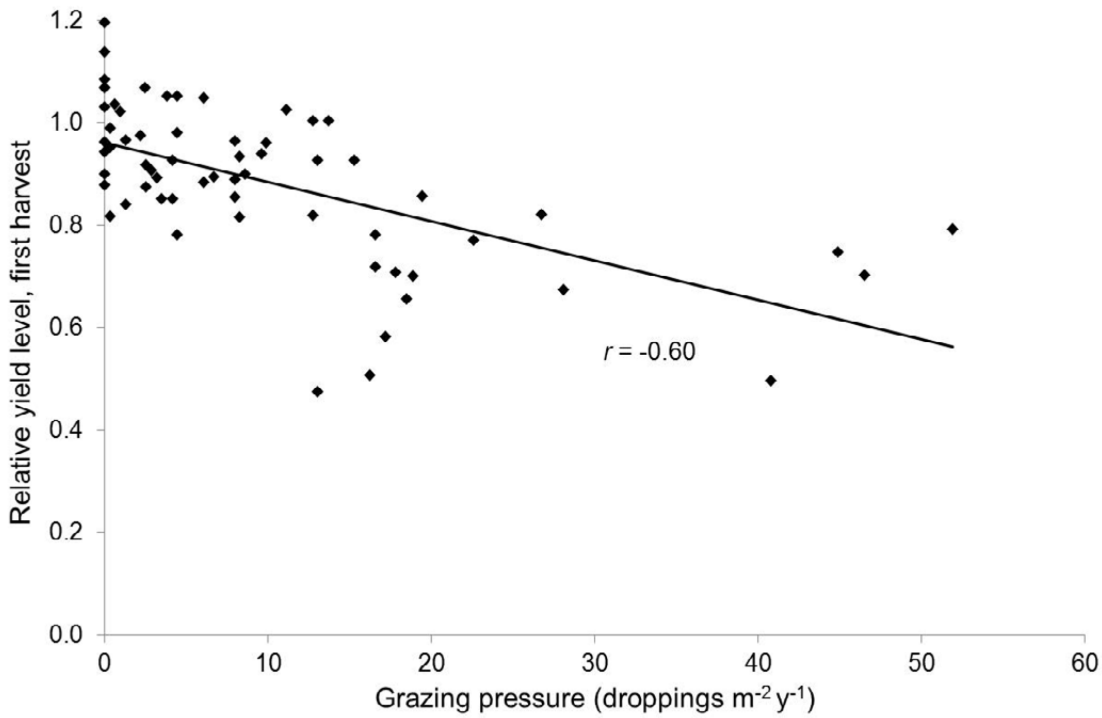


Figure 4. Relative yield level at first harvest as related to grazing pressure (sum droppings m^{-2} y^{-1}) with corresponding Pearson correlation coefficient. Data from eight field × year combinations with an annual grazing pressure > 1 dropping m^{-2} y^{-1}.

