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Assessment of goose damage to agricultural crops - is there a relationship between goose abundances and yield loss?

Report to the AEWA European Goose Management Platform

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Content

Summary

Goose damage to agricultural crops is increasing in many areas due to a recent exponential growth of numerous wintering and breeding populations of geese. Geese foraging on farmland causes harvest losses and conservation conflicts in several European countries. The conflicts have been a major impetus for the development of international flyway management plans for selected goose populations under the AEWA European Goose Management Platform. For huntable populations of greylag goose and pink-footed goose, the plans include actions to manage populations as a tool to reduce the conflict, while for barnacle geese (protected in the EU and Norway but hunted in some of the other range states), the plans do not include population management. However, they have to ensure that populations are maintained in a favourable conservation status and that offtake (derogation and harvest) does not jeopardise that. The plans require that Range States document if geese cause significant damage and whether it can be demonstrated that there is a relationship between goose abundances and damage to agricultural crops.

The aim of this report is to provide a synthesis of the current understanding of the dose-response relationship between goose abundance and damage. Initially, the intention was to include all three species, but information regarding greylag goose, as well as goose grazing on other crops than grass, is currently too patchy to allow for a thorough evaluation. Hence, here the focus is on barnacle goose and pink-footed goose foraging on grassland, while greylag goose is only partially covered.

Four different approaches are taken in the evaluation:

1) Time series trend analyses of damage (economic compensation paid to farmers) against national goose abundances
2) Spatial analyses of damage, or proxies of damage, and regional or national goose abundances
3) Experimental quantitative analyses of damage and dose-response relationships using exclosures
4) Modelling approaches: spatial resource depletion and renewal simulations.

For barnacle geese, there is evidence of increasing damage related to increasing population sizes, manifest by all four approaches. The level of damage in terms of yield loss per area has increased in key areas of continental Europe during the last 3-4 decades, now amounting to 40-50% of the first harvest (but no loss in the second harvest) (Friesland in the Netherlands, Lower Saxony in Germany). The increase is not only linked to goose grazing pressure but also to geese staying longer in spring in some regions, i.e., when (ungrazed) grass productivity increases and closer to the time of the first grass harvest. On Islay, the damage appears to be at a similar scale but cannot directly be converted to yield loss. In north Norway, the damage amounts to an average of 17% loss of the first harvest and 19% of the second harvest. The dose-response relationship is not necessarily linear, but shows a decelerating rate with increasing abundance in those studies specifically addressing the shape of the relationship. Observational spatial studies and modelling work suggest that barnacle geese (in particular the Russian population but also the Svalbard population) are expanding their wintering and staging ranges in response to increasing population sizes, which is predicted to lead to a spatial expansion of the damage.

For pink-footed geese, experimental studies in mid-Norway showed an increase in damage with increasing grazing pressure in spring, though with between-year and site variations. The results were corroborated by modelling predicting an increase in damage under a scenario of increases in abundance.

For greylag geese, time series trend analysis revealed that there is a relationship between the loss of biomass and the population number at a national level in Sweden.

It is concluded that damage caused by barnacle geese and pink-footed geese in spring is significant in key areas and that there is a relationship between goose abundances and damage to grass yields (the first cut, but in one case also the second cut), but most likely curve-linear. The geese have expanded their range and grazing period in some regions with increasing population sizes, and it is predicted that damage levels will continue to increase accordingly.

1. Background

In the EGMP International Single Species Management Plans (ISSMP) for the northwest/southwest European population of the greylag goose *Anser anser* and the barnacle goose *Branta leucopsis*, member states are mandated to quantify the consequences of changes in population size on fundamental objectives. This implies a need to investigate if there is a relationship between goose abundances and the amount of damage caused by the species to agricultural crops, risks to air safety or other sensitive flora and fauna (Powolny et al. 2018, Jensen et al. 2018). In the ISSMP for the pink-footed goose *Anser brachyrhynchus* (Madsen and Williams 2012), this requirement is not stated explicitly, but a key objective is to keep agricultural conflicts to an acceptable level, and population control is used as one of the actions. Hence, implicitly, it is assumed that there is a relationship between goose abundance and the level of the conflict, and the agreed population target rests on the assumption that 'population size matters'.

More specifically, the Adaptive Flyway Management Programmes (AFMP) for greylag goose and the two involved populations of barnacle goose state the following: *'The ISSMP envisages the use of more detailed analysis of data on damage to agriculture and risk to air safety and to other flora and fauna as set out in Box 1 and the following action to improve consistency in states' decision-making regarding derogations and the consistency of their justifications: Create a toolbox for decisions in relation to determining significant damage (including metrics, benchmarking, verification, monitoring, various management techniques to prevent damage, compensation)'* (Nagy et al. 2021a, 2021b, 2021c). Box 1 in the ISSMP's outlines that this includes *'Characterization of the spatial and temporal extent and trends of damage to agriculture and of risks to air safety as well as to other flora and fauna that can be attributed to the population/MU in question, including predicted future changes in these'* and *'Understanding of the link between population level and damages or risk.'* Gathering this information is a prerequisite for any further considerations of the application of international coordination of derogation schemes (e.g. to use derogation as a tool to manage populations).

Earlier studies demonstrate that geese can cause significant damage to crops. In a review by Fox et al. (2017) several cases with different degrees of damage were compiled showing crop reduction between 7-82% on cereals, rapeseed and grass. However, plants can show different degrees of compensatory growth to lost biomass, and grazing by geese may not necessarily ultimately reduce harvest (e.g., Percival and Houston 1992, Clausen et al. 2021). The compensatory ability is dependent on factors such as crop type, availability of resources (e.g. nutrients, water and light), goose grazing pressure, season and the part of the plant affected (McNaughton 1983). Some of the variation in yield loss found between studies can probably be explained by differences in study design, studied goose species and crops, seasons of grazing and harvest, weather conditions and sites.

In the past, relatively few studies have been designed to investigate the relationship between goose abundance (grazing pressure) and yield loss or proxies of damage (but see:
Bedard et al. 1986, Groot Bruinderink 1989, Summers and Stansfield 1991, Percival and Houston 1992, Mooij 1998).

These five studies include barnacle geese, bean geese *Anser fabalis,* brent geese *Branta bernicla,* greater white-fronted geese *Anser albifrons and* snow geese *Anser caerulescens,* and in general show that the higher the goose grazing pressure, the higher the yield loss. However, the studies are more than 30 years old and do not represent the current situation with much increased goose population sizes, spatial and temporal distributions and grazing intensities. Consequently, the effect of grazing geese on crops is still poorly understood and in particular the relationship between the number of geese and degree of crop damage.

In response to the need for updating of older studies and knowledge gaps, stakeholder requests and imminent management challenges, it is important to compile knowledge from recently conducted research to shed light on the current goose-agriculture issues.

2. Aim

The aim of this synthesis is to provide an overview of the current knowledge on the relationship between goose abundances and damage to agricultural crops in the ranges of the barnacle goose, the NW-SW European population of the greylag goose and the Svalbard-breeding population of the pink-footed goose. The synthesis serves wider decision-making in the EGMP regarding the use of management tools, such as mitigation of the agricultural conflict, derogations and population management, and the consistency of their justification.

According to the AFMPs for greylag goose and barnacle goose, this assessment was planned to be prepared by May 2021. However, due to funding constraints, Covid-restrictions and the fact that several studies were still in progress by that time, it was decided to postpone the assessment to May 2023. By May 2023, new key studies have been published to answer the question. However, there is still important work in progress and, particularly for greylag goose, there remain critical knowledge gaps. Here, we present a review of studies that recently have assessed the relationship between bird numbers and level of crop damage. The included studies are primarily based on barnacle geese and pink-footed geese foraging on grassland, but also includes greylag geese (and peripherally greater white-fronted geese). We have restricted the review to the most recent work (2013-2023) conducted on the focal species, and only refer to older studies where relevant.

3. Analytical approaches

Since the implementation of the ISSMPs for barnacle goose and greylag goose (2018), various technical studies have been conducted to investigate whether increasing abundances of geese have an effect on agricultural yields or proxies of the problem.

In order to scale up an assessment of the extent of damage or risks from local to regional, national or even flyway levels, it is necessary to apply a suite of approaches:

1. Observational time series analyses (correlations between goose abundances and proxies for damage)

Here correlational studies were used to study the relationship between damage levels and goose abundance over time (years) on a national level in Sweden and regional level (Friesland) in the Netherlands. Correlational studies use a research design that examines the relationship between two or more variables, such as the level of damage and the number of geese. The caveat with such a design is that it is non-experimental, which means that the variables are not manipulated or controlled. Therefore, it is not always possible to rule out effects of other confounding variables. However, by assuming that all other covariates have remained constant during the study, correlational studies can still be a tool to verify relationships between variables of interest. Moreover, the advantage of correlational studies is that it is possible to cover large spatial (e.g., nations and regions) and temporal scales (e.g., many years), for which it is in most cases impossible to conduct experiments.

