The impact of wintering geese on crop yields in Bulgarian Dobrudzha: implications for agri-environment schemes

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Abstract

Wintering wildfowl are widely perceived to damage agricultural crops, resulting in economic losses and conflict between farmers and conservationists. However, examinations of the nature and extent of the damage show very variable outcomes, ranging from no detectable impact to yield losses exceeding 50%; this makes it hard to infer losses in unstudied systems. In Bulgarian Dobrudzha, a large wintering goose population almost exclusively consumes winter wheat, but the impact on wheat yields is poorly understood. In 11 study fields over two winters, we used crop exclosures and dropping counts to manipulate and measure goose grazing intensity, and estimated crop yield and its components. Crop yield was 15% higher in exclosures than in unfenced control plots in one winter where goose grazing intensity was high, but there was no effect of exclosure in a second winter when goose grazing intensity was relatively low. A negative linear relationship between grazing intensity and crop yield was found, mainly driven by a lower stem density in heavily grazed plots. Extrapolation of this relationship to observed goose densities across the wider area indicated that yield losses would rarely exceed 15%. However, the generality of these results remains unclear because the impact of a given grazing intensity appears likely to vary according to factors such as timing of grazing, weather, stage of crop development and soil conditions. We discuss the results in light of a new agri-environment scheme that has been launched in the area with the aim of securing appropriate forage conditions for wintering geese and at the same time compensating farmers for losses and reducing conflict.

Keywords Red-breasted Goose · White-fronted Goose · wheat · compensation scheme · agriculture

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Introduction

In many parts of the world, herbivorous wildfowl are conflict species. Their aesthetic appeal means that they are often admired or even revered; however they are also quarry species, their grazing of cropland and farmed grassland can cause agricultural damage, their grazing of amenity grassland causes nuisance to human users and their aggregations can cause risks to aviation (e.g. Blackwell et al., 2013), Jensen et al., 2008), Mackay et al., 2014), Warren and Sutherland, 1992).

During recent decades, some of these conflicts have increased, particularly among migrant geese and swans that breed in the subarctic or arctic and winter in temperate areas. Intensively grown crops such as 'improved' grassland and autumn-sown cereals has increased winter food availability. These habitats attract the congregatory birds so that often the most capital-intensive farmland receives the heaviest grazing (Hassall and Lane, 2001), Percival, 1993).. At the same time, the increased food supply and improved management of hunting has allowed many populations to increase (Wetlands International, 2015)., in some cases to the detriment of arctic breeding habitats (Jefferies et al., 2006).

Successful resolution of these conflicts relies upon dialogue and consensus between stakeholders (Tombre et al., 2013).. It also depends upon robust evidence with which to quantitatively evaluate conflicts and suggested solutions. An important part of this evidence is assessment of the magnitude of crop yield reductions caused by grazing geese. However, such assessments remain problematic and conclusions uncertain. Patterson (1991) reviewed eight studies of the impact of goose grazing on autumn-sown cereals and found yield reductions between 0-56% following goose grazing, with approximately half of replicates showing a significant yield loss and no apparent relationship between grazing intensity and yield reduction. He noted that "there is considerable evidence that goose grazing is associated with significant loss of yield, but there is great variability in the degree of loss suffered at any given level of grazing" (Patterson, 1991).. This variation relates partly to methodological differences, and in some cases inadequate replication/sample sizes. However, there also appears to be very substantial variation between sites and years in the impact of given grazing intensities. Although widely speculated upon (Kahl and Samson, 1984), Parrott and Mckay, 2001), Patterson et al., 1989)., the causes of these variations are not well established. Evidence of crop damage has been used to inform the development of 'agri-environment' schemes that attempt to resolve farmer-conservationist conflict by providing payments to farmers in return for favourable goose management and/or as compensation for estimated economic loss (Jensen, Wisz and Madsen, 2008), Vickery et al., 1994)..

The Black Sea coast of Turkey, Greece, Bulgaria, Romania and Ukraine supports a very large wintering population of arctic migrant geese, comprising primarily Greater White-fronted Goose *Anser albifrons* (ca.250,000 individuals), and virtually the entire world population of the globally Endangered Red-breasted Goose *Branta ruficollis* (ca.55,000 individuals, with major uncertainty) along with temperate breeding Greylag Goose *Anser anser* (ca. 85,000 individuals) (Wetlands International, 2015).. Bulgarian Dobrudzha (Fig. 1) comprises a major winter site for these populations, with major roosts at the coastal lagoons of Shabla and Durankulak and on the adjacent Black Sea (Michev et al., 1991).. Total goose numbers at these roosts have peaked at ca.300,000 individuals in recent years (Dereliev et al., 2000), Kostadinova and Dereliev, 2001)..

A linked set of conflicts have arisen around this wintering site. The sites are considered a high conservation priority, being the main wintering site for a charismatic, globally Endangered bird species, and supporting a very large waterbird congregation. Consequently, both roost lakes are Ramsar sites, EU Special Protection Areas and national protected areas. The geese feed almost exclusively on winter wheat *Triticum aestivum* and outwith the protected areas, which creates a conflict with agriculture due to perceived crop damage. Previous attempts to quantify this damage in Bulgarian and Romanian Dobrudzha were contradictory, with Hulea (2002). finding that yields were 17-30% lower outside goose exclosures than within them (though with limited statistical significance), but no such impact found by Dereliev (2000).. However both analyses were limited to very few fields in a single winter. The Greater White-fronted Geese are legal quarry (including within the SPA boundary), while Red-breasted Geese are protected. This creates conflict between hunters and conservationists, because of perceived harm to Red-breasted Geese due to hunting disturbance, and perceived restrictions on legitimate hunting activity. However, there is also farmer-hunter conflict, because hunters regularly enter cereal fields in vehicles, causing crop damage. Conversely, alleged damage to crops by grazing geese has been used by hunters to justify prolonging the hunting season. Finally developers and conservationists have been in conflict, particularly in regard to the expansion of wind turbines in the area (e.g. http://europa.eu/rapid/press-release_IP-13-966_en.htm); these are often situated on agricultural fields which are used by grazing geese.

