Received: 17 January 2024 | Accepted: 11 July 2024
DOI: 10.1002/2688-8319.12386

Ecological Solutions and Evidence
BRITISH ECOLOGICAL SOCIETY

RESEARCH ARTICLE

Individual responses of GPS-tagged geese scared off crops by drones or walking humans

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Funding information
Swedish Environmental Protection Agency (OR Swedish EPA), Grant/Award Number: 16/71, 16/72, 19/128 and 19/129; Swedish Association for Hunting and Wildlife Management; Swedish University of Agricultural Sciences; Kristianstad University

Handling Editor: Errol Douwes

Abstract

1. Scaring of wildlife is commonly used in attempts to reduce crop damage in agricultural landscapes, but relatively few studies exist on its actual effect.
2. We tracked GPS-tagged greylag geese (*Anser anser*) in south-central Sweden, before and after scaring by approaching them either by walking or by drone. On the field level, we studied the scaring effect by estimating return rate to the field where scared. On the landscape level, we tested if geese were less prone to use agricultural fields after being scared.
3. Geese immediately left the field when scared and 5 min later they were on average 990 m (±56 SE) from the scaring position. The proportion of GPS positions near the scaring position decreased significantly for at least 4 h after scaring. Geese showed a significant shift from agricultural fields to wetland habitats the first 4 h after scaring. However, the effect of scaring soon levelled off; after 24 h the field where scaring had occurred was used to the same extent as any other field in the landscape, and agricultural fields were used to the same extent by scared and undisturbed geese. We did not find any differences in response depending on scaring technique. The probability to return and use agricultural fields after scaring was higher for geese scared in the morning compared to in the afternoon. Moreover, the probability to return and use of agricultural fields were higher in spring than in other seasons.
4. *Practical implication*. We found that scared geese tend to visit agricultural fields soon after scaring and that scaring alone tends 'to move the problem around'. This suggests that scaring needs to be repeated across the landscape, but also that accommodation fields where geese do not cause damage may be needed to keep geese off conventional fields. However, our study presents a glimpse of promise as the rather simple drone used covers large areas quickly and minimizes walking in growing crops. With technological advancement and possible autonomous techniques, drones may be capable of providing repeated scaring over large areas in the future.

KEYWORDS
conservation conflict, crop damage, drone, large grazing birds, scaring device, wildlife management

1 | INTRODUCTION

Expansion and intensification of agriculture result in more interactions between wildlife and humans (Decker & Chase, 2016; Hemminger et al., 2022; Lécuyer et al., 2022; Michalski et al., 2006). A pertinent example is the recent rapid population increase of several goose species in Europe and North America. Geese have not only increased in numbers but also transitioned from foraging primarily in natural grasslands to predominantly utilizing agricultural fields, as cropland provides higher abundance and quality of food (Clausen, Madsen, Nolet, & Haugaard, 2018; Fox et al., 2017; Polakowski, Broniszewska, Jankowiak, & Kasprzykowski, 2023). Many agricultural crops can compensate vegetatively as a response to grazing, but the capacity of seedlings to withstand it depends on several factors, such as grazing intensity, timing and frequency (Clausen et al., 2022; Parrott & McKay, 2001; Petkov et al., 2017). With increased goose populations, the risk of negative impact on crops and reduced yield increases (Düttmann et al., 2023). For example, reimbursements for crop damage caused mainly by geese but also swans and cranes, paid to Swedish farmers have increased from ~50,000 euros to ~750,000 euros between 1995 and 2022 (Frank et al., 2023; Montràs-Janer et al., 2019). Similarly, in the Netherlands, five million euros were paid annually for crop damage caused by geese in recent years (Jensen et al., 2018). Furthermore, in parts of Germany, losses due to goose grazing in the first annual harvest of hay have escalated from 15% to 50% over the period from 1996 to 2010 (Düttmann et al., 2023). Consequently, there is an immediate need for efficient management strategies to keep geese off conventional fields and crops (e.g. by scaring and/or accommodation fields) to reduce damage and conflict (Fox et al., 2017; Fox & Madsen, 2017; Lefebvre et al., 2017; Montràs-Janer et al., 2019).

Contemporary wildlife management practices utilize a broad spectrum of methods to scare geese and other wildlife off agricultural fields (Conover & Conover, 2022; Heim et al., 2022; Robai et al., 2024). Scaring is less invasive compared to alternative methods, such as culling. Scaring methods range from static installations such as colourful flags, unnatural objects and scarecrows, to more dynamic and technical devices like kites, inflatable scarecrows, laser beams, propane noise cannons, and playback of natural alarm/distress calls (Clausen et al., 2019; Conover & Conover, 2022; Hake et al., 2010). Human presence in the form of hunting and scaring by approaching on foot are also commonly used methods. Recently, also drones have been used for scaring wildlife in agricultural areas (Mulero-Pázmány et al., 2017; Wang et al., 2020). As their airborne movements resemble natural threats from raptors (i.e., hawks and eagles) an advantage may be that wildlife does not habituate to drones as easily as has been found for less natural threats such as bangers and propane cannons (Conover, 2002). In a review, Mulero-Pázmány et al. (2017) concluded that birds in general react stronger to drones compared to mammalian carnivores, primates and ungulates. Drones may also become important future scaring devices, as they can quickly reach wildlife far away and operate over fields where walking should be avoided due to growing sensitive crops. Moreover, drones can be equipped with additional fearful applications (e.g. auditory or visual deterrents) to increase the effect (Wang et al., 2017). Finally, drones present a relatively 'low noise´ solution compared to pyrotechnics and gas exploders, which may disturb people and non-target wildlife. However, few studies exist on the scaring effect of drones and more knowledge is needed about their efficiency compared to other widely used methods.

