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Hunting migratory geese: is there an optimal practice?

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Since the mid-20th century, many European and North American goose populations have increased dramatically in numbers, causing conflict with agricultural interests in their staging and wintering areas. In some cases, to mitigate such impacts of rapid population increases, population control has been attempted by increasing harvest rate. In this study, we investigated how autumn-staging pink-footed geese *Anser brachyrhynchus* responded to hunting, with a view to determine hunting practice that would lead to an increase in the hunting bag. There was a significant increase in the distance between the hunting site and the goose flocks, on comparing goose distribution on the day before the hunt up to one day after the hunt. The effect was significant when at least 10 shots were fired per site but not when 1–10 shots were fired. The timing of shooting in relation to migratory phenology did not affect the time taken by the geese to return to the hunting site, but after a hunt in the early part of the staging season, the number of geese in the study area increased more rapidly than towards the end of the season. The maximum number of geese shot per hunting event was obtained when hunting events were separated by three days. Our results indicate that hunters can increase local harvest by temporal and spatial optimisation of practices. These results may be used as a tool in wider-scale regional and international processes to regulate the population size of pink-footed geese by shooting, depending on the willingness of landowners, hunters and managers to coordinate hunting practices.

Since the mid-20th century, many goose populations in Europe and North America have increased dramatically in numbers, causing conflict with agricultural interests in their staging and wintering areas (Madsen et al. 1999, Bruggers et al. 2002, Fox et al. 2005, Davis et al. 2014). While the foraging on waste crops as well as grass and winter cereals during dormancy in autumn and winter is generally unproblematic, conflicts with agricultural interests arise when geese forage on pastures and crops prior of harvesting, sprouting grass and winter cereals or new-sown cereals (van Roomen and Madsen 1992). Some populations also cause the degradation of vulnerable tundra vegetation and coastal marshes in Arctic regions due to increasing grazing pressure (Ankney 1996, Jefferies et al. 2004a, b, Abraham et al. 2005, Speed et al. 2009, Pedersen et al. 2013a, b). The observed population increases are partly attributed to the improved protection and creation of widespread wildlife refuges (Madsen et al. 1999, Jefferies et al. 2004a, Abraham et al. 2005). Simultaneously, the winter survival rates of adult geese have improved from the intensification of agriculture throughout North America and Europe which has provided alternative and more abundant food resources throughout the winter season (Van Eerden et al. 1996, Abraham et al. 2005) and further fuelling population increases (Alisauskas et al. 1988, Therkildsen and Madsen 2000, Fox et al. 2005). Additionally, in recent years, a milder climate appears to be a driver for some population increases, especially for those breeding in the Arctic (Cadieux et al. 2008, Jensen et al. 2014).

The Svalbard breeding pink-footed geese *Anser brachyrhynchus* is one example of a goose population that has increased substantially in recent decades. The rapid increase causes management challenges, in terms of crop damage and arctic tundra degradation (Madsen and Williams 2012). The population has been selected as the first test case for development of an international species management plan under the African–Eurasian Waterbird Agreement (AEWA), using an adaptive management framework. The goal of the plan is to maintain the favourable conservation status of the population, while taking into account economic and recreational interests. To attain this goal, the management plan seeks to maintain a population size of around 60 000 individuals through the optimisation of hunting regulations (e.g. by extending the hunting season, as occurred in 2014) and by a voluntary improvement in hunting practices (Madsen and Williams 2012, Madsen et al. 2015). The study presented here was conducted in 2011–2013 when the population was at around 80 000 individuals (Madsen et al. 2015) and the harvest rate had to be increased in order to meet the target of 60 000 birds (Johnson et al. 2014).

The aim of the present study was to investigate the response by pink-footed geese to hunting, with the objective of determining how local hunting practices might be adjusted to maximise the hunting bag (total harvest per hunting event), based on evidence from controlled hunting experiments. Many previous studies have been undertaken on the response of waterbirds to hunting, but these focussed mainly on the effects of human disturbance from a site or species conservation perspective (Bell and Owen 1990, Madsen and Fox 1995, Madsen 1998, 2001, Bregnballe et al. 2004). Based on field studies, spatial and temporal restrictions on hunting are normally recommended to reduce disturbance to the target species. Intervals between hunting events may range from 1 day apart to several weeks (Andersson 1977, Jettka 1986, Jakobsen 1988, Ziegler and Hanke 1988, Gerhard 1994), and spatial restrictions may be implemented by establishing distinct hunting zones and refuge areas for the birds (Fox and Madsen 1997, Madsen 1998). Evidence from the disturbance studies can also be used to inform hunting practice that would increase the harvest, for instance by describing when geese might return to a hunting area so that hunting can be resumed. These studies also illustrate, however, that the birds' responses to hunting vary between species, location and the time of year, and moreover pink-footed geese are less wary of humans outside the hunting season (Madsen 1985). In order to be able to determine and implement optimal hunting practices, local and targeted studies therefore are needed, and the present paper is a contribution in that respect.

In a study on greylag geese *Anser anser,* behavioural responses to hunting, occurring on a single day at intervals of one, two or three weeks, were measured (Bregnballe and Madsen 2004). Neither the overall goose numbers, nor the probability of returning to the hunting site, were lower when the intervals between hunting events were extended. In the present study, we reduced the intervals between hunting events further to examine goose responses to a higher hunting intensity with the objective of optimising local hunting practices to maximise the hunting bag. As a surrogate of optimising local hunting practices, we used the minimum number of days between hunting events which maximized the hunting bag and the minimum distance between hunting teams, which did not affect each other, when hunting on the same day. Goose distribution was mapped on the day before a hunt, on the day of hunting, and for 1–3 days thereafter, with the response in terms of the hunting bag being quantified in relation to whether hunting occurred on a single day or on two consecutive days, and also in relation to the number of days between the hunts.