As a component of resolving these conflicts, we measured yield changes due to goose grazing in winter wheat crops in the area, in order to provide clarity on the issue and to inform the development of an agri-environment scheme to promote goose-friendly farming. We used goose exclosures and dropping counts to measure goose grazing intensity, in two years and across multiple fields, and estimated wheat yield and its components. In doing so, we attempt to provide more robust evidence on goose impacts on winter cereals generally, by designing a study with adequate replication and robust statistical methods.

Methods

Study system

Our study area comprised ca.750 km^2 in the municipalities of Shabla, Kavarna and General Toshevo, centred on ca.43.57N, 28.41E. The area was defined by the land lying within 15 km of the major goose roosts at Shabla and Durankulak lakes and the coast between the Romanian border in the north and Cape Kaliakra in the south (Fig. 1), because prior observations indicated that the vast majority of goose grazing occurred within this area (Dereliev, 2000).. The area is predominantly low elevation arable land, with approximately 50% of the land area under wheat crops in recent winters, alongside substantial areas of rape and maize. Fieldwork was conducted in growing seasons 2011/12 and 2012/13.

Goose use of the area is extremely variable within and between winters, apparently due to very variable winter weather conditions. Substantial numbers of geese can be present between late November and early-March, but within this period numbers can rapidly decrease when mild conditions result in a shift north and east along the coast, or severe conditions result in a south and west shift. The timing of wheat growth is similarly variable between years. In some winters there is full dormancy throughout mid-winter, due to freezing conditions and snow cover, whereas in others there may be substantial wheat growth in mid-winter. Winter 2011/12 was mild until mid-January, but thereafter very cold until mid-March, with extreme cold between 26 January and 11 February. Winter 2012/13 had a much milder November, but thereafter showed oscillating temperatures without the extremes of 2011/12. In each of the two winters of our study, there were approximately 20 days of snow cover, but in 2011/12 this was mainly between late January and mid-February, whereas in 2012/13 it was between mid-December and late January (Fig. 2). The weather pattern was reflected in goose numbers at the site. In 2011/12, numbers remained below 10,000 until the end of January, and were at ca.50,000 during February, with 15,000 until mid-March. In 2012/13, numbers exceeded 40,000 by mid-December and peaked at ca.270,000 in mid-January, before falling rapidly to less than 10,000 by mid-February (Fig. 2).

Plots and dropping counts

At the beginning of the study we selected 11 fields (five in 2011/12, six in 2012/13) that were expected to have substantial goose use, based on observations in previous years and proximity to roost sites. Within each of these fields we randomly placed goose exclosure plots, and control (non-exclosure) plots (N =190 control plots, 169 exclosure plots, N=18-49 plots per field). All plots were placed >100m from field edges, and other tall structures which geese avoid feeding close to (Harrison et al. submitted), and were a minimum of 78m apart.

The fields were cultivated under normal management for the area. They were sown between late September and early November with Enola wheat at a drilling density of 300 kg ha^{-1}. Nitrogen fertiliser was applied in March with herbicide and leaf fertiliser application in April. Crops were harvested between 27 June and 8 July. Exclosures were installed in late October/early November, prior to goose arrival. They were 1x1m weldmesh frames, with a height of 50cm. They were roofless, had a large mesh size (5cm) and were raised ca.10cm above ground level, in order to minimise any snowdrift accumulation or other microclimatic effect. Control plots were established at the same time, being marked by four 20cm wooden posts.

Goose droppings were counted in all plots (including exclosures, to ensure that they were effectively excluding geese) at approximately two-week intervals throughout each winter (N =6 counts per winter; 17 Dec – 10 Mar in 2011/12 and 27 Dec – 09 Mar in 2012/13), with the exception of one missed count in late January 2011/12 due to deep snow cover that made the area inaccessible. Based on roost count data, we estimate that the consequence of this missed count was that ca.1% of the total goose use of the study area during the winter was effectively unaccounted for in the dropping count data, because droppings that fell during this period would probably have been destroyed by the snowfall and subsequent thaw and therefore were uncounted at the next count visit.

At control plots, droppings were counted in 3x3m squares centred on the marker posts. In order to prevent any double-counting in subsequent sessions, at the end of each counting session, droppings were destroyed by stepping on them, but left in situ (so that any fertilising effect was retained). At the beginning of April, after goose departure, all exclosure cages were removed and the plots – both control and experimental - were marked using wooden posts.

Estimating wheat yield in plots

Wheat was removed by hand from the plots at the time that the fields were harvested. For each plot we counted (1) the total number of wheat stems; (2) the average number of grains per ‘ear’; (3) the average dry weight per grain.

For each plot, the number of grains per ear was estimated by counting the grains in 60 randomly selected ears. The average weight per grain was estimated by removing 50 of these grains at random, and drying them for 72h at 60C. The dried seeds were measured (±0.001g) on a Kernel and Sartorius analytical balance.