2. Observational spatial analyses (regression between goose abundances, spatial distribution, sensitive crops, proxies for damage)

Here correlational studies were used to study the relationship between damage levels and goose abundance on a field level in the region of Friesland, the Netherlands and between the number of approved derogation licences and goose abundance per postal area in Denmark .

3. Experimental studies: exclosures with variation in grazing pressure

The classic approach to analyse yield loss caused by geese is by using exclosure experiments in fields exposed to grazing by wild geese. This plot- or field-based approach is still important (with some possible caveats) because it provides a quantitative estimate of the damage. It is, however, difficult to extrapolate results to a wider scale, unless exclosures are spread on a wider landscape or regional scale in a randomised set-up.

4. Modelling approaches: spatial resource depletion and renewal

The daily movement and foraging of geese can be modelled by computer simulations. Two approaches have been used, one modelling individual geese (or small flocks of geese; individual-based models) and one modelling the day-to-day distribution of geese (in depletion models). In both models the geese are assumed to spend the night on water at roost sites and spread out over the surrounding fields to forage during the day, using rules to forage optimally. Resources are depleted by the geese, and are renewed when conditions allow. The number of geese can easily be varied. Here, mechanistic spatial resource depletion and renewal models have been applied.

4. Results and discussion

4.1 Observational studies - time series analyses

4.1.1 Sweden: barnacle goose, greylag goose

In Sweden, farmers are paid compensation for damage caused by geese. From 2000 to 2015, trained inspectors of the Swedish County Administration Boards evaluated and validated 2,194 damage reports, which accounted for 34,500 metric tonnes of yield loss (Montras-Janer et al. 2019). Of these reports, 88% received compensation, totalling 3.4 million euros. The remaining 12% were not compensated due to a lack of evident damage during the final pre-harvest inspection, possibly as a result of compensatory plant growth. The crops most frequently reported as damaged were barley (41%), ley (27%), and wheat (14%), while rapeseed, potatoes and legumes were less frequently reported (5%, 3%, and 2%, respectively). All other crops accounted for less than 2% of total damage reports.

During the study period, there was an increase in the annual number of damage reports, yield loss (in kg), and costs for compensation. These three indices of crop damage levels were positively correlated with national population indices of barnacle goose and greylag goose. While a linear relationship could not be ruled out for greylag goose, a non-linear relationship appeared to best fit the data. For barnacle goose, a curvilinear relationship was observed, with all three damage indices increasing at a lower rate as population numbers increased (Fig. 1). However, these relationships contained a high level of uncertainty. As such, given a specific population size, it is not possible to predict damage levels from one year to another based solely on this information, as other factors such as weather may also vary and ultimately affect damage levels.

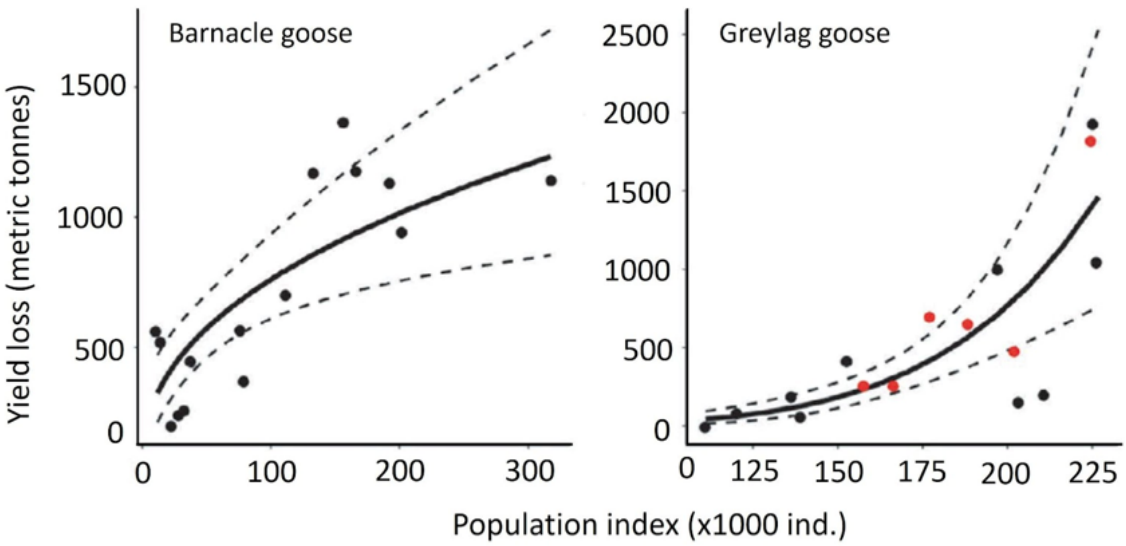

Fig. 1. Relationship between yield loss and population indices for barnacle goose and greylag goose in Sweden from 2000 to 2015. Solid lines represent the predicted relationships. Dashed lines, the 95% credible interval. Black dots, the observed values, one dot per year. Red dots in the greylag goose graph represent observed values after 2009 when compensation rules changed for this species (from Montraz-Janer et al. 2019).

4.1.2 Friesland, the Netherlands: barnacle goose, greylag goose, white-fronted goose

Within the framework of an evaluation of goose management in the province of Friesland, damage attributed to geese was related to goose numbers on a year-to-year basis (Latour et al. 2021). Goose counts were performed by Sovon (Dutch Centre for Field Ornithology) in September-May, and by Sovon and Wildbeheerseenheden/Faunabeheereenheid Friesland in July, and averaged over the months. Reports of damage to grassland were collated by BIJ12. Over the period 2005-2020, a period in which barnacle geese and greylag geese increased, while the white-fronted geese remained stable, the goose damage was related to the goose numbers, explaining about 50% of the variance. However, the goose damage increased approximately 9-fold, whereas goose numbers only increased by about 30%, implying a very steep increase in damage with a moderate increase in goose numbers. Both the damage per ha of grassland as well as per goose increased considerably, the latter becoming higher than the calculated grass intake per goose. The authors indicate that, while the potential for recovery of grass may be surpassed at a certain level of goose grazing, especially when combined with other effects of geese like trampling, it might also be that other negative effects on grass growth like spring droughts and vole outbreaks co-occurred. They also point out that the practice of damage assessment is also influential, as can be inferred from the strong increase in reported damage after the introduction of so-called automatic taxations (i.e., independent of a farmer reporting damage).

4.2 Observational studies - spatial analyses

4.2.1 The Netherlands: barnacle goose, greylag goose, white-fronted goose

In the Netherlands, actions to mitigate goose damage to crops include a combination of compensation payments to farmers for loss of yields, designation of accommodation areas for geese and scaring/derogation shooting outside accommodation areas. In a study based on data gathered in the province of Friesland (winters of 2016/17 and 2017/18), Buitendijk et al. (2022) compiled damage assessment reports, goose count data and goose tracking data. They examined the relationship between goose abundances and assessed grassland damages (first cut), considering the interplay between barnacle geese, white-fronted geese and greylag geese. They only relied on damage reports from the accommodation areas, because in these areas taxations of damage were carried out (by professional inspectors), irrespective of whether it was reported by the farmer, which prevents a reporting bias. Assessed damage was expressed as kg dry matter ha^{-1}. Goose abundances were derived from monthly surveys provided by Sovon (Dutch Centre for Field Ornithology) combined with GPS data on individually tracked geese of each of the three species studied to account for redistribution. With this approach, it was possible to assign the number of geese ha-1 of a given species to the fields from the damage reports. Goose numbers were converted to estimated daily grass intake (see Buitendijk et al. 2022 for details in methods and statistics).

The study showed that barnacle geese exerted the highest grazing pressure, followed by white-fronted geese and greylag geese. The best fitting, most parsimonious model describing assessed damage included grazing pressure of barnacle geese and white-fronted geese, and interaction effects between greylag geese and the other two species. Overall, it was found that assessed damages were positively related to grazing pressure of barnacle geese but showed a decelerating rate (Fig. 2a), but oppositely for white-fronted geese (Fig. 2b). Damage by greylag geese depended on the other two species and could be positive, negative or neutral dependent on species compositions. Setting out grazing pressures of greylag geese against the other two species, it was found that the highest estimates for barnacle geese coincided with low estimates for greylag geese, and vice versa.