Site use by pink-footed geese is strongly influenced by the location of the birds' night roost, which is usually a lake, a sheltered bay or tidal mudflats that provide safety against mammalian predators and human disturbance, adjacent to open fields where they can forage during the day (Jensen et al. 2008). Most goose hunting takes place in the fields used by geese for foraging, or alternatively adjacent to the roost sites when geese pass between the foraging areas and roost sites (typically around sunrise or sunset). Amongst local hunters it is known that goose flocks are likely to revisit good foraging fields during consecutive days unless they are disturbed (O. M. Gundersen pers. comm.). Hence, hunters can plan where to go hunting the next morning by observing the daily position of goose flocks. For this reason, we predict that before a hunt, geese will be closer to the chosen hunting site than in the following days after a hunt. We also assume that geese will learn from being exposed to hunting (i.e. disturbance) at a site, and predict that geese will take a longer time to return to a hunting site when two consecutive hunting days are conducted compared to only one day of hunting. In terms of the hunting bag, we hypothesise that more geese will be harvested during the first day of hunting compared to the subsequent day, and that there is a positive relationship between the number of hunting-free days and the harvest (up to a threshold).

At the beginning of the migratory season, there is a high turnover rate of individual geese at staging sites (Jensen et al. 2016), and newly arrived geese will have no experience of local hunting. We therefore also investigated the goose distribution for the early and late part of the migratory season and hypothesise that hunting in the beginning of the migratory season will have less effect on goose occurrence than later in the season. Finally, we investigated whether the intensity of hunting influences goose distribution. When geese leave the roosting site during the early morning hours, they leave in flocks of various sizes but then congregate in larger flocks at the nearby feeding areas. Hunters take advantage of this by positioning themselves, under cover, at the foraging site before the geese arrive. As the hunters usually have only one shooting opportunity per flock, hunting disturbance will depend on the number of flocks which choose to settle near the hunters and how many shots the hunters fire per flock. Hence, our hypothesis is that hunting will have less effect, in terms of goose distribution, when few shots were fired (as an indicator of none or few flocks disturbed) compared to events where many shots were fired (as an indicator of how many flocks were disturbed).

Material and methods

Study population

The Svalbard breeding population of pink-footed geese leaves its breeding areas in mid-September towards their wintering grounds in Denmark, the Netherlands and Belgium. During migration, the geese stop primarily in two regions; in the Trondheimsfjord area in Nord-Trøndelag County in mid-Norway and along the west coast of Jutland in Denmark (Madsen et al. 1999). Both regions are goose hunting areas, where 2600 and 8600 pink-footed geese are shot each year, respectively (average for 2010–2013) (Madsen et al. 2015). Hunting of pink-footed geese is from 10 August to 23 December in Norway (open season) and from 1 September to 31 December in Denmark (on land; until 31 January on the marine territory). The species is protected in the Netherlands and Belgium.

Study areas

The study was carried out in Nord-Trøndelag in mid-Norway, the first stopover site for pink-footed geese on their autumn migration. Around 80% of pink-footed geese reported shot in Norway are harvested in the Nord-Trøndelag County (Statistics Norway, <https://statbank.ssb.no/en/statistikkbanken>).

The study area encompassed the peninsula of Nesset, Levanger municipality. The peninsula consists of mixed farmland area covering approximately 10 km^2 that is mainly covered by cereal grain stubble and potato fields in autumn. Until 2011 goose hunting was rented out and administered through the local landowner association. There were no restrictions on hunting intensity except for an agreement of one shooting-free day per week and no organisation of shooting existed between groups of hunters. Goose hunting could be rented on a daily, weekly or seasonal basis. In 2011–2013, an agreement with the landowners at Nesset was adopted and our research group rented the goose hunting for experimental purposes.

The hunting experiment

The hunting experiment was designed with a spatial and temporal structure. The spatial structure was designed to represent independent but similar hunting areas, where hunting in one area not affected goose numbers in the other areas negatively. This setup allowed a higher number of replications of the temporal structure. Additionally, the spatial structure included an area free of hunting, hence an area where the geese could find rest during a hunt. This was done with the expectation that geese would stay longer and thereby allowing a larger number of hunts and potentially a larger harvest. The spatial structure in 2011 consisted of three hunting zones (1–3), a refuge zone and one zone reserved to practice hunting for inexperienced hunters (Fig. 1a). However as the refuge area in 2011 did not have the intended effect of attracting geese, the spatial structure for 2012 and 2013 was changed and consisted of only two zones, south and north on the peninsula (Fig. 1b). Hence, instead of having a permanent refuge area in 2012 and 2013, the hunt would shift between the two areas. As only one hunting team was out per hunting day in the study area, there was always one hunting-free zone. To allow for comparisons between years the data in 2011 was reanalysed and reclassified to only two zones as implemented in 2012 and 2013; zones 2 and 3 became North and zone 1, the refuge and practice areas were merged to become South. The refuge and practice areas where not fully covered by the study in 2012 and 2013, however neither of the uncovered areas were used by geese in 2011. Areas were divided by roads, farm houses, hedgerows or woodland which constituted natural buffers between the zones.