Wheat yield (g dry grain m^{-2}) was estimated as:

$$\text{wheat stems m}^{-2} \times \text{mean grains ear}^{-1} \times \text{mean dry grain mass (g)}$$

Analysis

We used General Linear Mixed Models to test hypotheses, using library LME4 in R 3.0.3 (Bates et al., 2014), R Development Core Team, 2008).. The primary response variable was 'Yield' for individual control and exclosure plots, measured as grams of dry wheat grain m^{-2}. Secondarily we separately examined some of the components of yield – number of stems, number of seeds per stem and seed weight as response variables. We attempted to explain variation in yield as a function of the categorical effects treatment (exclosure, control) and 'year' (2012/13 and 2013/14), as well as the intensity and timing of goose use (as measured by faecal counts through the winter). We controlled for non-independence of samples from within the same field, by declaring 'Field' as a random effect.

All response variables were treated as normal (Gaussian) distributed with an identity link function. We initially used REML estimation (Zuur et al., 2009). to derive an optimal random effects structure, with 'Field' as a potential random effect. We examined beyond-optimal models with random intercept, random slope and intercept and no random effect, and selected the model with the lowest AIC. In all cases, a random intercept model was selected. We then derived the optimal fixed effects structure with Maximum Likelihood (ML), using likelihood ratio tests to undertake stepwise model simplification until all remaining variables were significant ($P<0.05$). Where model validation indicated heteroscedasticity in residuals, we used a 'power of the fitted values' variance structure, and used this if it produced a lower AIC. Final parameter estimates were then produced for the optimal models using REML estimation

Results

Data summary

In both years, the great majority of control plots supported goose grazing (74/77 in 2012, 106/113 in 2013), however, average grazing intensity was far higher in 2012/13 (mean 38.2 droppings per control plot over the entire winter, SD =50.9) than in 2011/12 (mean 8.8 droppings per plot, SD =12.4). The great majority of goose grazing at plots tended to be concentrated in short time-windows, rather than being spread throughout the winter: on average 75% of the grazing that occurred within each plot occurred in the peak time interval out of the six time intervals for which faeces were counted, with no difference between winters in this pattern (Fig. 3). However, the timing of grazing differed greatly between winters: in 2011/12 peak grazing intensity occurred between 11-12 February and 24-25 February, whereas in 2012/13 the peak was between 27 December and 15 January (Fig. 3).

Effect of goose exclusion on yield

We initially tested the effect of exclosures on wheat yield, simultaneously examining year effects, with the model:

*Yield ~ Treatment + Year + Treatment * Year | random intercept = Field*

where Treatment is a two-level categorical variable (exclosure vs control) and Year is a two-level categorical variable (2011/12 vs 2012/13).

The Treatment x Year interaction was significant (LR =2.82, df =1, P=0.009), so we retained the full model. There was no difference in Yield between exclosures and controls in 2011/12 (Fig. 4). However, in 2012/13, wheat yield was ca.15% higher in control plots than in exclosures. Consequently, while wheat yield was similar in exclosures in the two winters, wheat yield was substantially higher in 2011/12 control plots than in 2012/13 control plots.

Effect of goose grazing intensity on yield

We tested the effect of goose grazing intensity on yield by calculating for each plot (including exclosures) the sum of dropping counts over the six visits, and using this as an explanatory variable.

The initial full model:

*Yield ~ Total Faeces Count + Year + Total Dropping Count * Year | random intercept = Field*

was discarded because the Year and Total Dropping Count variables were confounded: dropping counts were far higher in 2012/13 than in 2011/12. In the reduced model containing only main effects:

Yield ~ Total Dropping Count + Year | random intercept = Field,

both Year (LR =27.2, df =1, P <0.0001) and Total Dropping Count were significant (LR =11.7, df =1, P<0.001). In this model, Yield was 45.7 g m^{-2} (SE =16.3) higher in 2011/12 than in 2012/13, equivalent to an 8.1% yield difference, and Yield declined linearly with Total Faeces Count (slope = -0.42, SE =0.13). According to this relationship, at the peak observed grazing intensity in 2012/13 (maximum droppings per plot =193), yields were ca.15% lower than at zero grazing intensity. However, at the peak 2011/12 grazing intensity (maximum droppings per plot =55), yields were only ca.4% lower than at zero grazing (Fig. 5).

This analysis was partly correlative and so may have been confounded by other influences on crop yield: some plots that received low grazing may have been unattractive to geese. However, there are indications that this was not the case. First, the lightly grazed plots were those with highest yield, which one would predict would have been most attractive to feeding geese. Second, uncontrolled variation between plots was small due to the plot placement design and the Field random intercept. Third, there was little evidence of a difference in yield between exclosure plots and lightly grazed control plots. We compared Yield between exclosures and a subset of control plots in which the Total Dropping Count was $\leq$10 (N =23 plots in 2011/12, 17 in 2012/13), retaining the random Field intercept and power variance structure. The Year x Treatment interaction was non-significant (LR =0.92, df =1, P =0.34) and the main effect of Year was non-significant (Yield in 2011/12 =24.2 g m^{-2} (SE =18.7) higher than 2012/13; LR = 0.90, df =1, P=0.34). The main effect of Treatment was non-significant (parameter estimate: yield in exclosures =27.5 g m^{-2} (SE =23.1) higher than in control plots; LR = 0.08, df =1, P=0.77).