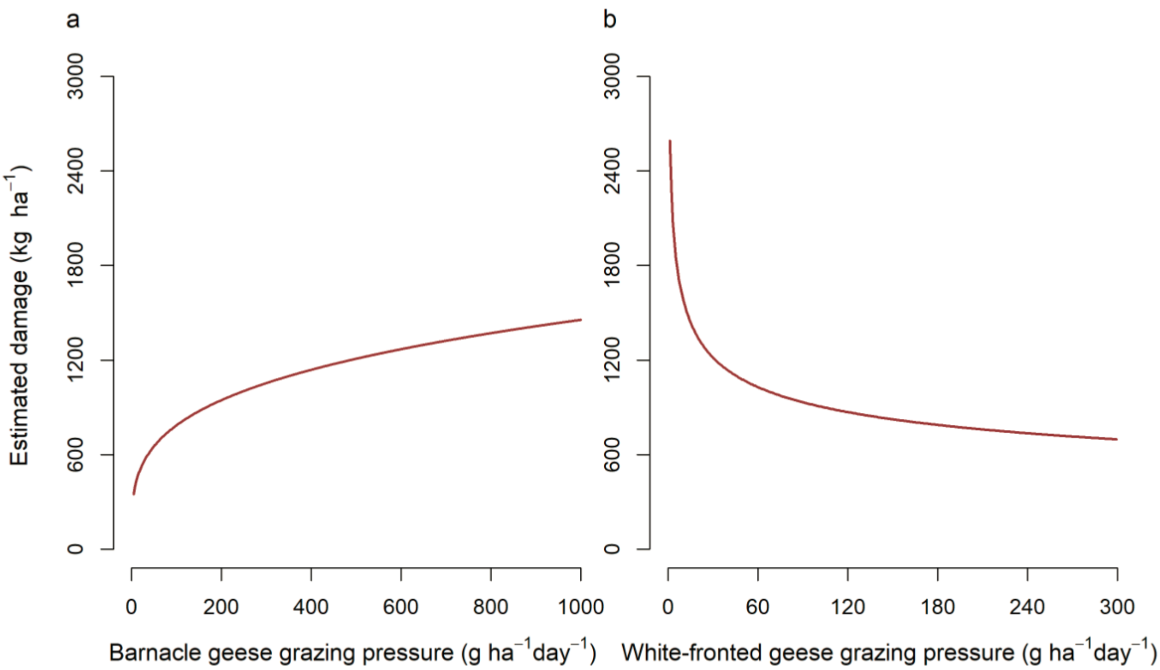

Fig. 2. A potential relationship between the estimated damage (kg/ha) and the grazing pressure (g/ha/day) of (a) barnacle geese and (b) white-fronted geese. This figure illustrates the general shape of the relationship; the exact relationship changes depending on the presence of the other two species (white-fronted and greylag geese or barnacle and greylag geese). Figure adjusted from figure 5C and D in Buitendijk et al. 2022.

The study suggests that the explanation for the decelerating rate of assessed damage may be that geese prefer fields offering the best balance between food intake and energy expenditure, leading to relatively lower energy requirements. The reasons for the negative interactions and relationships were ascribed to the fact that barnacle geese maintain a short sward height, which is less profitable to larger-billed species, leading to avoidance by the two larger species from fields heavily used by barnacle geese, and explaining spatial differences in the preferred feeding sites of the three species.

Furthermore, while white-fronted geese depart from Friesland in late March-early April and greylag geese retreat into marshes to breed, barnacle geese stay until mid-late May. The overall higher grazing pressures found for barnacle geese followed from this late grazing. Hence, the late spring grazing by barnacle geese is the main contributor to the high damage profile by the species. The few situations where both barnacle and greylag geese are abundant and assessed damages were high, likely occurred in May, when breeding greylag geese utilised fields grazed by barnacle geese to provide their goslings with short, nutritious grass. Excluding the damages attributed primarily to barnacle geese suggested a positive relationship between assessed damage and abundance of white-fronted and greylag geese, but this likely remains insubstantial compared to the effect of barnacle geese (cit. Buitendijk et al. 2022).

4.2.2 Denmark: barnacle goose

In Denmark, there is no compensation nor subsidy scheme for geese. Farmers can scare geese, shoot geese in the hunting seasons for huntable goose species, or apply for derogations to kill geese (outside the hunting season for huntable species, or for protected barnacle geese from October to May) to reduce local damage to agricultural crops where other means of scaring have been insufficient. Hence, the number of derogation licences granted by the authorities can be used as a proxy of the scale of the goose-agricultural conflict. In case of barnacle geese, the number of derogation shooting licences granted by the Danish authorities has increased since 2010. The increase over time can partly be attributed to increasing numbers of barnacle geese occurring in Denmark from autumn to spring, partly by an increase in opportunities to shoot geese under derogation licence. To analyse if increased derogation shooting reflects barnacle goose abundances, a time series analysis is therefore likely to give ambiguous results. As an alternative Heldbjerg et al. (2022) made a spatial national analysis of the number of licences granted per postal area versus goose abundances at a similar resolution, considering regional variation in crop types vulnerable to goose grazing and economics of crops. This was done for a three-year period when the derogation practices did not change. The analysis showed that differences in the number of issued derogation permits across the country was primarily explained by differences in barnacle goose abundance, and secondarily, by prevalence of vulnerable crops and differences in crop productivity. Hence, derogation efforts were highest in areas with many geese, high proportions of crops vulnerable to goose grazing and high crop yields. The results indicate that the level of conflict, and probably the economic impact of affected farmers, is proportional to the abundance of barnacle geese present locally (Heldbjerg et al. 2022).

4.3 Experimental studies

4.3.1 Study sites and methods

Several recent studies have been conducted to understand and assess goose grazing effects on grassland fields. By establishing exclosures on fields with goose grazing, their effects on the grass growth and corresponding dry weight biomass can be investigated in plots excluding geese compared with grazed plots. In a synthesis of exclosure studies we focus on nine papers and reports from the last decade: from

Germany (Düttmann et al. 2023), the Netherlands (Buitendjik and Nolet 2023), UK (Ewing 2021), Norway (Bjerke et al. 2013; Olsen et al. 2017; Bjerke et al. 2021) and Iceland (Hermannsdóttir 2015, 2018a, b) (see descriptions in Appendix 1). In addition, we include one older study in this synthesis (Groot Bruinderink 1989), as this study was conducted in the Netherlands in the same area and with methods comparable to those used in Buitendijk 2023 to allow a comparison between the situation in the 1980s and present. The general descriptions of the sites are listed in Table 1.

Table 1. Site descriptions of various goose-exclosure studies in Europe. BG=barnacle, W-f=White-fronted, P-f=Pink-footed, GG=greylag. Germany is divided in three time periods based on the set-up of experiments. Norway is separated in Mid- and North-Norway as they are different climate zones. Population size in the study area gives an indication of the scale of the goose abundance at the different study sites.

	Region (latitude)	Species	Grazing period	Years of study	Pop size in study area
Germany [1)]	Rheiderland, Lower Saxony (53.24)	BG W-f	winter & late spring	1996-1998 &	28 000 (BG), 35 000 (W-f)
				2008-2010 &	49 000 (BG), 40 000 (W-f)
				2015-2018	58 000 (BG), 30 000 (W-f)
The Netherlands [2)]	Friesland (53.16)	BG	late autumn- late spring	2020/2021	500 000 (BG), 300 000 (W-f, GG)
[3)]	Friesland (53.16)	several	winter - early spring	1983-1985	40 000 (BG), 260 000 (other species)
UK [4)]	Islay (55.48)	BG	winter - early spring	2015-2017 & 2020	39 000 (BG)
Mid-Norway [5)]	Trøndelag (63.7)	P-f	spring	2011-2014	75 000 (P-f)
North-Norway [6)]	Vesterålen (68.76)	BG (P-f)	spring	2012-2014	18 000 (BG), in 2014
Iceland [7)]	South-East Iceland (64.15)	P-f (BG, GG)	spring	2015 & 2016-2017	4 300 (P-f)

[1)] Düttmann et al. 2023
[2)] Buitendjik & Nolet 2023
[3)] Groot Bruinderink 1989
[4)] Ewing 2021
[5)] Bjerke et al. 2013, Olsen et al. 2017
[6)] Bjerke et al. 2021
[7)] Hermannsdóttir et al. 2015, 2018a, b

The exclosure studies in Germany, the Netherlands and UK measured goose effects at their wintering areas, including both winter and spring effects, whereas the study sites in Norway and Iceland were at the spring stopover sites and hence only measured spring grazing effects. The size of the exclosures were either 0.5x0.5 m (Netherlands 2020s), 0.8x1.5 m (Iceland), 3x1.5 m (UK), 1.5x3 m (Germany), 2x5 m (Norway) or 2x15 m (Netherlands 1980s) and established mainly using chicken wire or light steel reinforcement meshes, with wooden poles as corners for the largest exclosures.

Data from the first harvest was collected in all studies, as well as from the second harvest in the German and Norwegian studies, and from one of the studies in the Netherlands (Table 2). The timing for the first harvest varied among the studies reflecting the different latitudes. Hence, first harvests were from late-April to early-May in the Netherlands, from May in Germany, mid-June in mid-Norway, late-June on Islay, late-June to early July in North-Norway and mid-June to early-July in Iceland. The second harvest was in early-June in the Netherlands, August/September on Islay, mid-August in mid-Norway and late August in North-Norway. In North-Norway, if there are bad weather conditions, there may be one harvest only. In contrast, at lower latitudes, as for example in the Netherlands, there can be up to six harvests in a summer under favourable conditions.

In wintering and spring staging areas of barnacle geese in continental Europe, the lengths of the goose grazing periods, and hence the effects of winter and spring grazing, were from Mid-October to late-March/early-April in the 1980s to 2010s, but until early-/mid-May in the last decade. In spring areas geese are present in April and May.