The temporal structure was designed to investigate the minimum number of days it would take geese to return to a site after hunting, whether the time taken to return would change during the migratory season and whether it was optimal to have two hunting days in a row. In 2011, the temporal hunting structure alternated between a single hunting day and two consecutive hunting days in each zone, each followed by one to eight hunting-free days. As two consecutive hunting days did not seem beneficial in terms of the hunting bags in 2011, hunting was not conducted two days in a row in 2012 and 2013, but every second day, alternating between North and South resulting in a hunting-free period of three days per zone. Additionally, the results from 2011 indicated that the number of geese had a lower turnover rate in the late migratory season. Therefore, in 2012 and

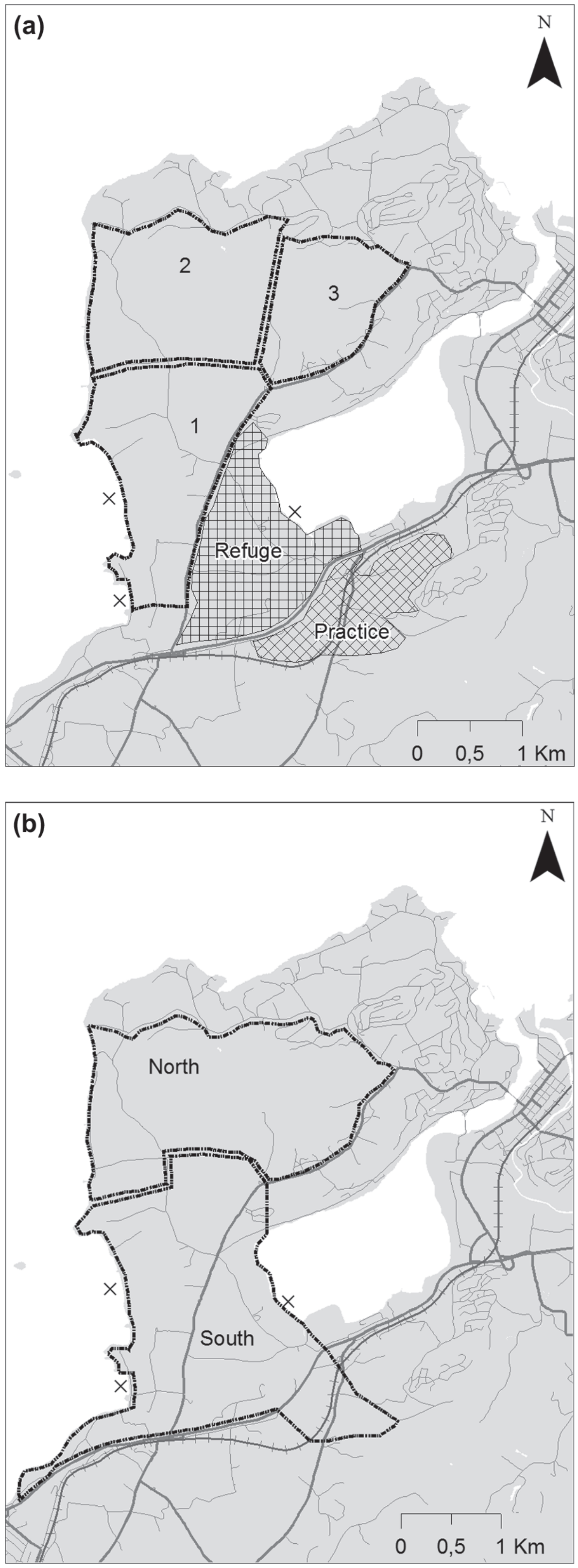

Figure 1. Spatial hunting organisation at Nesset in mid-Norway in (a) 2011, (b) 2012 and 2013. Shaded areas represent refuge and hunting practice areas, cross marks indicate roost sites.

2013 this practice was used until a drop in goose numbers was registered for more than two days. Thereafter the number of hunting-free days was doubled to four day intervals alternating between the two zones, to keep the geese in the area. In reality, however, the geese stopped using South after a couple of weeks and no further hunting was conducted here in 2012. In 2013, hunting was intensified in North and conducted every second day, whereas it was less intense in South (hunting only every five to six days).

A local hunting team was instructed to follow the predefined temporal and spatial study design of hunting activity in the study area. The team's hunting behaviour was not controlled for but represented general hunting behaviour. The hunting team consisted of two to four hunters, whom would hunt as a single unit. The team could choose to hunt from anywhere in the zone on a particular day. When a position had been chosen, the hunting team would hunt from a fixed position in a field from 04:00 to 11:00 hours. The position was chosen based on goose sightings/distribution the previous days, with preference on fields with a high number of geese and where the geese had been registered several days in a row. The hunters used decoys to lure flocks of geese to settle on the field when flying in from their roosting sites early in the morning. The same number of decoys were used for each hunt. The hunting team would position themselves, grouped together (a few meters away from each other), on an open stubble field, shooting from blinds and camouflaged by straw. Hunting was only conducted from stubble fields, as they contain spilt grain which is the main food eaten by geese in this area in the autumn (Jensen et al. 2016).

