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Research article

Regional differences in crippling rate in greylag geese *Anser anser*

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Goose populations across Europe have been subjected to long-standing harvest practices, which include shotgun hunting. In addition to immediate mortality, hunting can affect an animal's fitness by inflicting non-lethal injuries, often referred to as 'crippling' or 'wounding'. This could subsequently have negative effects on the population level and causes ethical concerns, ultimately challenging the legitimacy of hunting as a management tool. Understanding spatial variation in crippling rate can assist management to prioritize regions for enhancing awareness and implementing measures aimed at reducing crippling. We examined greylag geese from three subpopulations (Nyköping, Örebro, and Hudiksvall) breeding in three regions in Sweden (Södermanland, Örebro, and Gävleborg) to record prevalence of imbedded shotgun pellets and to quantify crippling impact. Our approach excludes birds that were wounded and subsequently died without being retrieved. We found that across the three subpopulations, 21% of the 176 x-rayed greylag geese were carrying imbedded pellets (average 2.33 pellets, range 1–16). Crippling rate varied among the subpopulations, being twice as high in Örebro and Nyköping (26.4 and 25.0%, respectively) compared to Hudiksvall (11.7%). However, the probability of being crippled differed significantly only between Nyköping and Hudiksvall ($p = 0.04$), but not between Örebro and Hudiksvall ($p > 0.05$) or between Nyköping and Örebro ($p > 0.05$). This study could not elucidate the mechanisms underlying the observed regional variations in crippling rate. Nevertheless, the regional disparities in these rates, and the potential links between crippling rate, levels of crop damage, attitudes, and hunting behaviors, present intriguing avenues for future exploration.

Keywords: animal welfare, *Anser*, goose, hunting, pellets, shotgun, waterfowl

Introduction

In many parts of the world waterfowl populations have been hunted for centuries and managed for decades (Nichols et al. 2007, Green and Elmberg 2014). Beyond immediate mortality, hunting can impact fitness by spread and later ingestion of lead, leading to poisoning as well as crippling and wounding. If vital organs remain largely unaffected

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when shot, shotgun pellets that penetrate the skin and tissues without causing immediate death can become embedded in body tissue. This can lead to long-term effects on body condition, reproduction, and survival (Madsen and Noer 1996), thereby potentially having adverse effects also on population development (Noer and Madsen 1996, Noer et al. 2007). In addition, wounded birds may suffer from pain and distress, hence this issue is also an ethical and animal-welfare concern (Noer et al. 2007). Consequently, crippling due to shotgun hunting has been an important issue in waterfowl management for a long time (Elder 1950, Jönsson et al. 1985).

Assessing the proportion of living birds carrying shotgun pellets is a possible way to quantify crippling impacts. Even though this excludes information from birds that were wounded and subsequently died without being recovered, it provides a minimum estimate of crippling rate. This is typically done in waterfowl by x-raying individual birds to detect imbedded pellets (Elder 1950, Noer and Madsen 1996). Several studies have assessed crippling rates in a wide range of waterfowl species and populations, finding rates ranging from zero to more than 60% (Hicklin and Barrow 2004, Mateo et al. 2007, Newth et al. 2011). As evidenced by previous research, significant disparities in crippling rate are observed among various waterfowl species and populations globally. These disparities can be attributed to several factors (Hicklin and Barrow 2004, Falk et al. 2006, Clausen et al. 2017). Larger-bodied species with longer lifespans tend to exhibit higher crippling rates (Buij et al. unpubl.); and, for instance, studies of European goose populations indicate a high incidence of crippling rate (ranging between 13 and 62%) compared to other smaller waterfowl species (Jönsson et al. 1985, Noer and Madsen 1996, Mateo et al. 2007, Holm and Madsen 2013). Additionally, increased harvest rate increases the likelihood of crippling (Noer et al. 2007, Clausen et al. 2017). The proficiency of hunters, including their shooting performance, ability to estimate distance, and choice of ammunition also plays a crucial role in this variation (Noer et al. 2007, Clausen et al. 2017).