Most earlier studies evaluating the effect of scaring geese have used indices such as number of droppings, grazing pressure, yield loss, or the number of culprit individuals at specific fields before and after scaring (Sudgen et al., 1988, Steen et al., 2012, Månsson, 2017). These studies have demonstrated a significant variation in effectiveness, with a reduction in bird numbers and damage ranging between 5% and 80% (Percival & Houston, 1992; Robai et al., 2024; Summers, 1990; Summers & Hillman, 1990). Variation in efficiency may not only depend on the scaring method per se, but also on factors such as scaring intensity and habituation by the birds (Askren et al., 2022; Bishop et al., 2003). Moreover, as there are seasonal differences in crop availability as well as in the daily and seasonal energetic needs of geese (Fox & Abraham, 2017; Gauthier et al., 1988; Shimada, 2002), their motivation to feed and take risks may vary over time. Hence, the timing of scaring may affect motivation to either return, use a new site for continued foraging, or to shift habitat for safety. However, very little is known about how individual animals behave after being scared off a specific agricultural field. For example, scaring may influence field use, activity patterns, and intake rate (Klaassen et al., 2006; Madsen, 2001; Nolet et al., 2016). These changes could, in turn, affect the risk of damage on a larger scale, for example to other fields in the landscape (de Jager et al., 2023). Studies limited to specific fields do not address the crucial question of whether scaring merely moves the problem to another field. Salvaging one field and one farmer is less of a success if the landscape as a whole still carries the same crop damage and reimbursements simply change mailboxes. By using GPS tracking devices, better understanding can be achieved about the behavioural response of scaring in individual birds and the effect at a spatial scale larger than specific fields (Askren et al., 2022; Heim et al., 2022).

We studied greylag geese (*Anser anser*), a native European species whose population was once threatened but has increased to number about one million birds (Fox & Madsen, 2017; Fox & Leafloor, 2018;

Powolny et al., 2018). It is a major culprit species when it comes to crop damage (Montràs-Janer et al., 2019), as it often occurs in large numbers in areas offering a combination of agricultural fields and wetlands (Fox & Madsen, 2017). In such settings greylag geese commute between wetlands providing safety and agricultural fields providing high-quality food in terms of growing crops or harvest residues (Fox et al., 2017). In Sweden greylag geese mainly cause damage to cereal fields (wheat and barley) and hayfields, but also to crops such as carrots, vegetables, and legumes (Montràs-Janer et al., 2020). Damage can occur year around, with seasonal peaks varying between regions (Montràs-Janer et al., 2020).

By approaching GPS-tagged greylag geese, either by walking or using a drone, we were able to experimentally assess the impact of the two methods by time of day and season. The effect of scaring was measured in terms of (1) flight distance of individual geese when disturbed, (2) their likelihood of return, and (3) the degree of habitat shift from agricultural fields to wetlands.

We predicted that: (a) drones, not being as familiar as an approaching walking human, would be more efficient in terms of lower probability of scared geese to return after scaring, increased use of safe habitats (wetlands), and greater distance moved after scaring; (b) after being scared, geese would be generally more likely to use safe wetland habitats than agricultural fields (compared to a situation when not scared (control)); (c) geese scared in the morning would be more prone to use agricultural fields than wetland habitat after scaring, due to higher energy demands in the morning compared to in the afternoon; and (d) in the fall season, the effect of scaring should be more pronounced than in spring and summer. In fall, geese are less restricted to particular fields compared to in other seasons, as more fields with high food abundance are available due to harvest residues (e.g. stubble fields with spilled grain providing high energy food).

2 | MATERIALS AND METHODS

2.1 | Study area

The study was carried out in 2018–2020 in south-central Sweden (59°10′ N, 15°22′ E; Figure 1). The area comprises two wetland reserves "Kvismaren" in a flat landscape, surrounded by farmland with pastures and fields of mainly cereals, ley, and potatoes. The two wetlands are shallow and eutrophic, bordered by narrow belts of grazed wet meadow and comprise in total 7.3 km^2. The wetland reserves are the only natural habitat locally available for the geese. Size of agricultural fields in the study area ranges from <1 to 72 ha. Ley fields are mowed from June to August (2–4 harvests per year), while other agricultural crops are harvested from August to October (Nilsson et al., 2016). Several goose species occur in the area, but greylag goose is the only species breeding in large numbers. Together with taiga bean geese (*Anser fabalis fabalis*) greylag goose (local breeders as well as staging visitors) is the most numerous staging species in spring and fall. In addition, smaller numbers of greater white-fronted geese (*Anser albifrons*), pink-footed geese (*Anser brachyrhynchus*), barnacle geese (*Branta leucopsis*), and Canada geese (*Branta canadensis*) stage in the area and use agricultural fields for foraging.