Goose grazing *pressure* was assessed by either goose numbers (systematic georeferenced counts) or by goose dropping densities in control plots nearby the exclosures. To directly compare these dropping densities, they were converted to the number of droppings per day per m^2. The goose grazing *effects* were quantified by measuring the compressed sward heights (CSH) or as absolute grass lengths inside and outside the exclosures and/or the dry weight biomass yields. Goose effects on sward heights were assessed as the difference between grass heights inside and outside the exclosures.

In the studies from the Netherlands and Norway, compressed sward height was measured using a disk moving along a vertical pin. Disks of various diameters and weights have been used, including 50 cm and 150g (Groot Bruinderink 1989), 30 cm and 150 grams (Bjerke et al. 2013; Olsen et al. 2017; Bjerke et al. 2021) and 20 cm and 32 grams. This may therefore have an effect on the grass lengths measured and direct small-scale comparisons should be made with caution. In Iceland and on Islay the absolute lengths of the grass were measured giving the true grass length, which in general is taller than the compressed grass height (Percival & Houston 1992; Hermannsdóttir et al. 2015, 2018a,b).

Measurements of dry weight were taken from biomass samples in several studies (Groot Bruinderink 1989; Bjerke et al. 2013; Hermannsdóttir et al. 2015, 2018a,b; Olsen et al. 2017; Bjerke et al. 2021), while for those in the 2020s in the Netherlands the dry weight was estimated by a conversion from compressed grass height measures. This conversion was based on samples taken on twelve fields in the Netherlands in April 2021 (N. H. Buitendijk, unpubl. data). There are indications that the relationship between sward height and dry weight may differ across the season, making this a rough estimate of the yield loss in dry matter.

4.3.2 Results

The daily accumulation of goose droppings outside the exclosures varied from zero to three droppings per m^2, regardless of season (i.e. wintering or spring staging). Cumulative goose dropping densities (during the studied periods), on the other hand, varied significantly with the highest densities quantified at the wintering areas (UK and the Netherlands) in recent years, with up to 95 and 120 droppings per m^2. At the spring staging sites in Norway, the highest number per m^2 was 43 droppings, which reflects the shorter registration and goose exposure period (Fig. 3). However, the weekly goose counts in this region are higher, suggesting that the geese are present in higher densities. This is comparable to the more heavily grazed fields in the recent study from the Netherlands, where grazing continued longer into spring.

Cumulative dropping densities in the Netherlands in the 1980s corresponded to the five least grazed fields in the current study in that region, with up to 44 droppings per m^2. This reflects both lower daily densities (up to 0.3 droppings/m^2/day) and a shorter grazing period.

Recent grass height measurements from four different regions (Fig. 3) illustrates the effect of the difference in climate, with generally taller grass at lower latitudes. Note that this may not be entirely apparent in the graph for Islay, as this is absolute grass heights and exclosures were only placed in January and dropping counts started in February, while geese were already present from mid- to late-

October. The lighter disk used to measure CSH in the Netherlands in the 2020s might also contribute to the taller grass heights measured, but this is unlikely to explain all the variation.

At the lower latitudes grass development starts earliest, and the first harvest (in the ungrazed situation) occurs almost a month earlier than in mid-Norway. Since geese can stay until mid-May in both regions, this also results in less recovery time between the moment geese leave the area and the first harvest at lower latitudes. This may explain the larger effect on the first harvest found in exclosure studies at lower latitudes (Table 2, Fig. 4).

Some of the studies have also looked at the effect of goose grazing on the second harvest (Table 2), but only in north-Norway a significant effect was found (Bjerke et al. 2021). The difference between mid- and north-Norway was attributed to the shorter period of time between the first and second harvest, and the cooler climate, which allows less compensatory growth after goose grazing (Bjerke et al. 2021). It has also been suggested that a delay in first harvest due to grazing may shift the last harvest of the season into less favourable growing conditions, resulting in a smaller final harvest (Bakken et al. 2009). In north-Norway, the main practice is two harvests, making the second harvest also the last harvest. This effect on the last harvest has not been studied in the lower latitudes (Germany, Netherlands, Islay); at the most southern locations up to six harvests may be possible during a season.

Table 2. Goose grazing effects (averages) from different studies listed in a common and comparable currency. The CSH-differences (Compressed Sward Heights) are differences between measures taken inside and outside the exclosures (except for Iceland where total grass lengths are measured). See Table 1 for references to the studies at each site.

	CSH-diff. (cm)	Time of CSH-measurement	Time of first cut	Estimated yield, ungrazed plots (dry wgt, kg/m^2)	Yield loss, first cut (dry wgt, kg/m^2)	Relative yield loss, first cut, %	Relative yield loss, second cut, %
Germany							
1996-1998			May	0.38	0.07	18	ns
2008-2010			May	0.35	0.11	30	ns
2015-2018			May	0.35	0.16	45	ns
The Netherlands							
2020/2021	11.1	early May	early May	0.53[1)]	0.21[1)]	40	
1982-1985	1.5	early May	early May	0.25	0.07	30	ns
UK	12.4[2)]	late-May	mid-June				
Mid-Norway	5.7	mid-May	mid-June	0.41	0.09	21	ns
North-Norway	1.5	late-May	late June/ early July	0.43	0.07	17	19
Iceland	16[3)]				0.10	28	

[1)] This is a rough estimate of the dry matter yield, see Methods for more details.
[2)] Based on real height-measurements, hence this value is higher than CSH-values.
[3)] Assessed from Fig.4 in Hermannsdóttir et al. 2018 based on real height-measurements, hence this value is higher than CSH-values.

In addition to differences in yield loss between latitudes, we also see a development over the years. Yield loss in the temperate region has increased since the 1980s/1990s, at least in Germany and the Netherlands (Fig. 4). This coincides with increasing numbers of barnacle geese, as well as an extension of their wintering period from late-March to early-May (Germany: Düttmann et al. 2023; Netherlands: Groot Bruinderink 1989 compared to Buitendijk 2023).