As migration strategy, hunting practices, and harvest rate can vary among subpopulations (Liljebäck et al. 2021, Månsson et al. 2022), crippling rate can be expected to vary at finer spatial resolution than on flyway and management unit levels. In species with an extensive distribution range, it is crucial to study crippling rate at various spatial scales to understand mechanisms contributing to the observed variation. This will guide management in prioritizing regions in which to enhance awareness and implementing measures to reduce crippling. Such measures could include training programs and initiatives to foster ethical awareness among hunters (Noer et al. 2007). One of the most well-studied European waterfowl populations in this respect is the Svalbard-breeding pink-footed goose *Anser brachyrhynchus*, in which crippling rates measured over time have permitted evaluation of awareness campaigns and training among hunters (Madsen and Noer 1996, Noer and Madsen 1996, Madsen and Rigét 2007, Clausen et al. 2017). Subsequent reductions in crippling rate were observed after application of such campaigns, a result ascribed to changes in hunters' behavior and performance (Noer et al. 2007).

The greylag goose *Anser anser* is an important quarry species subject to long-term hunting, but there have been surprisingly few studies of crippling rate (Mateo et al. 2007). It is a predominantly migratory species across its wide Holarctic distribution range (Powolny et al. 2018). The European population has increased from ~ 100 000 individuals to approximately one million individuals from 1980 to 2020 (Fox and Madsen 2017, Fox and Leafloor 2018, Powolny et al. 2018). This increase has led to ecosystem disservices, notably increased crop damage, but also other conflicts with human interests (e.g. air safety, littering), and consequently a need to manage population size (Bradbeer et al. 2017, Buij et al. 2017, Bakker et al. 2018, Powolny et al. 2018, Montràs-Janer et al. 2019). Concurrently, there has been a rise in derogation shooting, aimed at mitigating crop damage (Månsson 2017, Powolny et al. 2018), which may also affect crippling level. Therefore, it is important to obtain information on the current level of crippling and to monitor how a potential increase in culling affects the level.

Disentangling the origin of crippling can be challenging in migratory species such as greylag goose, since they move over large areas, due to their potentially long lifespan, and because individuals breeding in different regions may mix at staging and wintering sites. To increase the understanding of crippling rate, we caught, examined, and x-rayed greylag geese during the breeding season, in three spatially distinct regions in Sweden, with similar migration patterns and shared wintering areas (Månsson et al. 2022, Nilsson et al. 2022). We aimed to determine 1) overall crippling rate of greylag geese breeding in Sweden, 2) possible variation in crippling rate within the Swedish breeding population, and 3) to initiate a discussion about possible mechanisms behind any regional differences in crippling rate.

Material and methods

Catch sites, regions, and studied subpopulations

Three capture sites, Hudiksvall, Örebro, and Nyköping, in three different regions (the counties Gävleborg, Örebro, and Södermanland) of Sweden were used in this study (Fig. 1, Table 1). Based on telemetry and resighting data of banded birds these subpopulations show very little exchange (Månsson et al. 2022). However, all three have a similar migration pattern and spatial distribution during the non-breeding season. They arrive at their breeding areas in April and migrate southwestwards to Denmark, Germany, and the Netherlands in early October (Månsson et al. 2022, Nilsson et al. 2022). Wintering greylag geese are rarely seen in our study areas, and then only during mild winters. The proportion of time spent in different countries within the flyways is similar among the three studied sub-populations (Månsson et al. 2022).