In all years, surveys were systematically undertaken on a daily basis between 08:00–18:00 hours during the study period, to record goose distribution and abundance on the fields and roost sites. The location of the flocks and the number of birds counted were recorded in ArcGIS in order to measure and analyse distances between the hunting site and the nearest goose flocks before and after hunting, thus assessing the birds' response to the experimental hunting. The surveys were conducted from a car and done by driving on all concrete roads at Skogn and Nesset. The survey period ranged from 17 September to 3 November in 2011, 18 September to 24 October in 2012 and 16 September to 24 October in 2013. The daily observations commenced on the first pink-footed geese arriving in the study area each year, and continued until most had left the site. Hunting data was collected directly from the hunters during the same period as the goose counts, and consisted of hunting date, location (GPS position), number of geese shot and number of shots fired. In addition to the overall analyses, the data was separated into an early (< 6 October; first half of study period) and late season (> 5 October; second half of study period), since we predicted goose responses to hunting activity in these periods to be different, due to the higher turnover of newly arriving geese early in the migration season (Jensen et al. 2016). We also analysed the data in relation to the number of shots fired per hunting event, divided into few (1–10) and many (> 10) (Table 1). However, we have not had control of the number of shots fired during a hunt, which ranged from 0 to 120 shots fired. We expected that more shots fired would cause greater disturbance than fewer shots and hence influence goose distribution differently.

Table 1. Hunting data from Nesset in mid-Norway, 2011–2013, in terms of number of pink-footed geese shot, number of shots used, and number of hunting events (divided into days with 1–10 and more than 10 shots fired per hunt) in early/late season and north/south area.

	Total	2011	2012	2013
Geese shot	438	133	203	102
Early (< 6 October)	218	73	116	29
Late (> 5 October)	220	60	87	73
North	229	112	82	35
South	209	21	121	67
Shots used	940	270	351	319
Early (< 6 October)	471	154	208	109
Late (> 5 October)	469	116	143	210
North	481	211	153	117
South	459	59	198	202
Hunts	39	14	13	12
Early (< 6 October)	18	7	6	5
Late (> 5 October)	21	7	7	7
North	22	10	7	5
South	17	4	6	7
1–10 shots fired	11	5	3	3
> 10 shots fired	28	9	9	10

Geese used roosts that were within 2 km from each of the experimental areas (Fig. 1). This is within normal daily foraging flights of goose flocks (Jensen et al. 2016). Therefore, we did not take the distance to roost into account in the analyses.

Constrains of the experimental design

The design of the hunting experiment was constrained by a number of factors. Due to spatial restrictions, we could not conduct completely independent trials of goose responses to various hunting scenarios. However, we attempted to make the zones as wide as possible in order to avoid the possibility that geese in the core of one zone would be affected by hunting in a neighbouring zone. Hence, the geese would not be scared off in one zone when hunted in another zone. The spatial restrictions and the fact hunting was performed from a few fields limited our ability to perform a multiple regression as sample size was small (< 10); hence we had to rely on simpler statistical methods. Moreover, the hunting season for pink-footed geese in Norway runs over a limited stopover period on their migration southwards and the number of hunts are therefore controlled by this period. The experimental hunt was conducted in three seasons, so it was difficult to control for year effects in, for example, migration pattern (numbers of birds arriving to and staying in the area) and food abundance. Nevertheless, we did not expect that the absolute number of geese would influence their distribution in relation to hunting activity. Likewise, from detailed field status monitoring and counts of waste grain densities in the stubble fields, we found that food was still abundant when the geese departed the area (Jensen et al. 2016). As the food appeared to be plentiful in all years, we therefore expect that the variability in food availability is not a main factor determining field use in relation to the hunting activity. A strong aspect of the conducted field experiment is the relatively high number of replications. Due to a productive cooperation between landowners, hunters and researchers, it was possible to conduct and adjust the experiment for three hunting seasons. Moreover, we had full control of the hunting intensity with continuous information about the harvest (hunting date, location, number of geese shot and number of shots fired) and goose distribution. In addition, because of the geographically-bounded peninsula, disturbance from hunting and other human activities from neighbouring areas was avoided. Furthermore, the site represented an area big enough to meet the demands of large goose flocks for roosting and foraging and it is representative of sites used by pink-footed geese in mid-Norway during autumn.

Statistical analysis

We used analysis of variance (ANOVA) to compare distances from nearest goose flock to the most recent hunting site. The distance was calculated for each hunt, the day before the hunt (day –1) and each of the subsequent days without hunting 0–3, respectively (0: few hours after the hunt; 1–3: one to three days after a hunt). Day –1 to 3 is the range of days with sufficient data to provide statistically reliable results, as the hunters rarely had a hunting-free period of more than three days. When significant variation was found between days, a Tukey HSD (honestly significant difference) post hoc test was used to identify which days differed from each other.

To compare the number of geese shot between areas (North versus South) and periods (early versus late season) t-test was used. Additionally, to investigate whether there was an increasing trend in the number of geese shot per hunt with increasing number of hunting-free days (before a hunt), we used a locally weighted polynomial regression with a tricubic weighting and smoother span of 2/3, which provides a non-parametric regression analysis of the hunting bag data (Cleveland 1979).

Results

Goose numbers

The number of pink-footed geese in the study area varied greatly between years and days (Fig. 2). The highest daily number recorded (rounded to nearest 100 individuals) was 6900 pink-footed geese on 4 October 2011, while the highest yearly cumulative number was 116 100 in 2012. During all three years, pink-footed geese started to arrive by mid-September, reaching peak numbers in early October, whereas the departure time varied greatly. In 2011, the majority of geese left Nesset within a week after the peak in goose numbers. However, a number of flocks, of more than 1500 geese, appeared for short periods from late October to early November. In 2012, the geese stayed until late October, when a heavy snowstorm forced most of them to leave. In 2013, the daily number of geese never exceeded more than 2610, and after 17 October fewer than 500 geese remained (Fig. 2).