Because we were not able to model a Year x Total Dropping Count interaction, we separately modelled the effect of Total Dropping Count on Yield for the two winters. In 2011/12, there was no effect of Total Dropping Count on Yield (parameter estimate =0.79, SE=1.21; LR =2.96, df =1, P=0.086). In 2012/13 there was a significant negative effect of Total Dropping Count on Yield (parameter estimate = -0.48, SE=0.14; LR =16.1, P<0.001). The lack of a negative relationship between dropping count and yield in 2011/12, while there was a strong negative relationship in 2012/13, may be a consequence of the much greater range of values of goose grazing intensity in the latter year. However, the 2011/12 relationship is not even suggestive of a negative association. Further, Generalised Additive Mixed Models of the relationship between yield and goose grazing intensity gave no indication of any non-linearity or threshold effect, which might explain a negative relationship for 2012/13 (with more extreme values of goose grazing intensity) but not 2011/12 (with a smaller spread of values).

Components of yield

We repeated the modelling exercise for three components of wheat yield: seed dry mass, seeds per stem and stems per unit area. As previously, we used REML to develop an optimal random effects structure, and then selected the optimal main effects structure using ML, before finally extracting parameter estimates from the optimal using REML. The initial model was:

*Component of Yield ~ Treatment + Year + Treatment * Year | <random effect>*

For grain dry mass, optimal random effect structure was a random Field intercept without a power variance structure. The Treatment * Year interaction was marginally non-significant (LR =3.26, P =0.071), as was the Treatment effect (LR =3.43, P =0.064), although there was a suggestion that seed dry mass was greater in exclosures. Seed dry mass was 18.0% higher in 2011/12 than 2012/13 (LR =22.8, P<0.0001) (Fig. 4b).

For number of seeds per stem, the optimal random effect structure was a random Field intercept and power variance structure. The full model with interactions was a poor fit. Upon removal of the interaction term, there was no effect of Treatment on seed dry mass (LR =0.13, P = 0.71), but seeds per stem were 8.3% higher in 2012/13 than 2011/12 (LR =8.60, P <0.0034) (Fig. 4c).

For number of stems per m^2, the optimal random effect structure was a random Field intercept without a power variance structure. The Treatment * Year interaction was non-significant (LR =0.101, P =0.75), as was the Year main effect (LR =0.12, P =0.73). There were 6.5% more stems m^{-2} in exclosures than in control plots (LR =6.59, P =0.010) (Fig. 4d).

Agronomic impacts

If we assume a linear relationship between goose grazing intensity and yield reduction (see above), then the distribution of goose grazing across the landscape does not affect the overall impact on yield and consequent economic impact, and it is possible to estimate this impact using data on the numbers of wintering geese and estimated goose dropping rates (Table 1).

Our results indicate that the annual loss of winter wheat yield caused by the wintering goose population in Bulgarian Dobrudzha was in the range 58-594 tonnes during the winters 2011/12 and 2012/13, which represents 0.03 – 0.30% of total yield, which likely resulted in an economic cost of approximately 10,000-100,000 € year^{-1}.

Discussion

The exclosure experiment showed that goose grazing in this system had a negative effect on winter wheat yields, but only in one of two years. Grazing impact, as indicated by the difference in yield between exclosures and control plots, was large in 2012/13, when the intensity of grazing was much higher, reflecting a far higher number of goose-days in the area than in 2011/12. This gives some clarity on the impact of goose grazing on yields in the study area, which can potentially defuse conflict between farmers and conservationists. We were also able to demonstrate a linear negative effect of grazing intensity (as measured by dropping counts) upon winter wheat yield in 2012/13, which, when combined with information on total grazing pressure, allows approximate estimates of the economic cost of yield losses, which can be used to inform potential goose management schemes.

Nevertheless, our experiment reinforces the considerable challenge of generalising goose grazing impacts. Despite this study being among the most extensive yet published, the very different timing and intensity of grazing in the two winters, and the finding of minimal impact of grazing on yield in one of the two winters, means that the generality of the patterns observed here is unclear, even for our own study area. The variation in goose numbers and phenology in this study reflects the reality that these goose populations appear to be extremely flexible in their use of a range of discrete sites within the flyway.

Previous work has also been characterised by very variable impacts on yield between studies, and between years and locations within studies, and it appears that grazing intensity interacts with other factors to influence yield in ways that are not yet well understood (see Patterson, 1991) for a review., and (Crawley and Bolen, 2002), Hulea, 2002), Parrott and Mckay, 2001).. These other factors probably include the timing of grazing in relation to crop development stage and weather conditions. For example, extreme cold without snow cover is damaging to young wheat crops, and it has been suggested that grazing at such times exacerbates the impact (Kahl and Samson, 1984).. When grazing occurs in very wet conditions, and particularly in newly emerged crops, plants may be uprooted (this was observed in our study in winter 2011/12, AL Harrison pers. obs.), and/or soil structure may be damaged by trampling (Kahl and Samson, 1984).. When plants are defoliated later in their development and when actively growing, the effects may more severe (Abdul Jalil and Patterson, 1989), Patterson, 1991).; in Bulgarian Dobrudzha geese depart rather early in spring, and this may tend to limit damage. However, to robustly examine these interactions would require multiple years of experimental work, and in common with almost all published work to date, we do not have sufficient year replicates to do so.