Greylag geese generally arrive to the study area in March/April and leave in late September / early October (Månsson et al., 2022). They generally select foraging habitats and fields close to roost sites to minimize costs of commuting, and use fields with a high abundance of food with low fibre and high protein/energy content to minimize handling time (Fox et al., 2017). Natural predators such as white-tailed eagle (*Haliaeetus albicilla*) and red fox (*Vulpes vulpes*) as well as hunting (both open season and derogation shooting to protect unharvested crops) occur in the area and constitute threats to greylag geese. Total costs in terms of governmental subsidies for crop

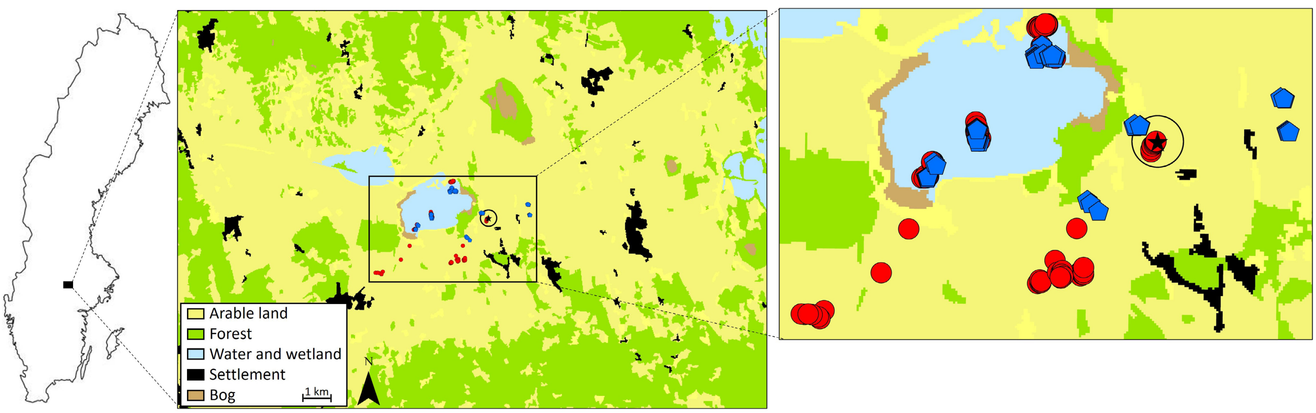

FIGURE 1 Location of the area in Sweden where we studied effects of scaring on GPS-tagged greylag geese ($n = 32$). The study area is dominated by agricultural fields. Two lakes (Kvismaren nature reserve, 7.3 km^2) provide breeding, foraging, and safe roosting sites. Symbols visualize one of the 299 scaring trials; the black star is the position where the GPS-tagged goose was scared and the circle around it is a 300 m buffer zone used to estimate the probability of return. Blue pentagons are positions 48 to 0 h before and red circles are positions 0 to 48 h after the scaring event. In addition to return rate, habitat use before and after scaring was studied by including two (agricultural field and wetland) of the five main habitat categories in the area (inset in middle map).

damage, preventive measures, and compensation for yield losses in the area have ranged between 80,000 and 140,000 Euros annually in the period 2018–2022 (Johanna M. Wikland, Örebro county administrative board, pers. comm.). Locally, there are two peaks of damage, namely before and after the moulting period in June (i.e., May and July–August, respectively; Montràs-Janer et al., 2020). Most reported damaged crops are cereals such as wheat and barley, but also grass (ley fields) (Montràs-Janer et al., 2020). Preventive measures in the area involve non-lethal practices such as scarecrows, kites, plastic flags, propane cannons, but also lethal scaring/derogation shooting (Hake et al., 2010; Månsson, 2017; Robai et al., 2024). The extent of other disturbances than our targeted scaring could not be quantified but can be viewed as part of the daily life of geese in the same manner as for example weather and agriculture affect goose behaviour.

2.2 | Goose tagging and GPS data collection during scaring trials

In June 2018 and June 2019, breeding and moulting (flightless) greylag geese ($N=32$) were caught in meadows and pastures near water. They were herded slowly by foot or canoe towards fences and corrals, where they were put in gunny sacks until further handling. In addition to classic tarsal metal rings, geese were provided with neck collars fitted with a solar powered GPS tracking device: Ornitela (OT-N35 or OT-N44). Geese were aged (juvenile or adult ≥2nd calendar year) based on plumage and sexed by cloacal inspection. Out of the 32 individuals, four were juveniles and 28 adults; 13 were females and 19 males. The GPS-tagged greylag geese scared in this study were local breeders, but the flocks they travelled in and foraged with most likely also included moulting and staging visitors. For the present study, we used GPS positions from 48 h before to 48 h after each scaring event of an individual. The default positioning rate was set to every 30 min (i.e. in total 192 positions per scaring event). In addition, we tracked the geese more intensively (one position every 5 min) from 4 h before to 4 h after each scaring event (96 additional positions per scaring event). This intensive and real-time positioning allowed us to find a certain individual targeted for a trial and to follow its movements before and after scaring. Inaccurate positions, measured with dilution of precision (DOP) >7, were excluded ($n=534$ out of 228,906 obtained positions, ~0.2%). The total number of positions obtained between 24 and 48 h before scaring was 12,614, and 12,836 for the same duration (period) after scaring (Table S1). Catching, handling during tagging, and scaring trials were done according to permits from the Animal Ethics Committee of Central Sweden (permission # 5.8.18-03584/2017).

2.3 | Scaring events and control (undisturbed) events

A total of 299 scaring events were performed between March and September: 76 in 2018, 75 in 2019, and 148 in 2020. Each scaring trial was preceded by selecting a GPS collared goose that had not been subject to experimental scaring within the last 5 days, to minimize the likelihood that the individual's behaviour was influenced by recent previous scaring events. Individual geese were scared on average 9 times (range 1–15). Scaring took place between 03:30 and 20:00 h and targeted only geese actively feeding in an agricultural field outside the boundaries of any protected area. As our main aim was to study behavioural response in relation to scaring, rather than damage level, geese were scared off both growing (unharvested) crops and stubble (harvested fields).