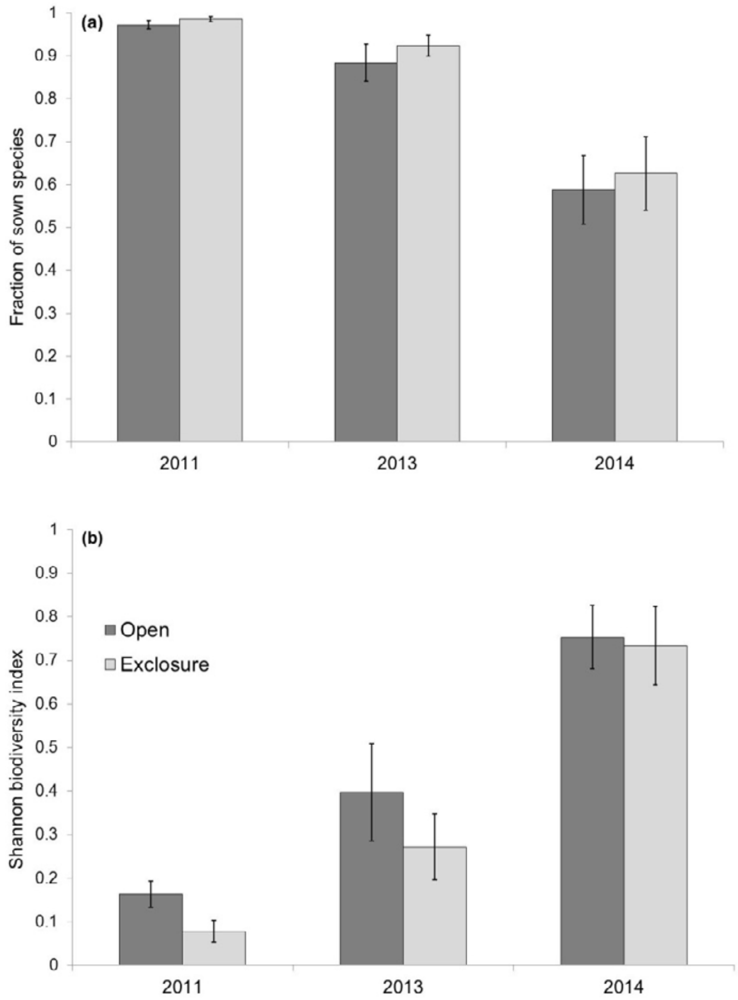
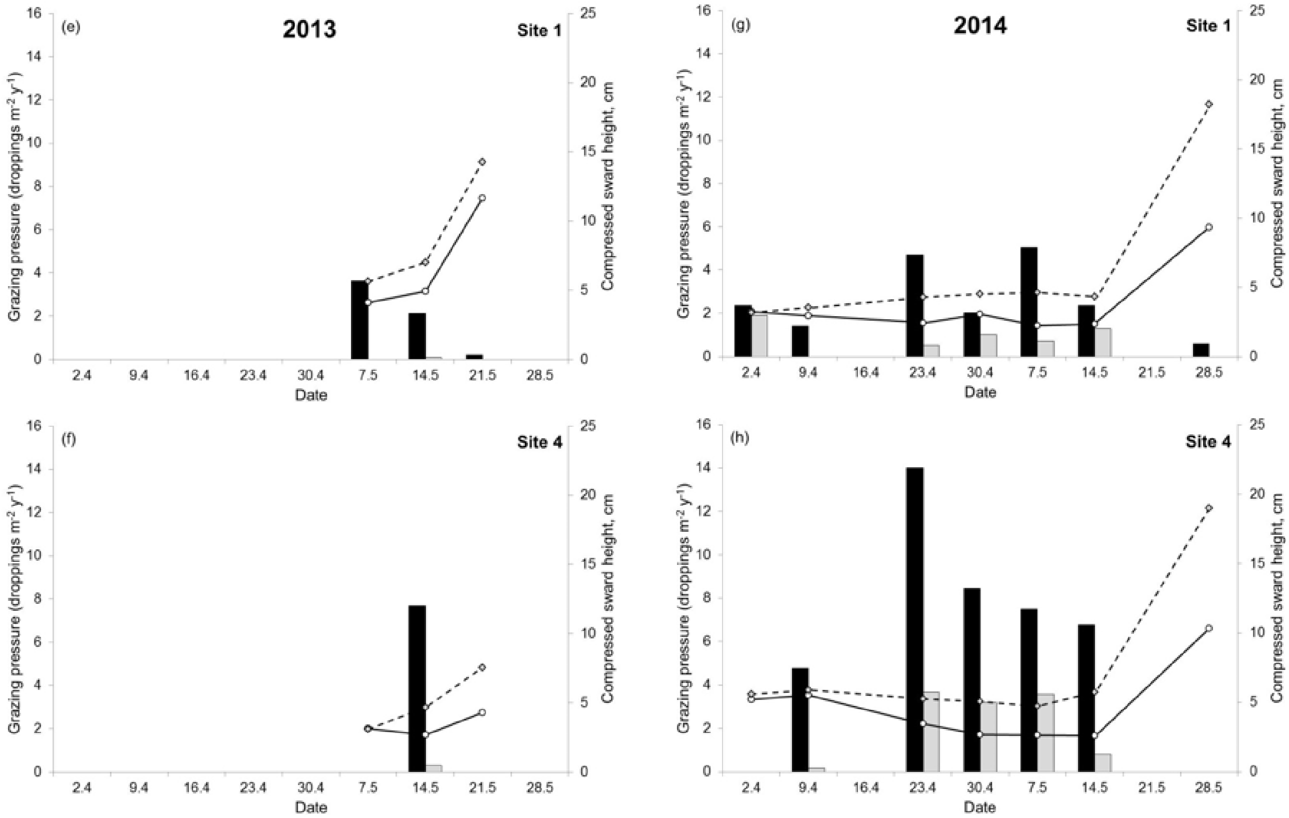