(Patterson, 1991). pointed out that for comparison of grazing intensity versus yield impact between studies, a common ‘currency’ for grazing intensity is required, and that the appropriate common denominator was the amount of dry plant matter removed. However, this is difficult to measure empirically in field conditions with wild geese grazing, and is generally estimated via proxies – typically dropping counts (Parrott and Mckay, 2001), Summers, 1990). as used here. Such proxies are adequate for within-study comparison, and it would be possible to convert our dropping counts to goose-hours and consequently food consumption, via published values of dropping rates and ingestion rates that are appropriate to the goose species and crop type (see (Patterson, 1991)..

It appears that the components of yield that are affected by goose grazing also vary between studies, and apparently in relation to the timing of grazing and the conditions in which it occurs (Allen Jr et al., 1985), Deans, 1979), Flegler et al., 1987).. For example, (Flegler, Prince and W.C., 1987). reported lower stem density and grain mass as a result of grazing, with a compensatory effect of more grains per ear, but also found that the affected yield component varied with the timing of grazing; conversely (Deans, 1979). reported lower grains per ear in heavily grazed plots. (Allen Jr, Sammons, Brinsfield and Limpert, 1985). reported that the components of yield affected by grazing varied between fields in their exclosure experiment.The lower yield in response to goose grazing was driven primarily by a reduction in the density of stems, with possibly an additional effect of reduced grain size, but no effect of grains per ear.

Implications for agri-environment schemes

In order to ensure continued provision of sufficient feeding habitat for goose populations of considerable conservation value, and in response to perceived goose-damage to winter wheat crops in Bulgarian Dobrudzha, , an agri-environment scheme for Shabla, Kavarna and General Toshevo municipalities was instigated in 2015 (following a pilot scheme in 2013 and 2014). Successful applicant farmers are required to sow 50% of the land with winter wheat, 30% with maize (maize is believed to be a valuable early-winter food for geese in the region) and 20% other crops. Plots that contain wind turbines are ineligible and minimum eligible plot size is 5h ha. The total area of the municipalities is 1,793 km^2, of which 75-80% is arable cropland and hence potentially eligible for the scheme (although wind turbines are relatively numerous, their effect on the total eligible land area is small). In 2015, 240 farmers with 173 km^2 of cropland applied to join the scheme. Currently, funds are disbursed on a first-come-first-served basis.

, suggesting that.

The payment rates and the size of the scheme area implies that if take-up of the scheme among eligible farmers becomes very high, the total cost could become very large, or it would be capped, with a proportion of applicants that meet the criteria being unsuccessful. This raises the question of whether the payments should be targeted towards high priority areas. In the current scheme, payments are not prioritised according to habitat suitability for geese, or in response to observed grazing pressure.

Some geographical refinement of the scheme area may be possible. Habitat selection models and GPS telemetry indicate that geese in the area strongly select wheat fields that are close to the major roosts at Shabla and Durankulak lakes, and the adjacent Black Sea (Harrison et al. submitted). Maximum observed foraging flight distances were ~25 km, and the overwhelming majority were much shorter, a pattern supported by a recent literature review that found mean foraging flight distances for geese of 7.8 km (SD =7.2 km)_(Johnson et al., 2014).. *Ca.*40% of the scheme area is greater than 25 km from the roosts. Habitat selection analyses also suggest strong localised avoidance of power lines, wind turbines, roads and tree lines (Harrison et al. submitted). It would therefore be possible to use suitability as estimated by habitat selection models to prioritise payments.

An alternative approach is to target funds by paying farmers retrospectively in proportion to observed grazing pressure, as done in some other schemes (Crabtree et al., 2010).. In Scotland, for example, observed goose density, estimated from periodic look-see counts, is used as a proxy for grazing pressure (Crabtree, Humphreys, Moxey and Wernham, 2010).. However, such an approach would be at odds with the ethos of the Dobrudzhha scheme, which is primarily a payment to farmers for providing suitable habitat, with compensation for lost yield as one component of this. Further, very substantial resources can be required to estimate goose grazing intensity or crop damage across large landscapes over the course of a winter. In our study area goose grazing is extremely patchy in both space and time and the effort required to monitor this, whether by direct goose counts, dropping counts, or responding to farmer notifications of damage, would be very large. The crop damage experiment reported here shows that goose grazing of even highly favoured fields typically occurred during only a short time window (see Fig 2).

One further potential refinement is worth considering in the future. Greater White-fronted Geese are legal quarry during a defined winter hunting season in the area, and hunters are permitted to enter fields that are part of the scheme to pursue feeding geese, creating substantial levels of disturbance and causing the birds to relocate from selected feeding locations (Dereliev, 2000). We speculate that this hunting disturbance is a major influence on the distribution of feeding geese in the study area. Because Red-breasted Geese very commonly feed in association with Greater White-fronted Geese, they are also subject to considerable hunting disturbance (N Petkov and A Harrison pers. obs.). The agri-environment scheme does not incorporate a 'go – no-go' strategy (wherein some areas receive payments and are managed as low disturbance refuges, while others receive low/no payments and it is permitted to disturb geese to protect crops). Such a strategy is deployed in most other European goose management schemes (e.g. Goose Management Group, 2010)., but in this scheme there are no additional restrictions on hunting within areas receiving compensation payments. This is because, in contrast to many other European countries, the right to hunt is not invested in the landowner, but in the state, and these rights are exercised by the Hunters Union. Therefore landowners may not prohibit the use of their land by licensed hunters. Notwithstanding these technical and legal challenges, we suggest that if fields that had high modelled suitability for geese were selected for payments, and if hunting (and other forms of) disturbance were minimised in these areas, then the geese might concentrate in such fields, allowing a closer fit between goose distribution and agri-environment payment than is currently possible: this is essentially a strategy of bringing the geese to the scheme, rather than the scheme to the geese..