Out of the 299 scaring events, 23 were subsequently excluded due to missing GPS data owing to failure of the drone and programming of GPS tracking devices, leaving 276 (60 events in 2018, 70 in 2019, and 146 in 2020), of which 161 were walking trials and 115 drone trials. The OrniTrack Control Panel portal provided by Ornitela (www.ornitela.com) was used to find the last recorded GPS position of a target goose in a given field before a scaring event took place. This defined the 'scaring position', which was used as the starting point for subsequent spatial analysis. The target goose was found by driving and we stopped at a distance before it and its flock were alarmed (stretched necks, wing-flapping, walking away). We then waited for at least 5 min before approaching it and its flock to minimize the potential effect of varying starting distance and disturbance when the car was parked. Before starting a scaring event we randomly selected which method (drone or walking human) to use, and we counted the number of greylag and other geese in the flock of which the target goose was part (flock size averaged 508 individuals, range 1 – ~10,000).

We used the DJI Phantom 4 drone, flown in a straight line towards the flock containing the target goose at a speed of 50 km/h at an altitude of 10 m. Scaring by walking was performed by approaching the goose flock in a straight line using a normal walking pace.

To be able to compare the behaviour of scared geese to an undisturbed situation (i.e. when geese were not scared from a field), the first (earliest) available position in an agricultural field during the pre-scaring period was selected as a control event (hereafter 'control position' and 'control event'). We then estimated the same parameters for these control events as for the scaring events that is, mean distance to the position, presence within 300 m of the control position, as well as habitat use of individual geese for all positions following the control position in time until the goose was scared.

2.4 | Data treatment

2.4.1 | Time intervals and frequency of positioning

GPS positions were grouped into 12 time intervals with respect to scaring: −48 (48–24 h before), −24 (24–4 h before), −4 (4–3 h before), −3 (3–2 h before), −2 (2–1 h before), −1 (1–0 h before), 1 (0–1 h after), 2 (1–2 h after), 3 (2–3 h after), 4 (3–4 h after), 24 (4–24 h after), and 48 (24–48 h after). For control events, we only used the time intervals before scaring. A few periods did not have a 5-min position frequency due to technical failure, hence less frequent positioning. We grouped scaring events and GPS data by season into 'spring' (March–April: 14002 positions), 'summer' (July–August: 39770 positions), and 'fall' (September: 16464 positions).

2.4.2 | Distance

For our analyses, we used the distance from the scaring position to each GPS position before and after each scaring event and control event to describe the movement pattern of each individual over time. We estimated average distance to the scaring position from the raw data 48 h before and after scaring for the 12 time intervals (Table S2). To illustrate how geese reacted to scaring, we estimated the average distance from their positions to the scaring position by analysing groups of approximately 1000 positions each. We divided the positions into sequential groups, each containing roughly 1000 individual position records. The positions were ordered based on the time they were recorded relative to the scaring event. The first group included positions 1 to 1016, which corresponded to times −48 to −46.1 h before the scaring event. The second group included positions 1017 to 2020, covering times −46.1 to −44.2 h before the scaring event. The last group included the positions 69,561 to 70,562, covering times 46.2 to 48 h after scaring. This sequential division of positions resulted in 70 groups. This analysis allowed us to observe and quantify changes in behaviour in response to the scaring event by examining how average distance to the scaring position varied over time.

2.4.3 | Presence close to scaring points and habitat use

We compared the probability of an individual goose being present within a radius of 300 m from the scaring position and in different habitats before and after a scaring event. A radius of 300 m translates to a field size of 28 ha, which matches well with fields in our study area. The number of positions inside and outside the 300 m radius was calculated for each goose using ArcGIS version 10.5.

Habitat characteristics for all goose positions were derived from the national land cover data base (Swedish Environmental Protection Agency). The land cover types in this data base were assigned to two habitat categories for our purposes: 'agricultural field' versus 'wetland' (inland water and open wetland). GPS positions from habitat types such as roads, built-up areas, and forest were few ($N=6648$, i.e. 0.03% of all positions) and were removed from the dataset.

2.5 | Statistical analyses

We used logistic regression with a binomial error distribution and logit link to test the effect of scaring on goose behaviour. We first tested the probability that geese were ≤300 m (coded as 1) or >300 m (coded as 0) from the scaring position in relation to time before and after scaring (12 time intervals), time of day when scared (morning (before 11 AM) or afternoon (after 12 AM)), scaring method (drone versus walking), season (spring, summer, fall), and the two-way interaction between time interval and either time of the day, method, or season. Secondly, we tested the probability that geese were in agricultural field (coded as 1) or in wetland habitat types (coded as 0) in relation to the variables as well as the two-way interactions described above. Finally, we tested the effect of an undisturbed situation on the probability of geese being close to the control position and in an agricultural field in relation to time after the control event (6 time intervals). Since most geese were subjected to more than one scaring event, we used the ID of unique scaring events, nested under the ID of individual geese as random factors to account for variation among events and individual geese. All analyses were conducted in R (version 4.2.2, R core team 2022) and using the glmmTMB package (Bolker, 2019). The statistical models are detailed in the Supporting Information. The effects of time interval and time of the day (morning versus afternoon), scaring method (drone versus walking), and season (spring, summer or fall), as well as the control event on goose behaviour, were evaluated by non-overlapping 99.9% confidence intervals. A 99.9% confidence interval corresponds to a family-wise error rate of 5% with a Bonferroni correction of 50 pair-wise comparisons.