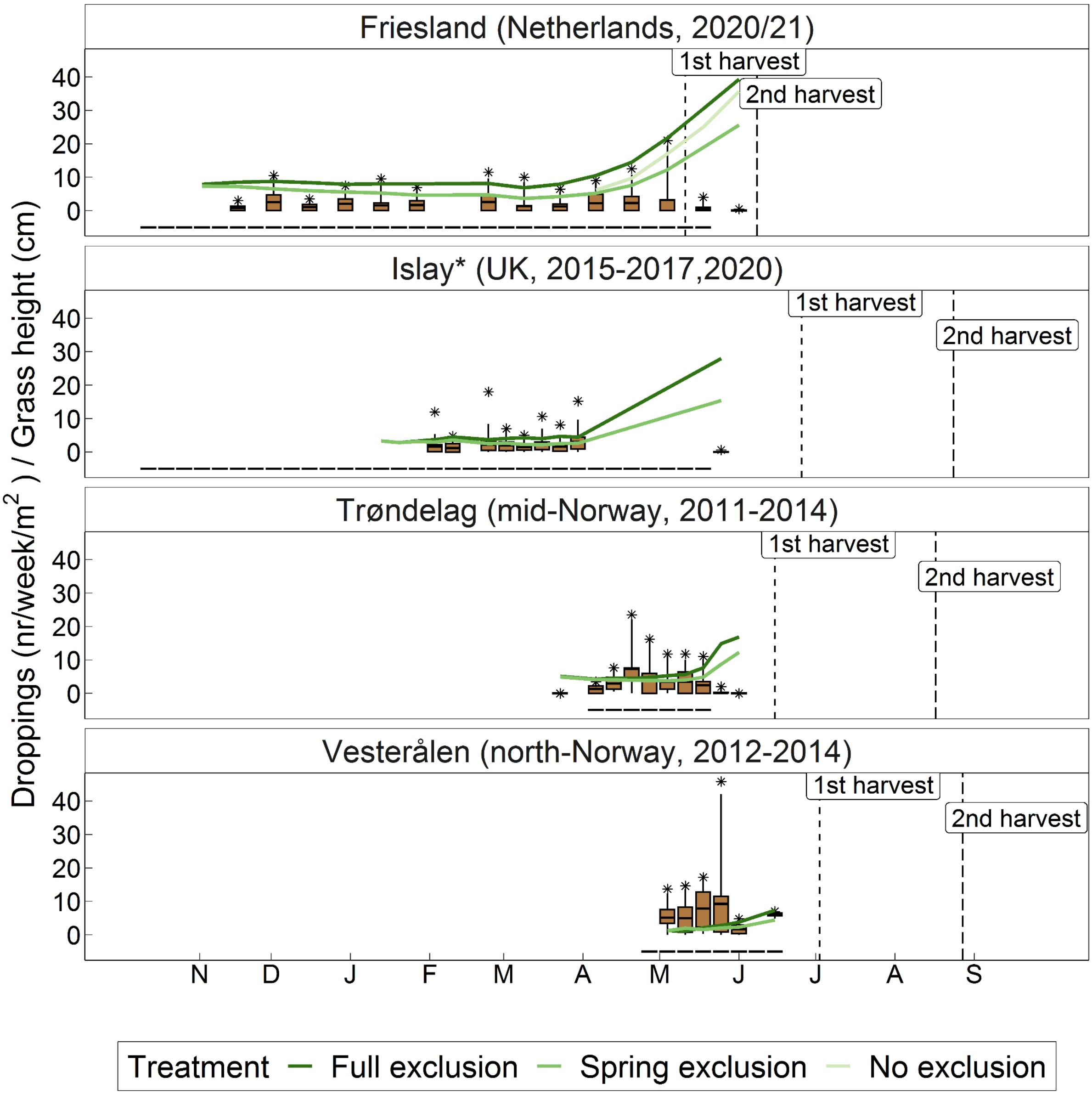

Fig. 3. The figure indicates the date of first and second harvest for Friesland, Trøndelag and Vesterålen (dashed vertical lines) and the grazing period (horizontal dashed lines), and gives the dropping counts (nr/week/m^2) and grass height measurements of exclosure studies in those regions, as well as on Islay. Brown boxplots indicate the spread of the dropping counts, with the stars showing the highest count. The green lines show the average grass height across all fields in the study (CSH for the Netherlands and Norway, absolute grass height for Islay, marked with an asterisk), in the grazed situation (light green, no exclusion) and the ungrazed situation (dark green, full exclusion). In the Netherlands a third treatment was present, where exclosures were placed in early April (medium green, spring exclusion). Note that goose foraging had already started prior to the start of dropping counts and placement of exclosures: on Islay up to three months earlier, in Friesland up to one month earlier, and in Trøndelag and Vesterålen approximately one week earlier (indicated by punctuated line). See Table 1 for references of the studies from the different regions and periods.

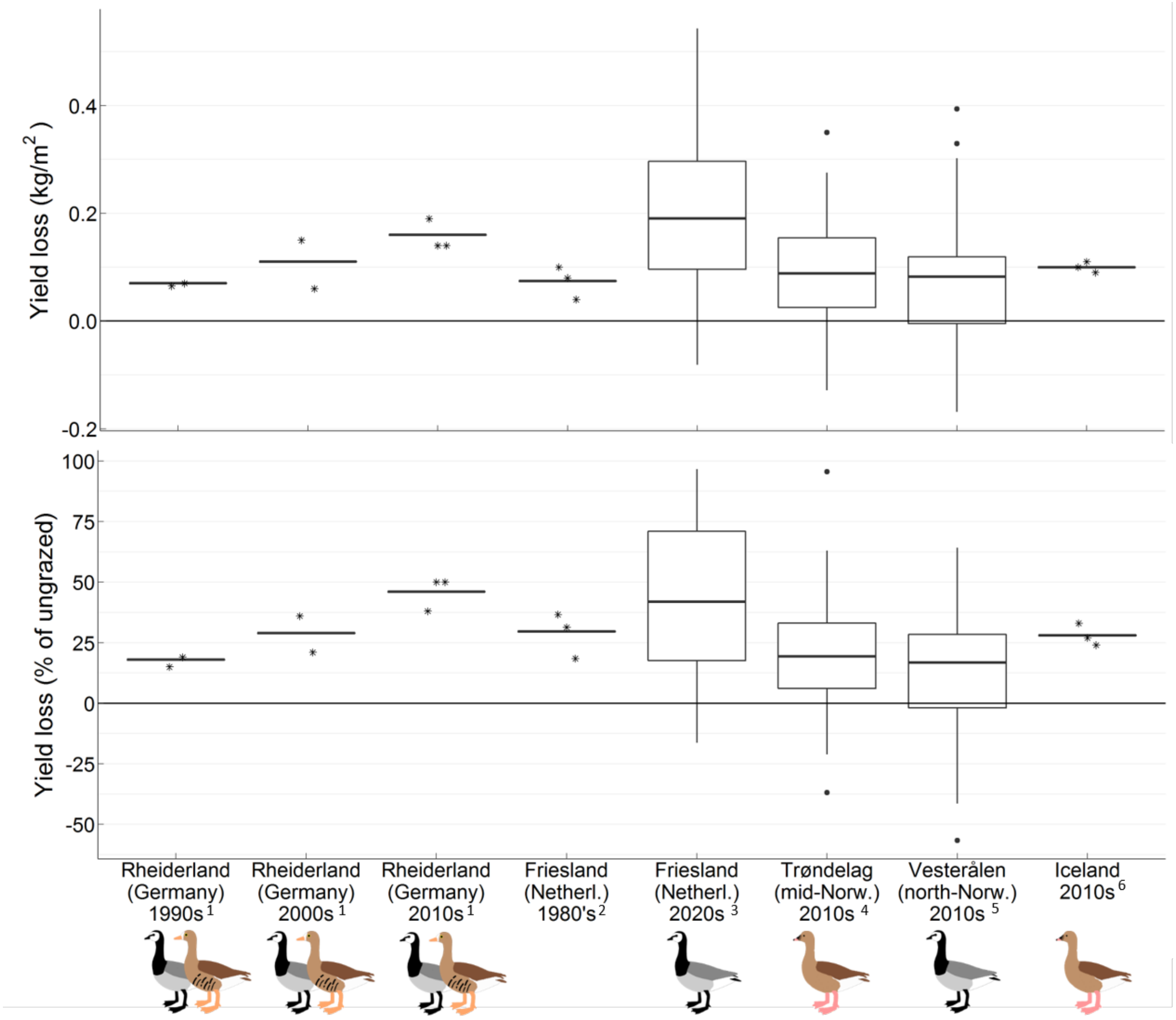

Fig. 4. The estimated yield loss in different regions and years in dry matter (kg/m^2) (top) and as a percentage of the ungrazed yield (bottom), based on several studies (see Table 1 for location characteristics and references to the studies). In some cases only average data per year was available, for these the line indicates the average across years and the stars the averages for individual years. The icons at the bottom illustrate the species present in the studies (not specified for Friesland in the 1980s). Note that for Friesland 2020s this is only a rough estimate of the dry matter yield loss (see Section 4.3.1 for more details).

[1] Yield loss estimated from figure 4 and 5 in Düttmann et al. 2023
[2] Groot Bruinderink 1989
[3] Buitendijk 2023; Dry matter weight was estimated from grass height measurements, using data on grass height and weight collected in April 2021 in Friesland. This is a rough indication of the yield loss in dry matter.
[4] Bjerke et al. 2013, Olsen et al. 2017
[5] Bjerke et al. 2021
[6] Hermannsdóttir et al. 2015, 2018a, b

Dose-response relationship

In general, the exclosure studies discussed here show an increase in the amount of yield loss with increasing grazing pressure. A few studies suggest that there may be a threshold to grazing pressure, below which no yield loss is registered (Olsen et al., 2017; Bjerke et al., 2021). Two other studies find that for barnacle geese, the relationship between grazing pressure and yield loss increases at a decelerating rate with higher grazing pressures (Düttmann et al. 2023; Buitendijk 2023). White-fronted geese have a smaller effect on first harvest yields (Ewing 2021; Düttmann et al. 2023), with Düttmann et al. (2023) finding a negative relationship between yield loss and grazing pressure for this species, similar to that found in the observational study in the Netherlands (Buitendijk et al. 2022). This was attributed to the earlier migration of the white-fronted goose compared to the barnacle goose, which allows more time for compensatory grass growth. For pink-footed geese the possibility of a non-linear relationship has not been tested.

Effects of the timing of grazing

In a number of studies different temporal factors of grazing have been taken into account to explain the yield loss. It appears that yield losses increase with longer grazing into spring (Groot Bruinderink 1989; Düttmann et al. 2023; Buitendijk 2023). Explaining the difference in grass height using only the grazing pressure in the spring period, rather than across the whole winter, results in a steeper dose-response relationship (Fig. 5 and figure 7 and 9 in Düttmann et al. 2023). It can also explain a larger portion of the variation. A linear mixed effect model using droppings from the whole winter to explain the difference in grass height had an adjusted R^2 of 0.55, while using only droppings found after week 14 resulted in an R^2 of 0.70. Furthermore, Buitendijk (2023) observed larger yield losses on fields where grazing continued longer into spring, although this was also correlated with the grazing pressure. Hence, the length of the grazing period and time of season are important to consider when evaluating the yield losses caused by geese.

The stronger effect of spring grazing has been attributed to the shorter recovery time between the last grazing event by geese and the first harvest (Groot Bruinderink 1989; Düttmann et al. 2023), but also to a negative effect of grazing on the grass growth rate (Buitendijk 2023). Like brent geese, barnacle geese appear to maintain a certain grass height or biomass on grazed fields (Ydenberg and Prins 1981; Düttmann et al. 2023; Buitendijk 2023), increasing their grazing pressure as grass production increases in spring. It has been shown that this delays the start of (harvestable) grass growth (Buitendijk 2023). Meanwhile growth of ungrazed grass accelerates as temperature and day length increase, and thus the difference in grass height grows at an increasing rate.