Conclusions

We have demonstrated and quantified a relationship between goose grazing and winter wheat yield in an area of south-eastern Europe where conflict exists between farmers and conservationists over crop damage. This has informed the development of a new agri-environment scheme which attempts to defuse this conflict. However, considerable uncertainties remain. The relationship between grazing and yield was not constant between years, and until we have a better understanding of interactions between grazing pressure, other influencing factors, and damage, any attempt to predict quantify yield loss will be very imperfect. The agri-environment scheme has achieved good early take-up and provides for sufficient goose feeding habitat to be retained in the region. However, further refinement might improve targeting of resources

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Tables

Table 1 Estimates of the total yield reduction and its economic cost caused by the wintering goose population in the study area.

Variable	2011/12	2012/13
Yield at zero grazing[a] (kg ha^{-1})	5642	5185
Area of wheat (km^2)[b]	386	382
Estimated Goose-days[c]	2,502,455	5,731,725
Yield reduction due to grazing (95% CI) (kg ha^{-1})[d]	4.1 (1.5-6.6)	9.4 (3.5 – 15.4)
Total yield reduction due to grazing (95% CI) (tonne)	158 (58-257)	361 (133-594)
Economic cost of yield reduction (€)[e]	25,852 (9,460-42,146)	59,213 (21,894-97,535)

a: the year-specific intercept of the model *Yield ~ Total Faeces Count + Year | random intercept = Field.*

b: estimated by calculating NDVI for each field using a RapidEye level 3A (2011/12) and a Landsat 8 (2012/13; Data available from the U.S. Geological Survey) multispectral ortho-image, and ground-truthing with known fields to distinguish winter wheat from other field types.

c: based on counts at all major roosts conducted at 14-day intervals throughout each winter, with linear interpolation of numbers between each successive count (see Fig. 2).

d: following (Hulea, 2002). we estimate 151 droppings $goose^{-1}$ day^{-1}, and use the slope (with 95% confidence limits) of the model *Yield ~ Total Faeces Count + Year | random intercept = Field* to estimate the yield reduction.

e: based on farm-gate prices for Bulgarian wheat = €164.11 $tonne^{-1}$

Figures

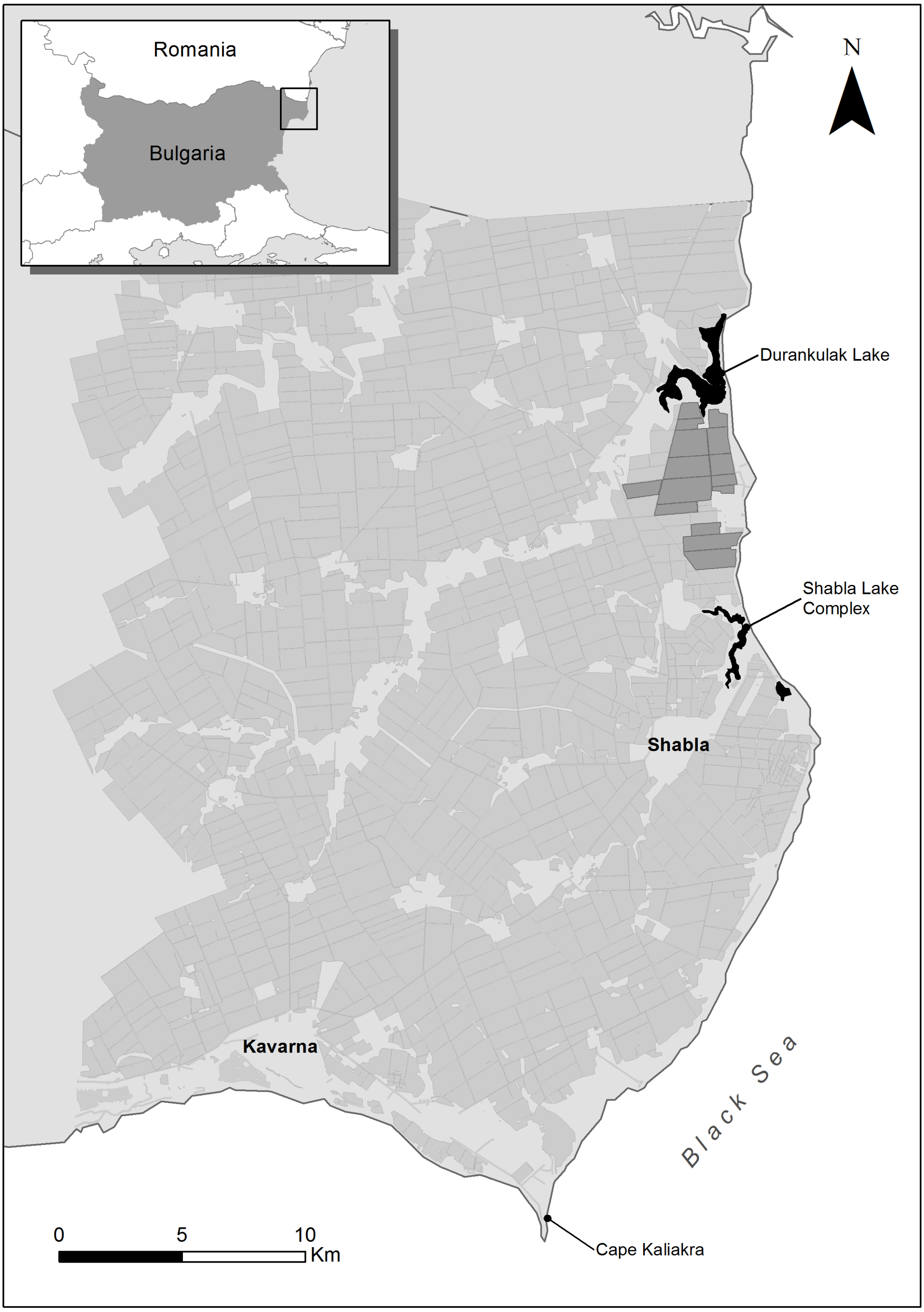

Fig. 1 Map of the study area.