3 | RESULTS

3.1 | Distance after scaring

The first GPS position (5 min) of target geese after scaring was on average 990 m (±56 SE) from the scaring position (Figure 2). In comparison, geese moved only slowly away from the control position during the first 5 min (mean distance 335 m ± 45 SE). The mean distance from the scaring point in scared geese and the mean distance to a control point in undisturbed geese differed significantly for the first 5 h. However, after 5 h mean distance to the scaring position in scared geese and distance to the control position in undisturbed geese did not differ significantly (Figure 2, Table S2; 2368 m ± 141 SE and 2197 m ± 108 SE).

3.2 | Presence close to scaring position

Regardless of scaring method (drone versus walking), time of day, and season, geese were significantly less likely to be present near the scaring position (<300 m) after scaring, compared to before scaring and to the control position (predicted probabilities were significantly lower, i.e. non-overlapping 99.9% confidence intervals) for at least the first 4 h after scaring (Figure 3a–c; Tables S3–S10). After 24 h the probability that scared geese were present <300 m from the scaring position was about the same as before scaring (Figure 3a–c; Tables S3–S10). The probability that geese were present near the scaring position was generally higher in spring and the effect of

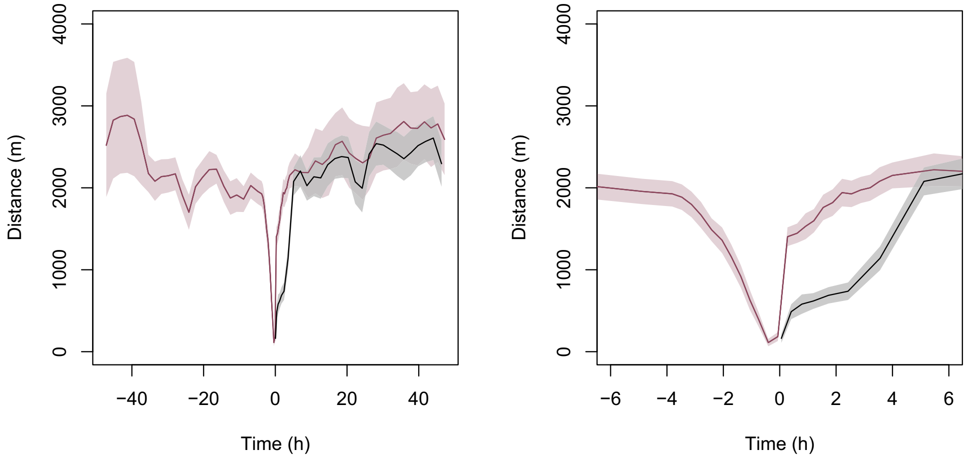

FIGURE 2 Mean distance and 99.9% CI (for groups of approximately 1000 positions) from the scaring position (Time 0), in pink, from 48 h before to 48 h after scaring (left panel) and from 6 h before to 6 h after scaring (right panel). Black lines show mean distance (for groups of approximately 1000 positions) from a control position, that is, in an undisturbed situation where geese were not scared. The data for 6 h before to 6 after scaring (right panel) are a subset of the 48-h data (left panel) to highlight the short-term effect.