Whether the time for recovery will result in a decrease in yield loss depends on whether the grazed grass grows more quickly than the ungrazed grass. If both have an equal growth rate, the difference in grass height will also remain equal. This was found in a recent study in the Netherlands (Buitendijk 2023), where even grazing limited to the winter period could result in a difference in grass height at the time of first harvest. It has been suggested that such losses might disappear with a short delay in the first harvest (Groot Bruinderink 1989). What the effect of such a delay might be on the final or cumulative harvest of the season has not been studied.

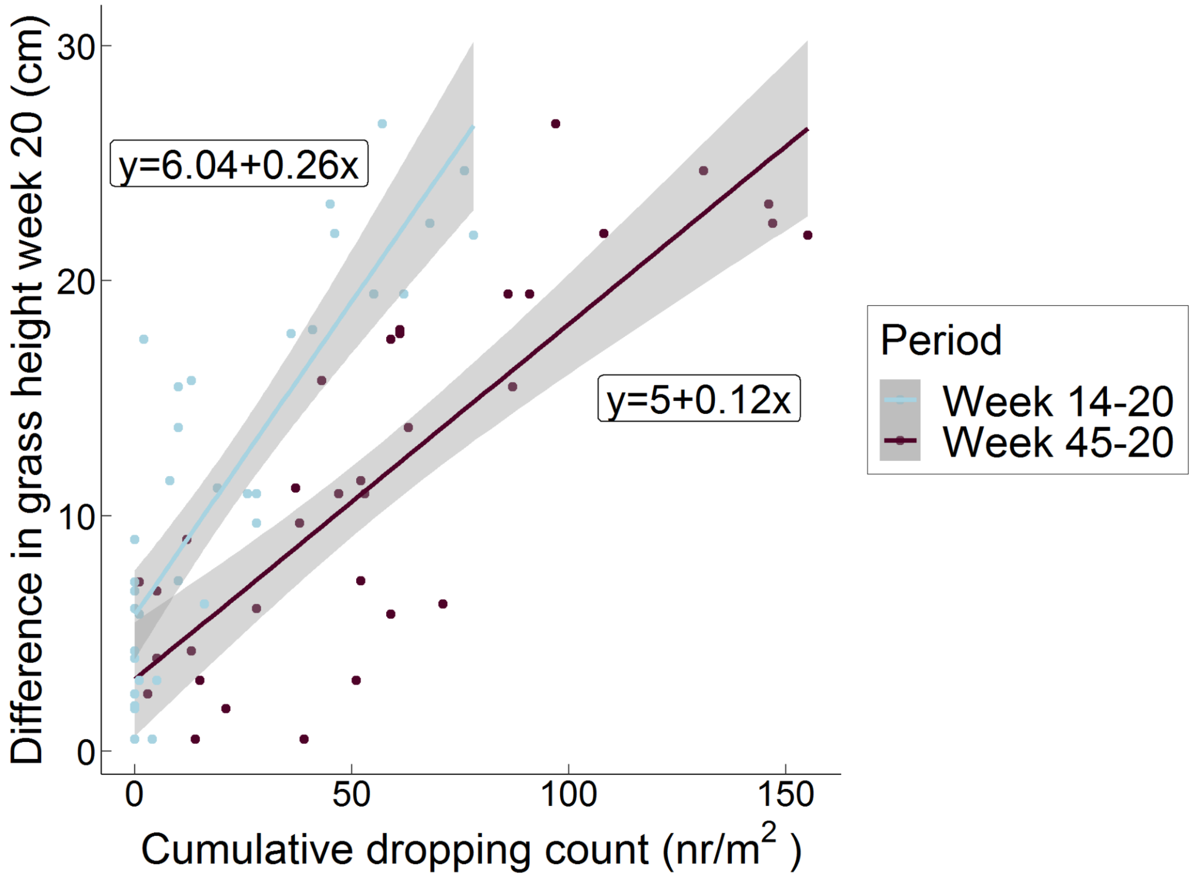

Fig. 5. Dose-response relationship between intensity of grazing by barnacle geese and yield loss, here expressed by the difference in grass height between grazed and ungrazed plots, measured in week 20 (around the time of first harvest in ungrazed plots). The x-axis gives the cumulative dropping count across either the entire winter (week 45-20) or only the growing season (week 14-20). Basic shape of the model is y~x, with field added as random factor. Cumulative dropping density was highly significant in both models ($p<0.0001$). Data from Buitendijk 2023.

Compensatory growth and compensation of yield loss

Compensatory growth refers to the regrowth of biomass following biomass removal. However, for this to result in compensation of yield loss requires a more rapid growth of the grazed grass compared to the ungrazed grass. In a recent and detailed study, Buitendijk (2023) looked at growth rates across springs, and found that there is a relationship between the individual growth rate and the size of the plant. This has also been described in other studies (Groot Bruinderink 1989; Schapendonk et al. 1998; Byrne et al. 2005). Smaller plants have less leaf area to intercept sunlight for photosynthesis, which limits their growth. However, in large plants the lower leaves become shaded by the higher leaves or the canopy, and this also limits the growth rate. Hence, this suggests that there is an optimal size in which the individual plant achieves the highest growth rate (Fig. 6).

For grass in the Netherlands, this optimal height appears to increase as spring progresses (Buitendijk 2023). In late March this is around 4.3 cm, but two weeks later this has already increased to 9.5 cm. By late spring the fastest growth occurs in grass of around 21 cm. Barnacle geese appear to maintain grass height between 3 and 5 cm, which is only favourable for the growth rate in late March. Later in the spring season it is likely that taller, ungrazed grass will have a faster growth rate, and thus that the difference in grass height will increase even if grazing ceases. Because of this, the amount of yield loss can exceed the amount of biomass removed by the geese (Fig. 6; see also Buitendijk 2022, chapter 2 and 4).

The change in the optimal height for growth likely depends in part on the temperature and on the sun-angle (Buitendijk 2023). When the sun is lower in the sky, shadows lengthen, and so shadow-effects on lower leaves can occur in shorter grass. This also means that the optimal height for growth will differ between regions at different latitudes, and may thus likely be one of the explanations for variable grazing effects across the regions. For example, the potential threshold to grazing pressure, below which yields remain unaffected (Olsen et al. 2017; Bjerke et al. 2021), may also be explained to some extent by this relationship between grass height and growth rate. The reduction in grass height will be smaller with lower grazing pressures, thus less yield loss needs to be compensated. If these also occur under colder circumstances or earlier in the season, the subsequent difference in growth rate may be smaller.

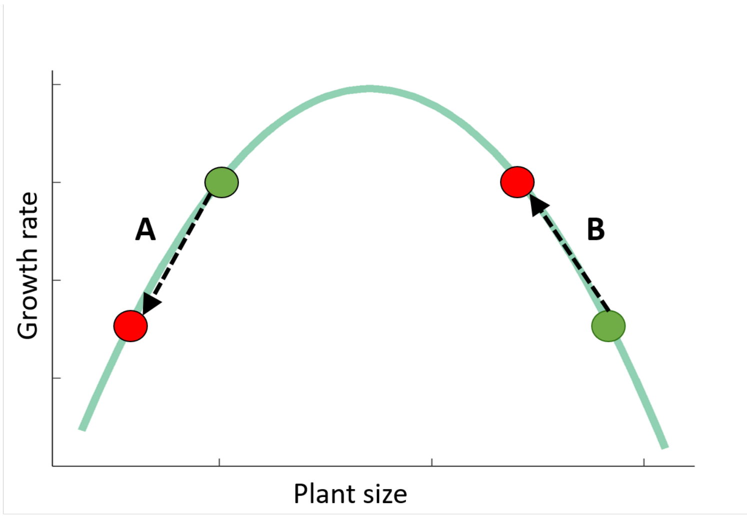

Fig. 6. The growth rate of a grass plant may depend on the size of the plant in relation to the optimal size for growth. The effect of biomass removal then depends on how grass height changes compared to this optimal height. In scenario A and B the plants are reduced to the same height by biomass removal. The green circles indicate the ungrazed situation, the red circles the grazed situation. In scenario A, the grazed plant will have a decreased growth rate compared to the ungrazed plant as the difference between the height of the plant and the optimal height has increased. In this scenario (A), the difference in grass height between grazed and ungrazed will increase over time. However, in scenario B it is the other way around: the grazed plant will have a faster growth rate than the ungrazed plant as it is closer to its optimal height for growth. In this scenario (B), the difference in grass height between grazed and ungrazed will decrease over time (adjusted from Buitendijk 2023).

Other influences on yield loss

Several other factors that influence how goose grazing can affect yield loss are addressed in some of the exclosure studies. The ambient temperature is an important environmental factor, as has been demonstrated in the study from northern Norway (Bjerke et al. 2021). Here, temperature significantly affected the sward height development; in one of the seasons of the study the spring was cold and most of the grass developed after the geese had departed, thereby having less effect on the biomass production and corresponding yield loss. Correspondingly, a spring with warmer temperatures may increase the yield from fields without goose grazing, as was demonstrated in the study from Germany (Düttmann et al. 2023). A study from the Netherlands also demonstrated the positive effect temperature has on grass and its recovery time after grazing (Groot Bruinderink 1989).