Goose harvest

The number of pink-footed geese shot varied not only between years but also on a daily basis (Fig. 2). There was no

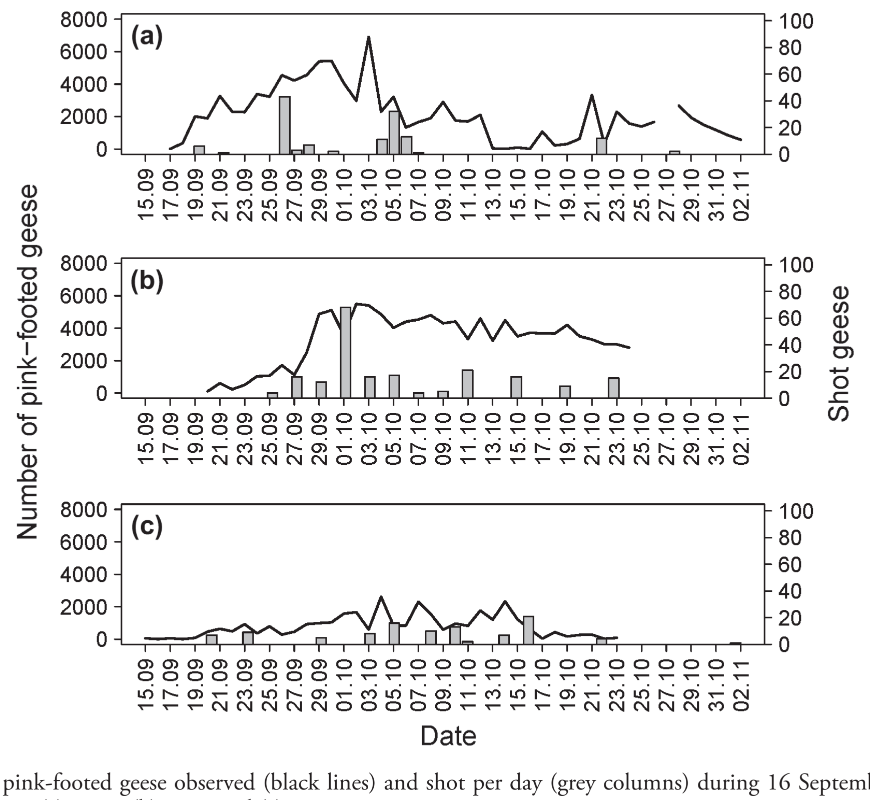

Figure 2. Number of pink-footed geese observed (black lines) and shot per day (grey columns) during 16 September to 3 November at Nesset in mid-Norway in (a) 2011, (b) 2012 and (c) 2013.

significant difference in the number of geese shot between the early and late seasons, and between North and South (Table 1; $p > 0.1$). The year with the highest amount of geese shot was 2012 with 203 harvested geese, and the maximum shot on a single day was 68 geese on 1 October (Fig. 2).

Goose responses to hunting

For hunts performed on a single day only, distances recorded from the most recent hunting site to the nearest goose flock differed significantly between the day before the hunt up to two days after the hunt ($F_{4,608} = 5.706$, $p < 0.01$). A posthoc test showed that the difference was significant between day –1 (day before hunting event) and day 0 (day of first hunting event), and day –1 and day 1 (one day after hunting event) ($p < 0.01$, Fig. 3). When hunting was performed on two consecutive days, the distances also varied significantly ($F_{3,86} = 3.828$, $p < 0.02$). A post hoc test showed no significant difference between day –1 and day 0, and day –1 and 1, only between day –1 and day 2 (two day after hunting event) ($p < 0.01$, Fig. 4).

When we analysed the data, for hunts performed on a single day only, with respect to the two zones, South and North, the distance from goose flocks to the last hunting site varied significantly between days for both areas (South: $F_{4,354} = 4.829$, $p < 0.01$; North: $F_{4,464} = 5.225$, $p < 0.01$). The post hoc test for South yielded significant variation between day –1 and day 0, day –1 and 1, and day –1 and day 3 (three day after hunting event) ($p < 0.01$), whereas for North the test yielded significant variation between day –1 and day 0, and day –1 and day 1 ($p < 0.01$).

During the early season (< 6 October) we found an increase in the total number of geese in the study area on days after a hunt relative to the total number of geese the day before a hunt, whereas in the late season (>5 October) there was a decrease in the total number of geese after a hunt (Fig. 5). For both early and late season, the distance between the goose flocks and the hunting site varied significantly between the days before and after hunting (early: $F_{4,327} = 4.001$, $p < 0.01$; late: $F_{4,276} = 3.067$, $p < 0.01$) and the post-hoc test yielded significant values between day –1 and day 1 ($p < 0.01$) for both early and late season.

When dividing the data into hunting events with few and many shots fired, the distance from goose flocks to the last hunt did not vary significantly between days for cases

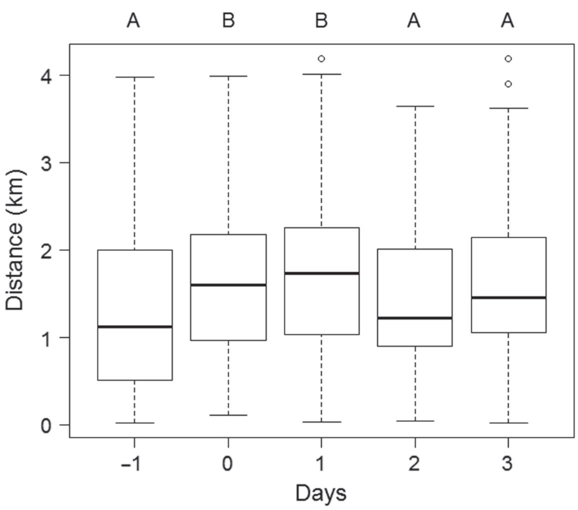

Figure 3. Effect of single hunting days on the local distribution of pink-footed goose flocks at Nesset in mid-Norway, 2011–2013, expressed by the distance (km) from hunting site to goose flocks the day before hunting (–1), the day of hunting (0) and 1–3 days after hunting (1–3). Vertical lines represent minimum and maximum, boxes are interquartile ranges, horizontal lines medians and open dots outliers. Labels (A, B) show whether there is a significant difference (different letters) in median distance or not (same letters).