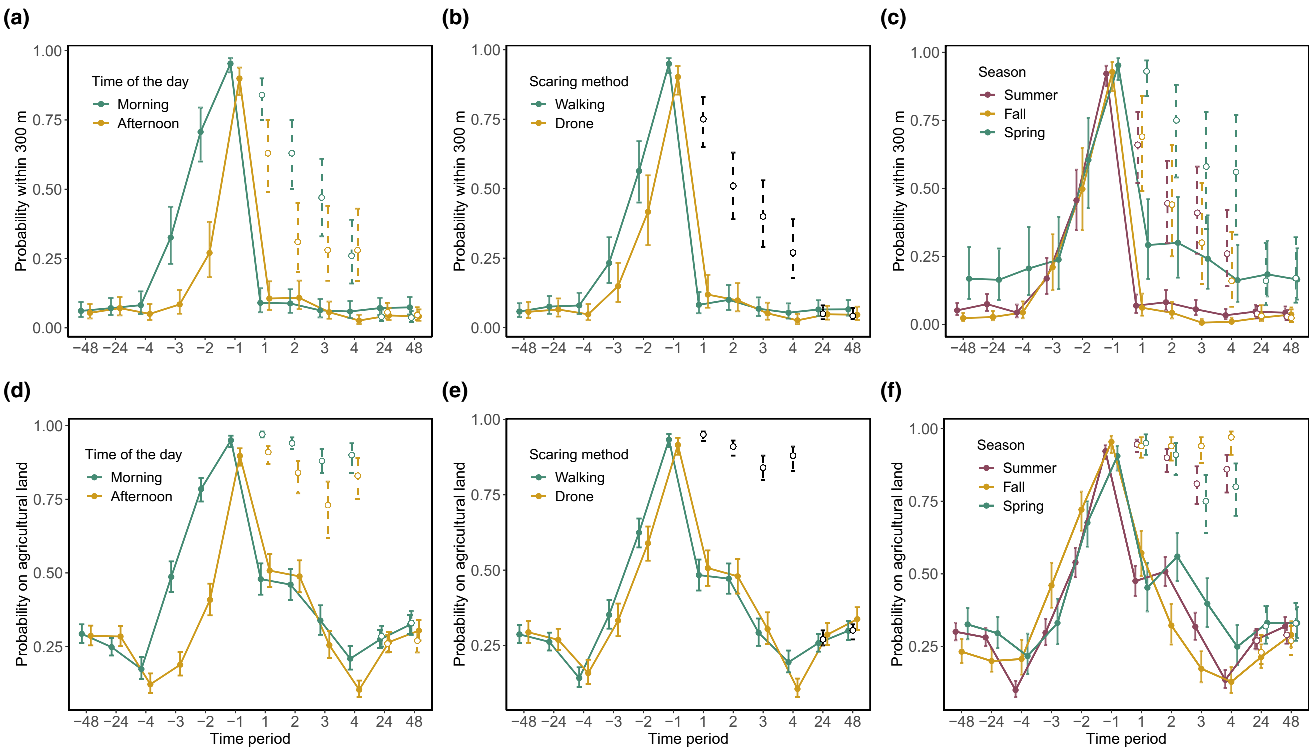

FIGURE 3 Mean probability and 99.9% CI of geese being present near (<300 m) the scaring position (a–c) and in agricultural fields (d–f) during 12 time intervals (48 h before (negative values) to 48 h after scaring). (a and d) compare probabilities depending on whether geese were scared in the morning (before 11 AM) versus in the afternoon (after12 AM). (b and e) compare different scaring methods, and (c and f) compare the three seasons. Open circles and dashed lines refer to corresponding probabilities in a control situation that is, where geese were undisturbed and not scared. Non-overlapping 99.9% CI indicates significant difference with a family-wise error at 5% with a Bonferroni correction of 50 pair-wise comparisons.

scaring was also less pronounced in spring (Figure 3c). The probability of presence near the scaring position after scaring did not differ significantly between drone and walking, nor by time of day (Figure 3a,b). However, as the probability of a targeted goose to be within 300 m from the scaring point was higher in the morning before scaring and in an undisturbed situation (control position) the relative effect of scaring was actually higher in the morning compared to in the afternoon. The probability of presence near the scaring position was the same 48 to 4 h before scaring as 24 to 48 h after scaring and compared to the control position (overlapping 99.9% confidence intervals, Figure 3).

3.3 | Time spent in agricultural fields versus wetlands

Scaring had an effect on time spent in agricultural fields versus wetlands for at least 4 h. The predicted probabilities to find geese in an agricultural field were generally lower during the first 4 h after scaring than before and compared to the control position (non-overlapping 99.9% confidence intervals, Figure 3d–f; Tables S11–S18). After 24 h the probability that target geese were in an agricultural field was about the same as before scaring, regardless of scaring method (drone versus walking), season, and time of day (Figure 3d–f; Tables S11–S18). When geese were not scared (control positions), probability was higher that they were in agricultural fields, compared to scared geese during the first 4 h after the control event, but no corresponding difference was found 24 to 48 h after scaring (Figure 3d–f). In spring, geese spent a larger proportion of their time in agricultural fields, both before and after scaring, compared to in summer and fall (Figure 3f). The same trend was found in the control events, but the confidence intervals overlapped between seasons (Figure 3f). Similarly, the probability of being in agricultural fields was higher in geese in the morning before scaring and in the control events. However, after scaring the probability of being in agricultural fields in general did not differ between geese scared in the morning versus in the afternoon. The relative effect of scaring geese was therefore higher in the morning compared to in the afternoon.

4 | DISCUSSION

Our results imply that both an approaching human and a drone may keep individual geese away from a specific field, but contrary to our prediction there was no difference in effect with respect to method. In accordance with our prediction, soon after being scared geese used wetlands to a higher extent than before scaring. However, already after some few h the effect levelled off and after 24 h there was no difference in field use between scared and non-scared geese.

Numerous studies have demonstrated that agricultural fields offer a higher abundance and quality of food compared to natural habitats (Clausen, Madsen, Nolet, & Haugaard, 2018; Fox et al., 2005, 2017; Polakowski, Broniszewska, Jankowiak, & Kasprzykowski, 2023). On the other hand, wetland habitats provide shelter and protection (Fox et al., 2017). Consequently, it is unsurprising that scared geese, experiencing an immediate threat, leave agricultural fields for safety in wetlands, but later return to forage in fields once any immediate threat is not present (Chudzinska et al., 2013; Jankowiak et al., 2015). We also show that geese change foraging sites regularly, as the proportion of positions near the selected control positions also decreased (from 75% to 27% the first 4 h following the control; no scaring) event (Figure 3). Such turnover implies that even if we did not see a short-term return to the same field by targeted geese, other geese, not affected by our scaring, are likely to 'fill the void' after the scared geese had left. The high density of geese in our study, coupled with the observed high turnover rate and the displacement of targeted geese to other agricultural fields, aligns with previous studies (Clausen et al., 2019; Heim et al., 2022; Jensen et al., 2016; Månsson, 2017; Simonsen et al., 2015). This suggests that coordinated and repeated scaring is necessary to deter geese from specific fields and, more broadly, agricultural land.