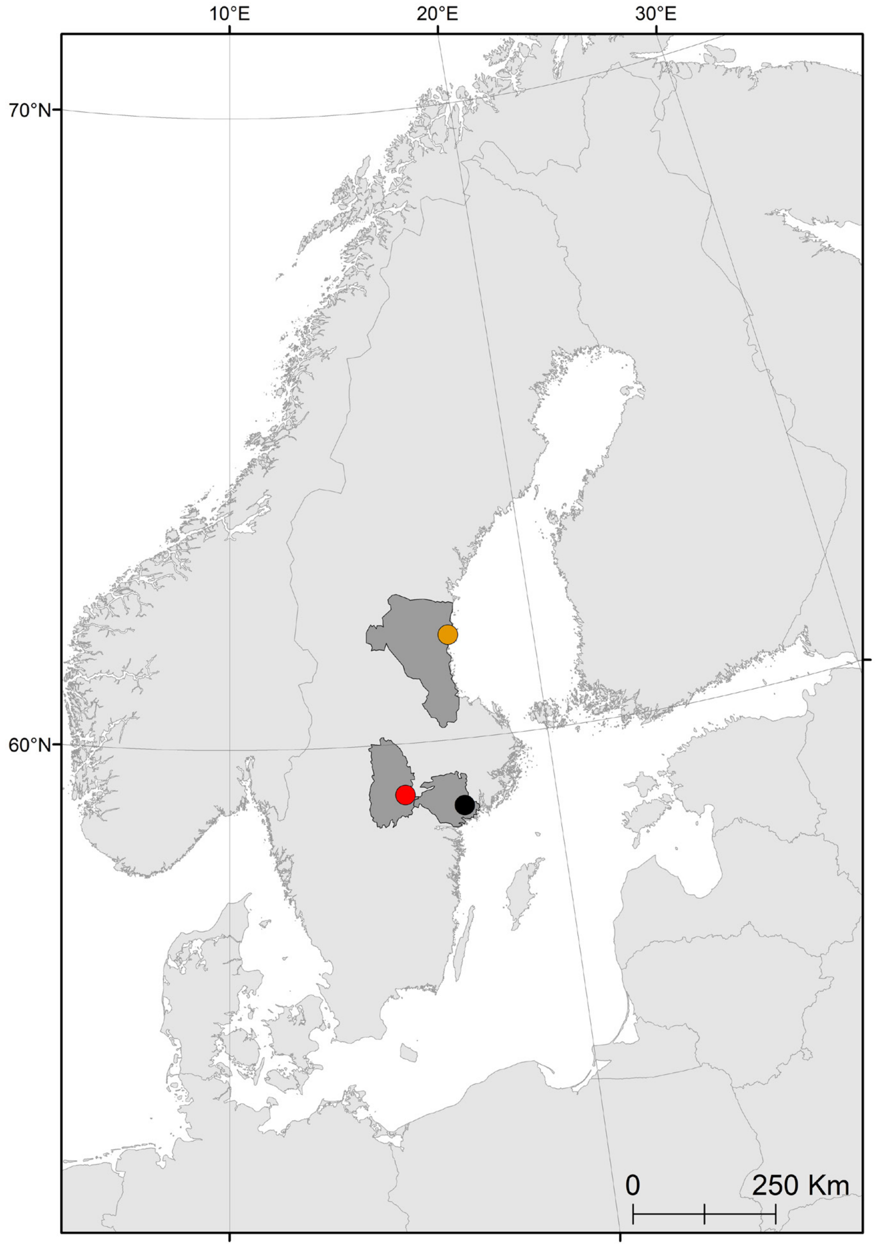

Figure 1. Location of the three catch sites and the regions/counties (shaded); Hudiksvall (orange dot in Gävleborg county), Örebro (red dot in Örebro county), and Nyköping (black dot in Södermanland county).

The Hudiksvall site is an urban wetland surrounded by grasslands and lawns in a city park (61°44′0.1′′N, 17°6′50.1′′E). Hudiksvall is located in the southern boreal zone (Ahti et al. 1968, Hallanaro and Pylvänäinen 2002) and the surrounding region is a mix of forested and agricultural land. The Örebro site includes two wetland reserves (‘Kvismaren’ and ‘Oset’; 59°9′40.0′N, 15°22′50.8′′E and 59°16′0.9′′N, 15°15′53.0′′E, respectively) situated 13 km apart in the transition zone between the southern boreal and boreo-nemoral zones. The area is dominated by agricultural fields and attracts large numbers of greylag geese for breeding, as well as for staging in spring and autumn. The Nyköping site (58°58′17.5′′N, 17°9′07.1′′E) is a wetland surrounded by a patchy landscape of forests, extensively managed grasslands, agricultural fields, and lakes. This wetland is situated in the boreo-nemoral zone. All three sites host a mix of breeding and molting greylag geese; more details of goose numbers and catch sites in Månsson et al. (2022) and Nilsson et al. (2022).

Number of greylag geese, level of crop damage, and hunting pressure vary among the three regions (Montràs-Janer et al. 2019, 2020, Liljebäck et al. 2021; Table 2). The number of greylag geese counted in September (2017–2021) ranged between 104 and 2344 in region Gävleborg; 2250 and 10 115 in Örebro; and 10 267 and 17 043 in Södermanland (Haas, unpubl.; see Table 1 for yearly goose

Table 1. Descriptive data related to the subpopulations of greylag geese *Anser anser* in the three different study regions (counties) surrounding the catch sites (Hudiksvall, Örebro, and Nyköping): 1) total cost (Euros) for compensation for damaged crops, and subsidies for preventive measures for geese, cranes, and swans, 2) number of greylag geese counted in September (N_{count}), and 3) estimated total bag ($N_{harvest}$). Harvest rate (H_{rate}) is the mean harvest during the study period divided by the mean number of birds in September counts. The study was conducted at three sites in three counties in Sweden in 2019, 2021, and 2022.