Figure 5. Fraction of sown species in relation to unsown species/weed (a) and Shannon biodiversity index (b) as recorded from open plots and exclosures at Site 1 in 2011, 2013, and 2014. Vertical lines indicate ± 1 S.E.

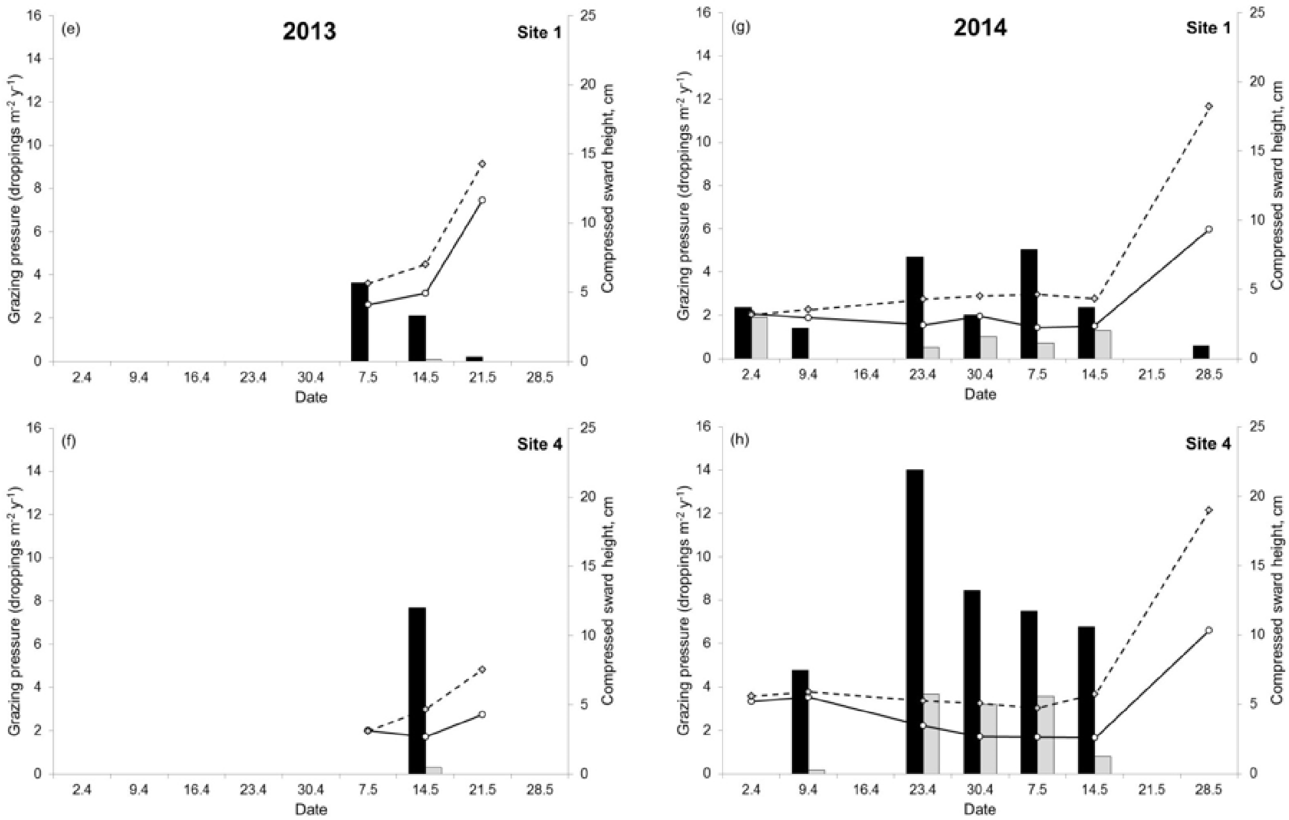
Supporting Information

This document contains supporting data on treatment responses and includes all data used for the present paper.