There are still few studies on the effects of drones to scare birds, but Wang et al. (2020) showed that they can be efficient to protect fruit crops. On the other hand, Grémillet et al. (2015) found that wild flamingos (*Phoenicopterus roseus*) and common greenshanks (*Tringa nebularia*) were not disturbed by drones. In the present study, we used a less advanced drone than did Wang et al. (2017), but one that is also affordable for smaller farms. We standardized our drone scaring events to a specific speed and altitude, and we landed it at the position from which geese took off. This was necessary for data collection purposes and consistency, but it may not provide a true representation of how drones best can be employed for scaring. Considering this conservative standardization, it is perhaps not surprising that our study shows a limited efficiency of scaring by drone. We think drones may still be important in future scaring solutions, though, as they have the potential to provide repeated scaring over large areas by developing autonomous techniques. Moreover, drones are already a time saving tool, as they can quickly reach geese far away and operate in fields where it is not advisable to walk due to sensitive growing crops. Therefore, future studies should investigate how scaring geese by drones may become more efficient and how to minimize habituation if the method is used repeatedly. Recent studies suggest that the scaring effect of drones may increase if equipped with fearful sounds or visual deterrents (Wang et al., 2017). There have been attempts to develop adaptive scaring devices (i.e. varying the timing and frequency of disruptive bioacoustic stimuli) using machine learning algorithms to recognize behaviour of specific bird species by visual and audio-based detection systems (Steen et al., 2012). While still in the early stages of development, these systems offer a glimpse of promise. Hypothetically, with continued technological advancement drones could perform automated 'patrol missions' around fields after strategically placed sensors have triggered detection algorithms for specific culprit species.

In line with our predictions, spring was the season when geese in general were more prone to return to the field where scared, and to use other agricultural fields in the landscape (rather than wetlands) after scaring. Similar results have recently been obtained for barnacle geese, which in spring returned faster to areas where they had been scared, compared to in autumn (Heim et al., 2022). In spring greylag geese are more territorial and also need to accumulate more energy stores for breeding, in contrast to other seasons (Fox et al., 2005; Madsen, 1985; Polakowski, Broniszewska, Jankowiak, & Fox, 2023). Moreover, the availability of energy rich food is higher in late summer and fall (spilled grain and residues in harvested fields) than in other seasons, and may correlate with local movements and the time required for foraging in a certain field to meet energy needs (Clausen, Madsen, Cottaar, et al., 2018; Fox et al., 2017). This may in turn affect the impact of scaring. We also found an effect of time of the day, where geese tended to use agricultural land more in the morning. This is in line with earlier findings showing higher intake rates and higher foraging activity during mornings (Chudzinska et al., 2013; Shimada, 2002). However, contrary to our prediction, there was no significant difference in habitat use between geese scared in the morning versus in the afternoon. Hence, the effect of scaring was stronger in the morning than in the afternoon, both in terms of probability to return and the use of agricultural fields.

Earlier studies have evaluated the effect of other methods than drones and human presence, such as propane cannons, flags, and fire-crackers on a wide range of bird species including geese (Bishop et al., 2003; Conover, 2002; Conover & Conover, 2022). However, these studies have considered numerical response in relation to scaring, and not individual behaviour (as in the present study). Limited effect of scaring has been observed for other methods requiring the scarer's active presence in the field. For example, fields treated by lethal scaring showed about 60% reduction in goose numbers compared to control fields (Månsson, 2017) and fields treated by laser had seven times lower density of goose droppings (Clausen et al., 2019). However, the latter study found that the scaring effort was as costly as the subsequent harvest gain (Clausen et al., 2019).

In this study, we did not distinguish between different types of crops and crop stages, and the presence of the targeted geese on cropland should therefore be viewed as only a proxy of damage risk. Still, one important conclusion is that agricultural fields are a very attractive foraging habitat for geese and that a lot of effort is needed to succeed in scaring them away in the long term. The overall efficiency of scaring methods most likely depends on both the intrinsic nutritional needs of the geese and food availability in the landscape (Fox et al., 2005; Polakowski, Broniszewska, Jankowiak, & Kasprzykowski, 2023; Therkildsen & Madsen, 2000). When the energy need is low and when high-quality food is abundant, geese are probably more prone to move elsewhere to find food after being scared. As the effect of scaring is context dependent (e.g. species, scaring type, extent of scaring, season, food availability, internal state of animals, flocking behaviour; Bishop et al., 2003; Fox et al., 2017; Simonsen et al., 2015) generalization of our result should be made with some caution. Moreover, comparisons with other areas are difficult since we could not quantify any other form of disturbance than our own targeted scaring. However, in general, geese commute between sites providing food and shelter, and also prefer well-managed agricultural fields over natural habitats for foraging (Fox et al., 2017). Therefore, a similar response, where scared geese leave specific foraging sites to seek shelter or alternative foraging sites when scared, would be expected also in other areas and in other goose species.

5 | CONCLUSIONS

Our study demonstrates that scaring local and abundant geese off agricultural fields by drones or walking does work, but only for a limited time. To successfully keep geese off vulnerable crops at a landscape level, scaring needs to be repeated and most probably also combined with measures providing high-quality food where geese do not cause damage, for example sacrificial crops or harvested fields (Jensen et al., 2008; Teräväinen et al., 2022; Vickery et al., 1994; Vickery & Gill, 1999). In other words, non-coordinated management and low intensive scaring tend 'to move the problem around' rather than solve it. With increasing goose populations even more effort will be needed to scare geese off conventional fields and our work thereby supports earlier studies showing that the effort may outweigh the benefits (Clausen et al., 2019; de Jager et al., 2024). However, we acknowledge that the effectiveness of scaring tactics may be higher in landscapes with a lower abundance of geese. Although we found only a short-term effect of scaring, our study presents a glimpse of promise. The rather simple drone scaring technique covers large areas quickly and spares growing crops from walking. With continued technological advancement and autonomous techniques, drones may be capable of mimicking raptors, cover vast areas, and promote repeated scaring events. Provided that cost and flight safety regulations permit, drones may become more effective as a scaring device in the near future.