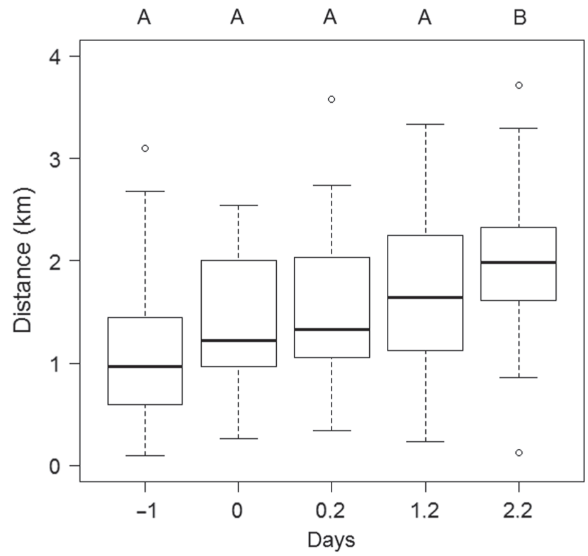

Figure 4. Effect of two consecutive hunting days on the local distribution of pink-footed goose flocks at Nesset in mid-Norway, 2011, expressed by the distance (km) from hunting site to goose flocks the day before hunting (–1), the first hunting day (0), the second hunting day (0,2), the first day after two hunts in a row (1,2) and the second day after two consecutive hunting days (2,2). Vertical lines represent minimum and maximum, boxes are interquartile ranges, horizontal lines medians and open dots outliers. Labels (A, B) show whether there is a significant difference (different letters) in median distance or not (same letters).

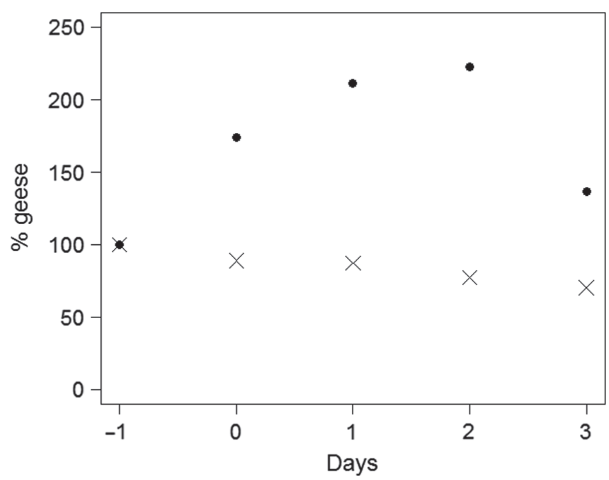

Figure 5. Average relative numbers of pink-footed geese staging at Nesset in mid-Norway, 2011–2013, the day before a hunt (–1; set to 100%), on the day of hunting (0) and 1–3 days after hunting (1–3), for early (dots) and late hunting/migratory season (crosses).

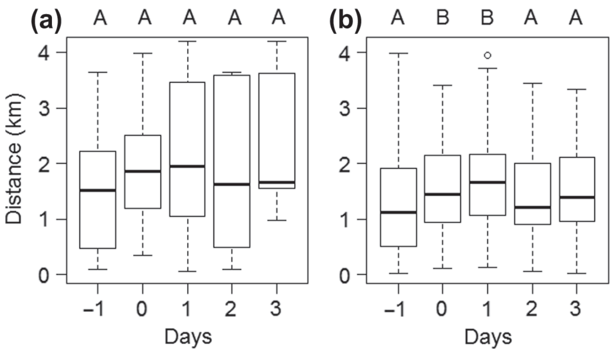

Figure 6. Effect of single hunting days on the local distribution of pink-footed goose flocks at Nesset in mid-Norway, 2011–2013, expressed by the distance (km) from hunting site to goose flocks the day before hunting (–1), on the day of hunting (0) and 1–3 days after hunting (1–3), for hunting days with a) few shots used (1–10) and b) many shots used (> 10). Vertical lines represent minimum and maximum, boxes are interquartile ranges, horizontal lines medians and open dots outliers. Labels (A, B) show whether there is a significant difference (different letters) in median distance or not (same letters).

with few shots fired ($p > 0.1$), but varied significantly for cases with many shots fired ($F_{4,468} = 3.448$, $p < 0.01$). A post hoc test for cases with many shots fired yielded significant variation between day –1 and day 0, and day –1 and 1 ($p < 0.01$, Fig. 6).

To estimate the distance at which hunting events affected goose distribution away from the hunting site, we plotted the cumulative number of pink-footed geese observed between 0 and 4000 m from the hunting site (grouped in 250 m intervals up to 2250 m, with all goose observations between 2250–4000 grouped as > 2250) on the day before and the day after hunting. The day before hunting 56% of the observed geese were positioned within 750 m from the hunting site used the following morning, whereas only 21% were observed within this distance the day after a hunt. The day after hunting 62% of the observed geese were located more than 1750 m from the hunting site, compared to 26% the day before the hunt (Fig. 7).