Figure S1 (next page). Mean compressed sward height (lines) and goose grazing pressure based on dropping counts (bar chart) in open plots and exclosures at three grasslands during the geese' spring-staging period in 2011 (a – b), 2012 (c - d), 2013 (e – f), and 2014 (g – h). Open plots: black bars and solid lines, exclosures: grey bars and dotted lines. Goose grazing at Site 2 was limited and is not shown.



(e)
2013
Site 1
(f)
Site 4
(g)
2014
Site 1
(h)
Site 4
Grazing pressure (droppings m^{-2} y^{-1})
Compressed sward height, cm
2.4 9.4 16.4 23.4 30.4 7.5 14.5 21.5 28.5
Date



(e)
2013
Site 1
(f)
Site 4
(g)
2014
Site 1
(h)
Site 4
Grazing pressure (droppings m^{-2} y^{-1})
Compressed sward height, cm
2.4 9.4 16.4 23.4 30.4 7.5 14.5 21.5 28.5
Date

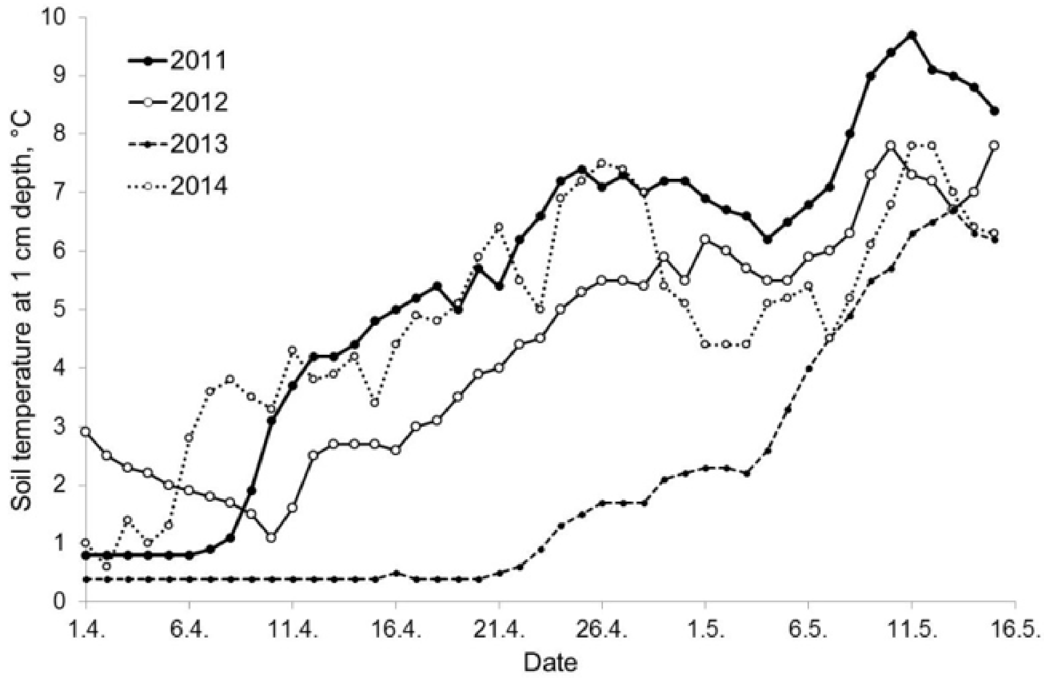


Figure S2. Recorded soil temperature at 1 cm depth at a climate station located close to Site 1 from April 1 to May 15. Data from 2011 to 2014 are shown. Data obtained from Agrometeorology Norway (http://lmt.bioforsk.no).