It has been suggested that one explanation for the non-linear relationship between yield loss and barnacle goose grazing pressure might follow from a preference for fields close to roost sites (Buitendijk et al. 2022). Using these fields would reduce energetically costly flying time, and thus reduce their required energy intake. Several older studies have shown that geese indeed use fields closer to roost first and more intensively (Si et al. 2011; Fox et al. 2017). This has also been confirmed in one more recent study (Madsen et al. 2022), although this was not found in Düttmann et al. (2023). They attribute this to the presence of smaller roost sites near their study area, which were not accounted for in the distance to roost. These results suggest that the distance to roost may influence the amount of yield loss, with higher losses occurring near roosts. Further study is needed to determine if these losses may be comparatively lower when considering the yield loss per goose.

A final factor discussed in the goose impact studies is yield loss in relation to farming practices. At the spring staging sites in mid-Norway, the overall grazing pressure by pink-footed geese is lower in seasons with late stubble-field ploughing, which provides an extra source of energy for the arriving geese (Olsen et al., 2017). Postponing spring ploughing may therefore reduce the impact on the new-sprouting grass fields (Baveco et al. 2017; Olsen et al. 2017).

Other effects of goose foraging

In addition to an effect on the amount of yield, goose foraging activity could also have other effects on agricultural grasslands.

Older studies in natural areas have found that goose grazing resulted in swards with higher protein content and increased tiller density, allowing geese to increase their own harvest. However, these results were not replicated on agricultural grasslands (reviewed in Fox et al. 2017; Groot Bruinderink 1989). Groot Bruinderink (1989) found that energy content decreases with sward height, with highest protein content and digestibility at around 5 cm. Hence, no effect of grazing was found on energy content, due to the limited difference between the grazed and ungrazed sward height. In a more recent study, Düttmann et al. (2023) did find higher energy and nutrient concentrations and lower fibre content in grazed compared to ungrazed grass at harvest time, which became more pronounced with the years. However, as there was also a difference in the harvest between grazed and ungrazed plots, we may expect a difference in sward height. It thus remains unclear whether this is truly an effect of grazing or due to shorter sward heights.

Another factor to consider with regard to yield quality is the maturity of the grass. At a certain time in spring grass will start to flower, regardless of the grass length. This means that the quality of silage is strongly reduced. Such effects have not been directly studied as of yet.

Finally, both older and more recent studies have looked at the establishment of weeds as a consequence of goose foraging. Geese are selective foragers, and one aspect of their grazing is the reduction of sown species and the increase of weed. This is an argument often voiced by farmers, as the fields with goose grazing must be re-sown more often (Eythórsson 2004). An index for vegetation composition demonstrated that grazing increased the proportion and diversity of weed and decreased the proportion of sown species in one study (Bjerke et al. 2013), but several other studies were unable to establish this effect (Olsen et al. 2017; Bjerke et al. 2021; Buitendijk 2023).

4.4 Modelling studies: resource depletion and renewal

4.4.1 Trøndelag, Norway: pink-footed goose

Pink-footed geese from the Svalbard population concentrate in Trøndelag, Norway during April-May. They forage in a sequence of farmland habitats (cereal stubble, cultivated pastures, new-sown cereal), and the timing is dependent on the onset of spring. They primarily cause damage to grasslands (Bjerke et al. 2014). Using a combination of modelling approaches, i.e. a species distribution model and a resource depletion model, incorporating input data from five springs with different grass growth and weather conditions, Baveco et al. (2017) simulated effects of different goose abundances on regional grass yield loss. The model assumes that individuals always meet their daily energy requirements. Two population scenarios were chosen; 1) the defined population target of 60,000 individuals according to the ISSMP (Madsen and Williams 2012), and 2) 140,000 individuals which was the projected population size in 2022 (the year of originally planned revision of the ISSMP) if no management actions were taken to control the population size.

Between years, the simulated annual yield loss by 1 June varied by a factor 6 (based on Fig. 4 in Baveco et al. 2017), heavily dependent on the onset of spring. The earlier the spring (and snow melt), the sooner would the grain stubble be depleted and geese switch to the pastures. Going from a population size of 60,000 to 140,000 individuals (increase by a factor 2.3), predicted yield loss on average increased from c. 86,000 to 271,000 kg dry weight (increase by a factor 3.2). Hence, predicted yield losses were higher by the larger population, and increased proportionally more than bird numbers. One of the reasons for the non-proportional relationship was that the model predicted that the larger population would deplete the stubble grain resource earlier than the smaller population, leading to a higher grazing pressure on pastures.

Overall, the predictions based on the model for pink-footed goose habitat depletion corroborate the findings of the exclosure experiments that there is a relationship between goose abundances and damage to grass crops in mid-Norway.

4.4.2 The Netherlands, with focus on Friesland: multiple goose species

The spatial mechanistic resource and renewal model described for pink-footed geese above, was originally developed for multiple species of waterfowl for the Netherlands (Baveco et al. 2011). This work addressed the combined impact of different goose species overwintering in the same region (the Netherlands) on resource availability in accommodation areas. The original work has now been updated and extended, taking advantage of detailed geo-data to define available resources in- and outside areas with different management regimes. It incorporates a mechanistic model for grass growth (Schapendonk et al. 1998), allowing for a more precise estimate of grass yield loss in spring, at first and/or second cut. It also includes a simulation to predict the relationship between increasing goose numbers and grass yield loss, with focus on Friesland. The species included are barnacle goose, greater white-fronted goose, greylag goose and pink-footed goose (Baveco et al. in prep.).

The overall conclusions from this work are:

(1) On the local (field) level, harvest yield loss increases faster than linear with grazing pressure (sum of consumed grass over the season). This is due to the fact that high grazing pressure can only be realised when grazing takes place late in the season (model runs from Oct 1 to May 31), when there is more biomass to be grazed. But then the possibility for ‘compensatory growth’ is also small as it takes time

for the grass to grow back to +/- ungrazed length – asymptotically, due to the non-linearity in the grass growth model. So on the field scale, more geese will cause (much) more yield loss, with the note that more geese refers to the sum of goose-days over the whole season.

(2) On the larger regional scale, yield loss summed over all fields, is predicted to increase linearly with population size. The basic relationship between yield loss and grazing pressure on field scale remains more or less the same, irrespective of whether small or very large populations have been used in the simulations. Differences between species, scaring induced energetic costs do not have a noticeable impact on this outcome. However, this may be related to the specific situation in Friesland, where resources are very abundant, even for populations several times larger than current.

Overall, the findings, especially on the field scale, are rather different from those of Buitendijk et al. (2022), who found a decelerating rate of yield loss with increasing numbers of barnacle geese. The difference is likely due to the processes and assumptions underlying the mechanistic model, which do not include the detailed grass growth parameters described by Buitendijk (2023).

5 Conclusions

The overall question to be addressed in this synthesis is: what is the observational, experimental and predictive evidence of the relationship between goose abundances and damage to agricultural crops? The primary focus of the assessment has been on barnacle geese, supplemented by information on pink-footed geese, both species foraging on grasslands. For greylag geese, we have only limited information at hand.

Effects of grazing by barnacle geese

The time series, spatial and experimental studies unambiguously show that damage, or proxies of damage, increases with increasing abundances of barnacle geese, and this is manifest at local and regional (national) scales. In key areas in the continental European wintering range the level of damage has increased during the last 3-4 decades, now amounting to 40-50% of the first harvest (but no loss in subsequent harvests). The increase is not only linked to goose grazing pressure but also to geese staying longer in spring, i.e., closer to the time of the first grass harvest. On Islay in Scotland, the damage appears to be at similar levels, but cannot at present be converted to yield loss. In north Norway, the damage amounts to an average of 17% loss of the first harvest and 19% of the second harvest. The grazing shortly before the first cut gives the grass vegetation limited time to compensate for the consumption by geese, while spring-grazing also limits the grass growth. This may be further affected by meteorological conditions. Hence, yield loss depends not only on the number of geese, but also timing of grazing and temperature.

Considering that yield losses are higher with longer grazing into spring and barnacle goose densities are found to increase during spring, it is surprising that several studies have found a non-linear relationship between yield loss and grazing pressure. Several hypotheses have been suggested to explain this difference, but these have not been tested. It seems likely that on those fields which are most heavily grazed, there is some energetic advantage: either less energy is spent to forage here, or there is a higher energetic gain per m^2 (see Buitendijk 2023, chapter 3, 4 and 6). Factors reducing energy requirements could be the distance to roosts or reduced disturbance. Increased energetic intake could be due to swards with a higher density or quality, potentially stimulated by the grazing proces itself. A higher sward in autumn might also allow a larger number of geese to be sustained throughout winter. While sporadic evidence is available for some of these hypotheses, this is not enough to come to any real conclusions.