Response in harvest

In 2011, we had three episodes of two consecutive hunting days in the same zone (all from the northern area and the early season; 20–21 September, 27–28 September and 5–6 October). During the three consecutive hunts, the hunters shot 6, 43 and 11 geese, respectively, during the first day and 0, 3 and 32 geese during the second day.

Overall, the locally weighted regression showed an increase in the number of geese shot per hunt, when the number of hunting-free days before the hunt increased, up to a threshold of three hunting-free days (Fig. 8).

Discussion

The main findings from this study are that geese moved away from hunting sites during the day of hunting and the first day after, but started to return on the second day. This was pronounced for hunting events with more than 10 shots fired, while the geese showed no response in distance when only few shots (1–10) were fired. The geese did not have a shorter return time in the early phase of the migration period compared to later in the season. The number of geese, however, increased faster in the early phase of migration compared to late in the season. For two consecutive hunting days, the results are not as clear. In terms of harvest, however, there was a positive relationship between the number of hunting-free days and the number of geese shot up to a threshold of three days (after a hunting event at any given hunting site). These findings suggest that more geese will be harvested on the first day of hunting and that there is a negative effect if hunting is also performed the day after.

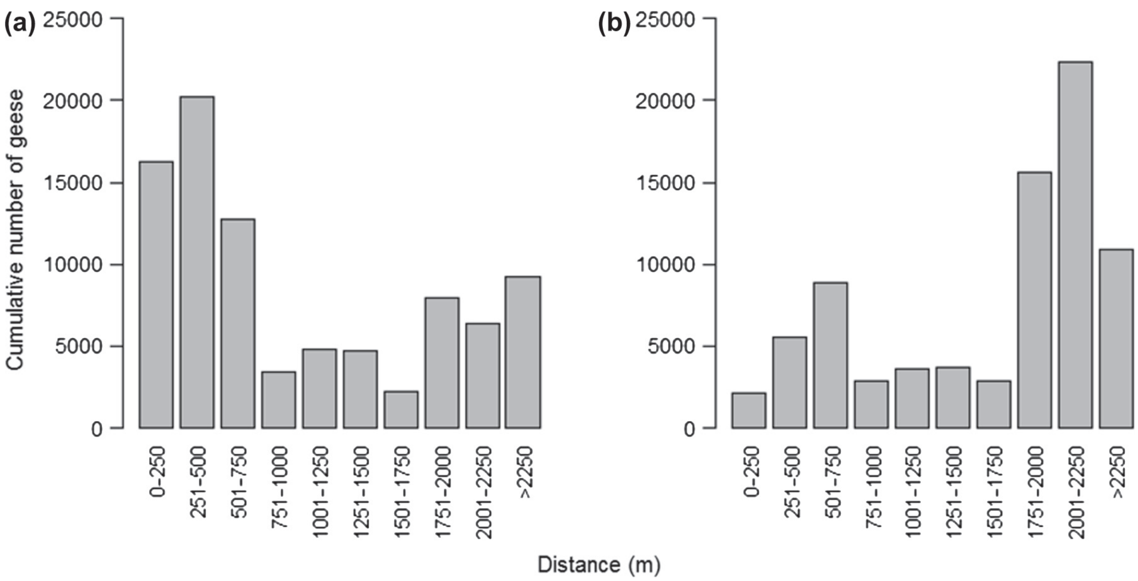

Figure 7. Cumulative numbers of pink-footed geese observed between 0 and 4000 m from the hunting site (grouped in 250 m intervals up to 2250 m, hereafter as one group) for (a) the day before hunting and (b) the day after hunting.

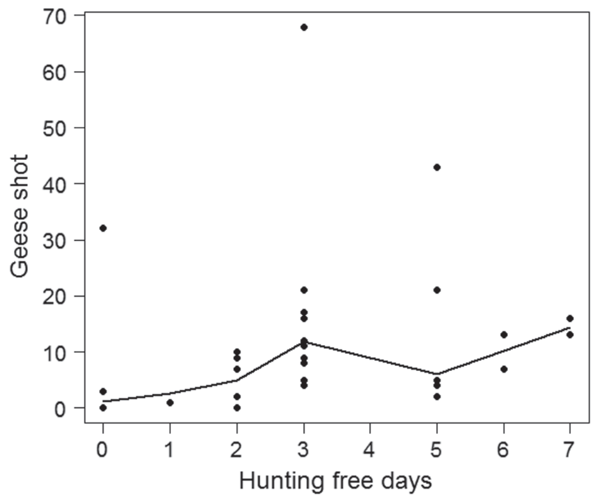

Figure 8. Trend in number of pink-footed geese shot per hunt with 0–7 hunting-free days between hunting events at Nesset in mid-Norway, 2011–2013.

Our study shows that geese are closer to a hunting site the day before hunting, than in the following hours and the first day after hunting. This is contrary to the study by Bregnballe and Madsen (2004), who found that greylag goose numbers near the hunting site were not significantly reduced on the first or second day after a hunting event, hence the geese did not move away after a hunting event. These differences could be caused by interspecific differences in disturbance tolerance, and Madsen (2001) also suggested that pink-footed geese are less tolerant to disturbance than greylag geese.

In this study, the majority of pink-footed geese moved from being within 750 m from the hunting site the day before hunting, to more than 1750 m from the hunting site the first day after hunting. For local organisation of hunting this means that hunting teams will benefit from coordinating their hunting practices with other teams by considering their spatial location in relation to previous day's hunting events. Even though we do not have direct observational evidence from effects of two teams hunting at the same time, our data suggests that teams should stay approximately three km apart to avoid mutual disturbance. From a site conservation perspective this also suggests that hunting, e.g. along borders of refuge areas, will cause a disturbance of geese affecting their distribution up to a distance of ca 1.5–2 km.