Mid-grey shading: arable fields within the study area. Dark grey shading: the fields used for the crop exclosure experiment.

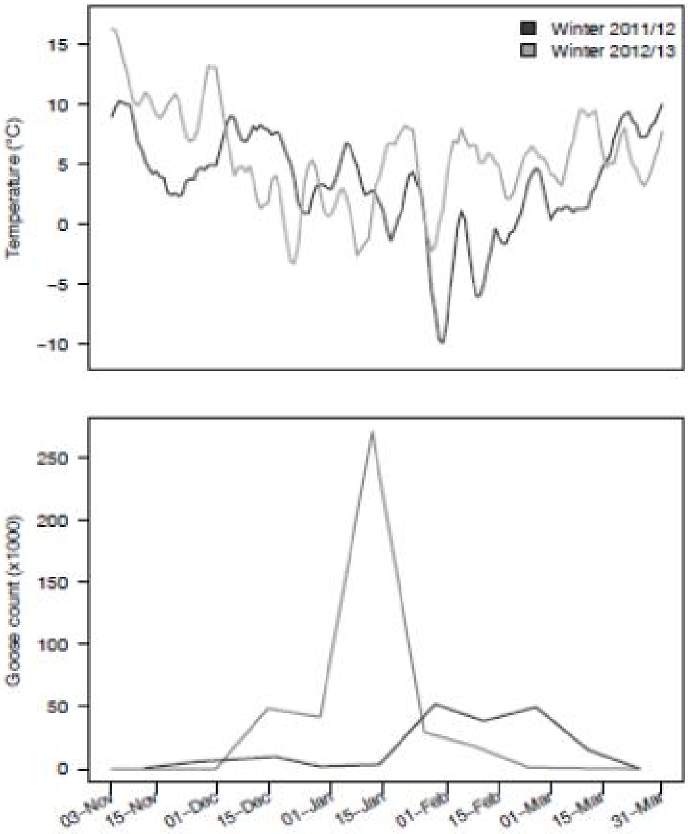

Fig. 2 Goose numbers and weather conditions in the study area during the two winters of the experiment.

Weather data are taken from Shabla weather station (43.53N, 28.53E) sourced from www.freemeteo.com.

Goose count data are taken from fortnightly roost counts at the major roosts (Shabla Lake complex, Durankulak lake, Black Sea), with linear interpolation between the counts.

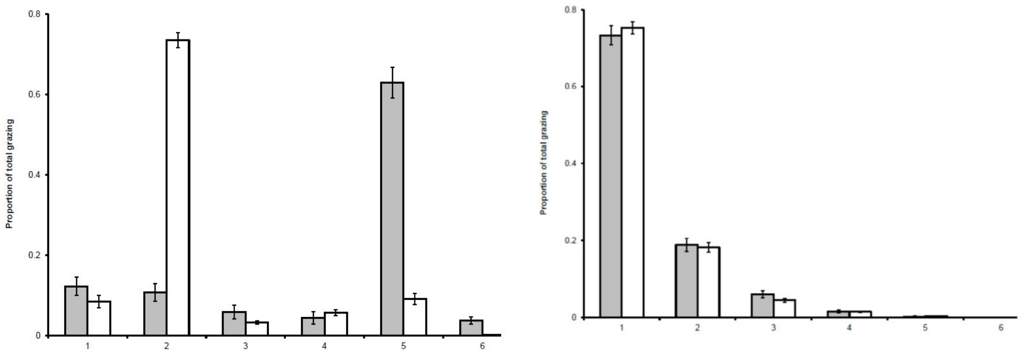

Fig. 3 Average distribution of grazing intensity (±SE) among collection intervals in control plots. (a) percentage of the total grazing at each plot by collection interval, in chronological order. (b) percentage of the total grazing at each plot by collection interval, ranked from highest to lowest (independent of chronology).