AUTHOR CONTRIBUTIONS

Johan Månsson and Johan Elmberg launched the original idea of the manuscript. All authors contributed to refining the idea and approach. Malin Teräväinen, Wade Million and Johan Månsson performed fieldwork. Malin Teräväinen, Henrik Andrén and Johan Månsson developed the modelling and analysed the data. Johan Månsson, Malin Teräväinen and Wade Million initiated the first draft of the manuscript. All authors significantly contributed to later versions of the manuscript. Johan Månsson, Henrik Andrén and Johan Elmberg revised the last versions of the manuscript and all authors gave final approval for publication.

ACKNOWLEDGEMENTS

This work was supported by grants from Swedish Environmental Protection Agency (Grant no. 16/71, 16/72, 19/128, and 19/129), the Swedish Association for Hunting and Wildlife Management, the Swedish University of Agricultural Sciences, and Kristianstad University. Thanks to David Ahlqvist, our professional scarer, to Giorgia Ausilio for help with the figures and three anonymous reviewers for valuable comments on earlier drafts of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interests to declare.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/2688-8319.12386.

DATA AVAILABILITY STATEMENT

Data available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.3bk3j9kv5 (Månsson et al., 2024).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1. Number of GPS positions of studied greylag geese *Anser anser* for each of the time intervals before (negative values) and after the scaring event and after a control event (i.e. during undisturbed conditions).

Table S2. Distance (mean ± SE) between GPS positions where studied greylag geese were scared and the positions during time intervals before (negative values) or after scaring.

Table S3. Predicted probability and confidence interval (99.9 % C.I.) of greylag geese being <300 m from the scaring position before and after a scaring event.

Table S4. Predicted probability and confidence interval (99.9 % C.I.) of greylag geese being <300 m from the scaring position before and after scaring.

Table S5. Estimates of generalized linear mixed model predictions of GPS positions within (1) or outside (0) a radius of 300 *m from the scaring position*.

Table S6. Estimates of generalized linear mixed model predictions of GPS positions within (1) or outside (0) 300 m of the scaring position.

Table S7. Estimates of generalized linear mixed model predictions of GPS positions within (1) or outside (0) 300 m of the scaring position.

Table S8. Estimates of generalized linear mixed model predictions of GPS positions within (1) or outside (0) 300 m of the control position (i.e. position selected to estimate a comparable probability for an undisturbed situation).

Table S9. Estimates of generalized linear mixed model predictions of GPS positions within (1) or outside (0) 300 m of the control position (i.e. position selected to estimate a comparable probability for an undisturbed situation).

Table S10. Estimates of generalized linear mixed model predictions of GPS positions within (1) or outside (0) 300 m of the control position (i.e. position selected to estimate a comparable probability for an undisturbed situation).

Table S11. Predicted probability and confidence interval (99.9 % C.I.) of greylag geese being in agricultural fields before (negative values) and after scaring. Independent variables are twelve time intervals before or after scaring, time of day (morning (before 11 AM) vs. afternoon (after 11 AM)), and scaring method (drone vs. walking).

Table S12. Predicted probability and confidence interval (99.9 % C.I.) of greylag geese to be in agricultural fields before (negative values) and after scaring. Independent variables are twelve time intervals before or after scaring and season (spring, summer, or fall).

Table S13. Estimates of generalized linear mixed model predictions of GPS positions in agricultural fields (1) versus wetland (0). Independent variables are twelve time intervals before or after scaring (time interval −48 to −24 reference), and time of day (morning (reference time interval) versus afternoon).

Table S14. Estimates of generalized linear mixed model predictions of GPS positions in agricultural fields (1) versus wetland (0). Independent variables are twelve time intervals before or after scaring (time interval −48 to −24 reference), and scaring method (drone (reference method) vs. walking).

Table S15. Estimates of generalized linear mixed model predictions of GPS positions in agricultural fields (1) versus wetland (0). Independent variables are twelve time intervals before or after scaring (time interval −48 to −24 reference), and season (fall, spring (reference season) and summer).

Table S16. Estimates of generalized linear mixed model predictions of GPS positions in agricultural field (1) versus wetland (0) of the control position (i.e. position selected to estimate a comparable probability for an undisturbed situation). Independent variables are six time intervals after the control event (time interval 0 – 1 reference) and time of day (morning (reference) vs. afternoon).

Table S17. Estimates of generalized linear mixed model predictions of GPS positions in agricultural fields (1) versus wetland (0) of the control position (i.e. position selected to estimate a comparable probability for an undisturbed situation). Independent variables are six time intervals after the control event (time interval 0 – 1 reference).

Table S18. Estimates of generalized linear mixed model predictions of GPS positions in agricultural field (1) versus wetland (0) of the control position (i.e. position selected to estimate a comparable probability for an undisturbed situation). Independent variables are six time intervals after the control event (time interval 0 – 1 reference) and season (spring (reference season), summer and fall).

How to cite this article: Månsson, J., Teräväinen, M., Andrén, H., Million, W., & Elmberg, J. (2024). Individual responses of GPS-tagged geese scared off crops by drones or walking humans. *Ecological Solutions and Evidence*, *5*, e12386. https://doi.org/10.1002/2688-8319.12386