The spatial analyses (Denmark) and modelling work (the Netherlands) both suggest that the barnacle geese are expanding their wintering and staging ranges in response to increasing population size, and, in effect, it is predicted that the damage will expand spatially. This has also been the case in north-Norway where spring staging barnacle geese have expanded their range from extensively farmed remote island areas to more intensively farmed areas (Tombre et al. 2019), causing damage to pastures.

Effects of grazing by pink-footed geese

The experimental study in Norway showed an increasing damage by increasing grazing pressure, but with annual and site variations. The results were corroborated by modelling predicting an increase in damage under a scenario of increases in abundance. The level of damage amounted to an average of 21% of the first harvest yield, which is close to what has been measured in south Iceland (average 28%).

Effects of grazing by greylag geese and greater white-fronted geese/larger goose species

The apparent negative relationship between damage and yield loss for the greater white-fronted goose found in Düttmann et al. (2023) and for both greater white-fronted and greylag geese in Buitendijk et al. (2022) can most likely be explained by an avoidance of these species from those areas used most heavily by barnacle geese. As barnacle geese crop the grass much closer than the larger species, and stay longer into spring, these are the areas with the heaviest damage. These findings do not exclude that greater white-fronted geese nor greylag geese can cause damage (which has been shown in previous studies by for example Mooij (1998) for greater white-fronted and bean geese), but that interspecific exploitative interactions, timing of grazing and foraging preferences can offset major impacts. For greylag geese, time series trend analysis revealed that there is a relationship between the loss of biomass and the population number at a national level in Sweden.

It is concluded that damage caused by barnacle geese and pink-footed geese in spring is significant in key areas and that there is a relationship between goose abundances and damage to grass yields (the first cut, but in one case also the second cut), but most likely curve-linear. In some regions, geese have spread with increasing population sizes, and it is predicted that damage will increase accordingly.

Outstanding research questions

Obviously, there is a lack of information and quantitative studies from the summer period, when greylag geese forage on grasslands at the time of mowing. Furthermore, it is known that greylag geese may cause damage to ripe cereal crops shortly before harvesting, but the amount and extent of damage in relation to distribution and abundances of geese are poorly documented.

The damage caused by geese in the wider landscape is due to a combination of the effect of grazing and the spatial and temporal distribution of geese and habitats, all of which are affected by a number of variables. The further development of dynamic modelling tools to regularly predict areas sensitive to damage and alternative habitats could provide a tool to mitigate and manage the problems more strategically. It will require incorporation of more detailed grass growth models, including the shifting relationship between grass height and growth rate throughout spring.

Current studies on grass development have been targeted at late spring and summer, which is most relevant to agricultural practices. However, to better understand the effects of goose grazing on grassland yields, we also need to understand how grass develops in winter and early spring, especially in temperate regions.

In addition to the effect of grazing on the amount of yield loss, there are other factors that may merit further study. It has been shown that grazing may delay the first harvest, but the consequences of this for the quality of yield and for the final harvest of the season have not yet been studied. It is also generally unclear how grazing may affect the quality and density of a sward on agricultural grassland, and what this means for the harvest of the farmer. Furthermore, it is unclear under which circumstances the establishment of weed species in foraged plots may increase.

There is a need to standardise methods, such as tools for measuring vegetation height, exclosure designs, sampling design and protocols including recording of goose grazing intensities and timing, and also taking into account representativeness of sampling. Furthermore, it would be useful to standardise metrics in order to improve repeatability and comparisons among studies.

This synthesis has almost solely considered goose grazing on grasslands; however, damage to other crops such as winter cereals have often been claimed. Apart from the study by Mooijj (1998) there is no evidence of dose-response relationships and only few studies of effects of grazing at different times of the season and compensatory growth (Clausen et al. 2022). Due to the wide-spread use of winter cereals by several waterfowl species this merits further studies.

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Appendix 1 - main findings and conclusions of recent experimental studies

North-Norway, Vesterålen

Bjerke et al. 2021

Exclosures and open grazed plots were measured over three spring seasons (2012-2014). The grazing *pressure* was quantified by goose abundances based on goose registrations in the study area and densities of goose droppings in grazed plots. The grazing *effects* were quantified by differences in compressed sward heights inside and outside the exclosures, and dry weight biomass yield at the first and second harvest. The first harvest is 1-1,5 months after the geese have departed for their breeding areas. The goose numbers, and hence dropping densities, varied both between years and fields, but not within fields. The yield losses due to goose grazing were only found at fields with high goose abundance, but where this limit is will depend on variable growing conditions. Overall, the relative yield loss was on average 17 and 19% of the first and second harvest, respectively. Temperature significantly affected the sward height development, and in a cold spring most of the grass was developed after the geese had departed, having less effect on biomass production. There was a positive correlation between goose abundance and dropping densities and first harvest yields, demonstrating that geese find the most productive fields. This finding should be kept in mind when evaluating goose abundance and yield production, and preferably not only consider absolute figures but assess relative yield loss instead.

Mid-Norway, Trøndelag

Bjerke et al. 2014; Olsen et al. 2017

Exclosures and open grazed plots were measured over four spring seasons (2011-2014). The grazing *pressure* was quantified by densities of goose droppings in grazed plots. The grazing *effects* were quantified by differences in compressed sward heights inside and outside the exclosures, and dry weight biomass yield at the first and second harvest. The first harvest is about one month after the geese have departed for their breeding areas. The compressed sward heights inside and outside the exclosures varied both between years and fields. In general, there was a negative relationship between grazing pressure and yield at first harvest but no significant grazing effects at the second harvest. The correlation and effects were stronger when only the fields with high grazing pressure were included, and when analysing the relative yield levels (yield loss divided by total yield in un-grazed plots). Overall, the relative yield loss due to goose grazing was 21,4% at the first harvest. No significant effects were found on the second harvest. The overall grazing pressure was lower in seasons with late stubble field ploughing, which provides an extra source of energy for arriving geese.

UK, Islay

Ewing 2021

The study summarises four winter- and spring-months (January, February, March, May) of exclosure data over four years (2015-2017 and 2020). Goose grazing *pressure* was investigated by quantifying the goose numbers (field averages) and densities of goose droppings in grazed plots (also including, and controlling for, other herbivores in the analyses). The *effects* were measured as differences in absolute sward heights inside and outside the exclosures, and as grass coverage. There was a significant difference in grass heights between grazed areas and inside exclosures (except in January), and patterns were more pronounced in March and May than in February. There were no trends across years in goose grazing patterns. An increase in goose droppings correlated with decreased grass height in March, with a similar pattern that was not significant, in February. The grass coverage was not significantly higher in exclosures than on grazed areas, except when looking at February grazing by barnacle geese only.

Germany, Lower Saxony

Düttmann et al. 2023

This is a long-term exclosure study covering three time-periods (1996-1998, 2008-2010, 2015-2018). Grazing *pressure* was quantified comparing grazed and ungrazed (exclosures) plots and by weekly registrations of geese. The *effects* were quantified as dry biomass yields and as herbage quality (energy, ash, crude protein and fibre). Yield reductions correlated positively with goose densities (barnacle geese). The relative loss in dry biomass yields increased over the study periods, from 15% in the early years to around 50% in recent years. The energy and crude protein contents were higher in grazed compared to ungrazed plots, suggesting that geese, with their grazing, maximises their potential nutrient intake. The prolonged length of stay for barnacle geese reduce the time for the grass to compensate between grazing and first harvest, hence increasing the yield losses in spring.

Iceland, Hornafjörður/Skaftárhreppi

Hermannsdóttir et al. 2015, 2018a, b

Exclosure experiments were conducted in three spring seasons (2015, 2017 and 2018). Grazing *pressure* was assessed by goose counts in the region with variable count frequencies among the different sites. Grazing *effects* were quantified by comparing the length of the grass inside and outside the exclosures, as well as the dry biomass yields at first harvest. The first harvest is 1-1,5 months after the geese have departed for their breeding areas. Grass lengths were taller inside the exclosures compared to outside for almost all grass measurements. First harvest yield losses were on average 33, 27 and 24% in the different years. There were no significant correlation between goose numbers and yield losses, but whether the goose counts performed reflect the real goose abundances at the different sites are questioned and discussed.

Netherlands, Friesland

Buitendijk 2023 - Chapter 4

An exclosure study was conducted across one season (November 2020 until June 2021). Grazing *pressure* was quantified through two-weekly dropping counts next to grazed plots. The grazing *effect* was quantified through differences in compressed sward heights between plots with exclosures placed in early-November (full-exclusion), in early April (spring-exclusion) or without exclosures (no-exclusion). On some fields grazing only occurred during late winter and early spring, others were grazed from late autumn until shortly before the first harvest in the ungrazed situation. Both winter and spring grazing resulted in a difference in grass height at the time of first harvest, with an average relative difference of 40%. This difference increased with grazing pressure, but at a decelerating rate. Spring grazing depressed (apparent) grass growth, causing the difference in grass height to increase as grazing continued longer in spring. Fields grazed until May showed differences in grass height between 68% and 93%. A relationship was found between grass height and growth rate, with an optimal height for grass growth that increases as spring progresses. Because of this the difference in grass height can initially increase after geese have stopped foraging on a field.