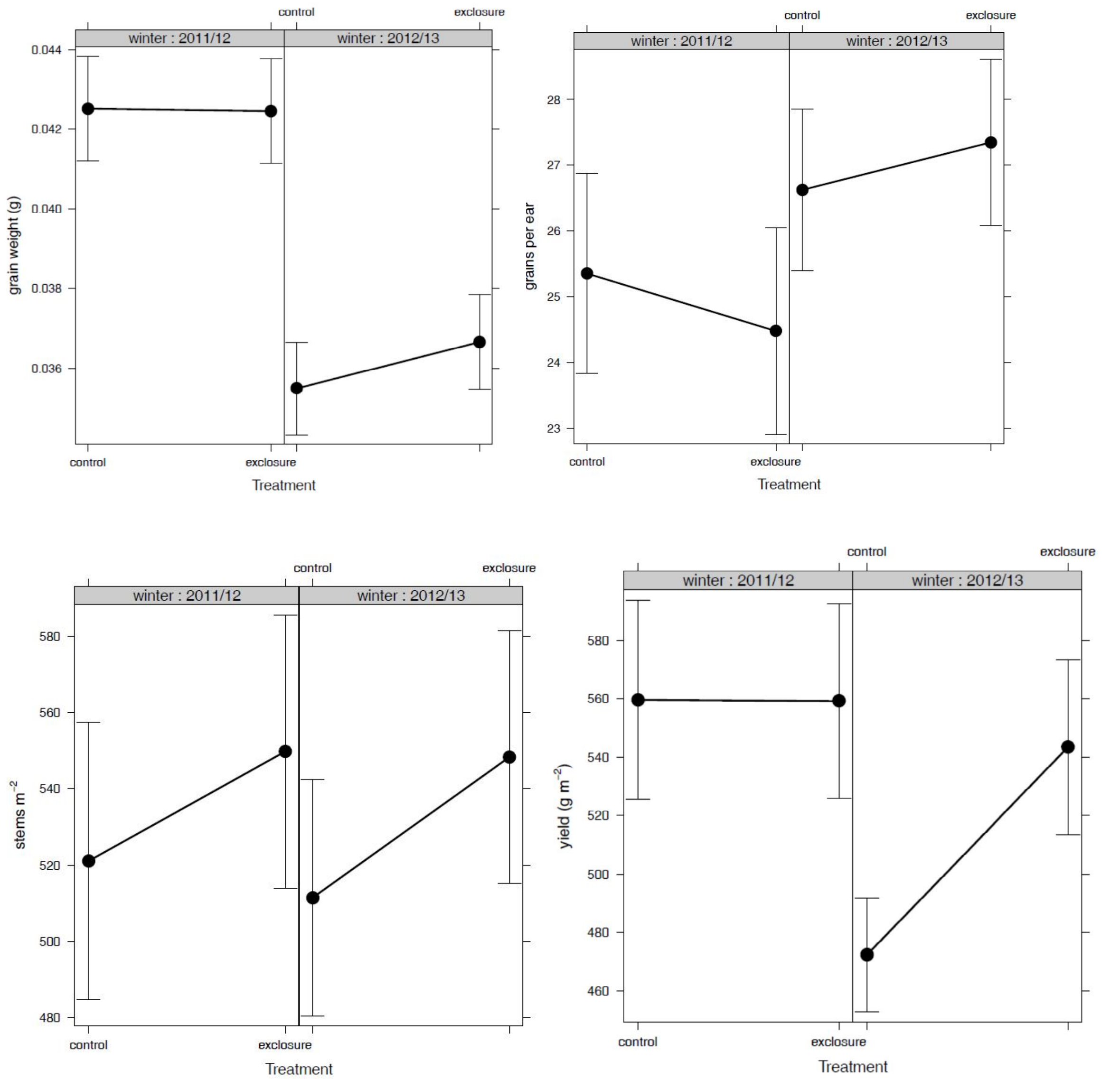

Fig. 4 Modelled effect of exclosures on crop yield and its components. Values are modelled means ±SE from GLMM's. Graphs show full-models including both Year, Treament and Year x Treatment effects, even where these were not the minimum adequate model (see text). a) Grain Dry Mass (g); b) Grains per ear; c) Stems m^{-2} d) Yield (g m^{-2}).

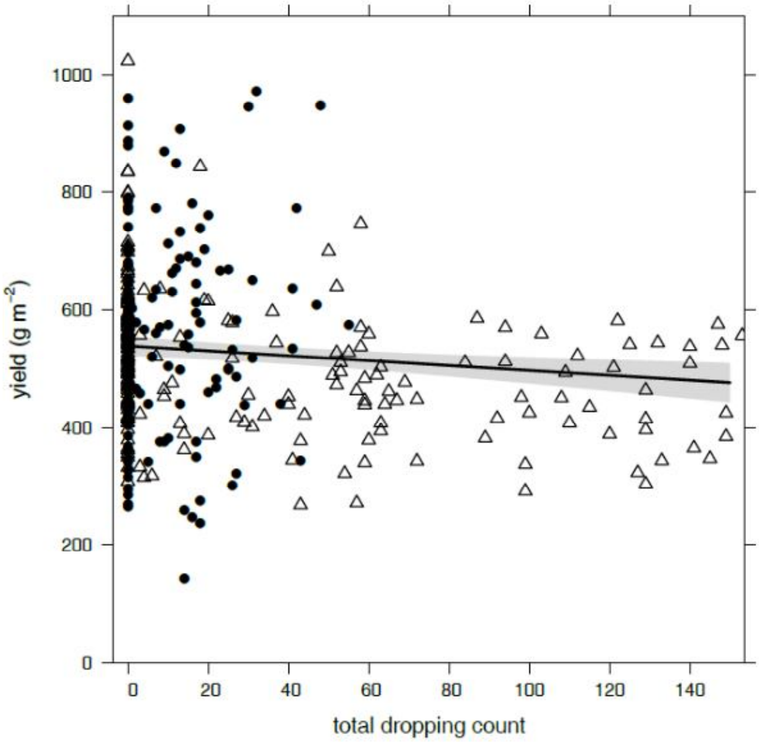

Fig. 5 Modelled effect of goose grazing intensity, as measured by dropping counts, on winter wheat yield. Line represents best fit from a GLMM of Yield vs Dropping Count, with Year as fixed effect and a Field random intercept, with data from all plots included (both exclosures and controls). Shaded area represents SE of the slope. Values for individual plots are shown: circles = winter 2011/12; triangles = 2012/13.