Field size and distance to physical elements like buildings, roads etc. are other factors which are known to affect the distribution of geese (Vickery and Gill 1999, Jensen et al. 2008) and, hence, possibly also the time it takes to return to a given site after disturbance, in this case hunting. The experiments in the present paper were not designed to evaluate the potential effects of a range of different environmental variables, but the hunting zones were selected in order to cover large-sized fields with suitable habitat (stubble fields). Accordingly, we expect that differences in field sizes and other physical factors were not likely to have affected the use of zones by the geese.

Sightings of individual geese marked with neckbands indicated that the early arrivals stayed for only a short period, however, with $>$92% of 51 individual geese identified up to early October in 2011–2013 being seen for only one day, whereas 68% of 87 individual geese identified later in the season stayed for at least one week (Jensen et al. 2016). For this reason, we expected hunting in the beginning of the migratory season to have less effect on goose distribution than later in the season. Regardless of the time of season, however, the geese appeared to respond similarly to hunting in terms of distances between goose flocks and a hunting site. This may be because of the flocking behaviour of geese, whereby inexperienced newcomers will follow individuals that are more experienced. Nevertheless, corresponding to the timing of arrival and departure at the study site, the goose numbers increased faster after a hunt in the early phase of the migration compared to late in the season.

In a study by Bregnballe and Madsen (2004), there were no differences in goose response in relation to the number of shots fired. In their study, the majority of waterfowl abandoned the area immediately after hunting commenced. In the present study, we do not have direct observations of goose behaviour during the hunting event, but we do have measures of the distance from a hunting site to goose flocks the day before and 0–3 days after a hunting event. This gives us the resulting effect of hunting on goose distribution after hunting, instead of the immediate and behavioural effect of hunting. By using this method, we see a difference in goose response in relation to the number of shots fired. In our experiment, however, the lack of response to few shots fired could be because the hunters were far away from the main goose flocks (the distance to goose flocks day –1 was $>$1.5 km; Fig. 6a). This could indicate that most of the geese did not take any notice of the hunting. Regardless of explanations, these results demonstrate that the hunters will benefit from searching for large goose flocks and place themselves as close as possible to this location the following day for hunting.

Our few cases with hunting on two consecutive days suggest a cumulative distributional effect for consecutive hunting days than the single hunting day events, but the harvest data give ambiguous results. However, in 2011, the hunting team cancelled some of the second day's hunting because there were no geese in the area, suggesting that the expected bag would have been very low. Therefore, we judge that two consecutive hunting days will result in longer response time and reduced bags. Other studies have also shown that local waterbird abundance declined during consecutive days of hunting (Jakobsen 1988, Meltofte 1994).

The finding that the number of geese shot was reduced on the two days after a hunting event corresponds roughly with the goose distributional response showing that after 2–3 days they will be back again to where they were before the hunting event. Variations in the hunting bag response was probably also influenced by the high between-year variation in goose abundance, and hence the availability.

The age composition of the autumn population of pink-footed geese may also have an effect on the annual harvest. Families tend to fly in smaller flocks than non-breeding geese, making them more susceptible to harvest (Madsen 2010). Therefore, the harvest may be affected by the breeding success on the Svalbard breeding grounds. In autumn 2011–2013, the proportion of juveniles in the population was 19.5, 9.9 and 11.8%, respectively (Madsen et al. 2015). Intuitively, this should result in a higher harvest in 2011; however, as shown this was not supported by the local harvest data.

Conclusions

The results of this study provide useful information in support for the international species management plan for the Svalbard population of pink-footed geese, a plan that seeks to maintain a population size of around 60 000 geese by means of harvest regulation (Madsen and Williams 2012). When the present study was conducted, the population was above the target of 60 000 (ca 80 000 during 2011–2013, Madsen et al. 2015); and an increase in harvest was identified as a management method to help reduce population size to within the target range (Johnson et al. 2014). Our results show that hunters can optimise their practices to increase local harvest by temporal and spatial means. Firstly, hunting events should be separated by approximately three days both in order to increase harvest of geese and for letting the geese return to utilize the resources in the hunting fields. Hence, we do not recommend hunting on two consecutive days if the aim is to shoot many geese. There is also a higher chance of encountering newly arriving, and inexperienced, flocks early in the season, so the highest hunting intensity should take place at that time. Secondly, hunters will benefit from coordinating hunting with neighbouring hunters, staying approximately, for the present location, three km apart if they hunt on the same day. When possible, hunters should position themselves as close as possible to the goose flocks observed the day before a hunt.

It should be borne in mind, in terms of optimal hunting practices, that these results only apply to situations where only morning hunts are performed, by few hunting teams in the hunting area and with an adjacent hunting-free area. The response by geese is likely to be species-specific and depend on local environmental factors. Nonetheless, in terms of improved goose hunting, we believe that goose hunters in general will benefit from our findings and suggested recommendations. The change in practice is a voluntary decision to be made by the landowners/farmers, who need to communally design a temporary hunting zones and safe refuges for the geese on their properties. This will require cooperation among many landowners/farmers, and for the mid-Norway case some landowners' associations have started the process (Jensen et al. unpubl.). Hence, the local implementation of the objectives in the flyway management plan for pink-footed geese will depend on the willingness of landowners to collaborate and the hunters to adjust to the arrangements. Local and regional managers may facilitate the process by supporting the local initiatives with guidance material and advice in the field.

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