	Gävleborg (Hudiksvall)				Örebro (Örebro)				Södermanland (Nyköping)			
Year	Cost	N_{count}	$N_{harvest}$	Hrate	Cost	N_{count}	$N_{harvest}$	Hrate	Cost	N_{count}	$N_{harvest}$	Hrate
2019	9364	2296	272		95 909	10 960	401		39 273	11 670	876	
2020	545	2672	301		128 182	6355	227		24 545	12 618	902	
2021	727	2344	224		125 364	2250	233		49 636	10 267	1136	
2022	1091	2250	255		112 273	12 349	233		19 455	12 350	779	
Mean	2932	2391	263	0.11	115 432	7979	274	0.03	33 227	11 726	923	0.08

numbers and a mean value for the study period). The open hunting season in Sweden has lasted from 11 August to 31 December for decades, but it was prolonged to 31 January in 2021. In addition to open hunting, derogation shooting to protect crops from goose grazing has been allowed, regardless of season, since 2009 (Månsson 2017, Montràs-Janer et al. 2019). Annual regional hunting bags are reported to the Swedish Association for Hunting and Wildlife Management (Liljebäck et al. 2021; see Table 1 for yearly harvest during our study period). Estimation of the total harvest, including both open season hunting and derogation shooting, is based on voluntarily reported hunting bag data (Liljebäck et al. 2021). As crippling may depend on harvest rate ('hunting bag' divided by 'population size'; Clausen et al. 2017) and because the number of individuals crippled for each one successfully bagged can provide a relative index of hunter performance (Clausen et al. 2017), we estimated both these indices as part of the study population description (Table 1–2). We used the mean of regional harvest and regional greylag goose numbers counted in September (i.e. autumn staging season) during the study period (2019–2022) to estimate the harvest rate (Table 1). We then used harvest rate to estimate crippling ratio (crippling rate/harvest rate; Table 2).

Catching and x-raying

The primary purpose for catching the greylag geese examined in this study was to ring them and provide them with neckband collars or transmitters to study movement patterns (Månsson et al. 2022, Nilsson et al. 2022, Navarro-Ramos et al. 2024). In June 2019–2022, breeding and molting (flightless) greylag geese were caught when foraging in fields near water. They were herded by foot and canoes towards standing nets and corrals. The birds were kept in gunny bags until further handling. During ringing, geese were aged (juvenile versus adult) based on plumage, and the adult birds were x-rayed for the purpose of the present study. Juveniles were not yet fledged and had not yet been exposed to hunting, hence they were not x-rayed. After ringing, adult birds were again placed in gunny bags and fitted in a plastic box so that they would not move during the x-ray examination.

In total, we x-rayed 176 individuals (Table 2) and they were released immediately after examination. In 2019, 103 geese were x-rayed using a Mars1417V-TSI detector plate from iRay Technology combined with a portable ACOMA PX-15HF. In 2021, 25 were x-rayed using a VIVIX-S 1417N detector combined with a portable Econet Vet20BT x-ray unit. In 2022, 48 individuals were x-rayed using a Sedecal SP-VET-4.0 with Beam device r 72/170A DHHS. The x-ray was set at 50 kW and 3 mAs. Both lead and steel ammunition have been used in Europe over the last 20 years, but stricter rules to restrict the use of lead ammunition have recently been implemented. Due to their density, metals such as lead and steel are easily detectable, regardless of the detector used. All x-ray images were inspected in the field for presence of

Table 2. Number of greylag geese *Anser anser* surveyed ($N_{x\text{-rayed}}$) for tissue-imbedded shotgun pellets, number of individuals carrying imbedded pellets ($N_{crippled}$), proportion of individuals crippled (crippling rate), and and the mean ± stdev. (within brackets) of the number of pellets imbedded per individual carrying pellets ($N_{imbedded}$). The crippling ratio (CR; crippling rate divided by harvest rate – see Table 1) mirrors the number of individuals crippled for each one successfully bagged.

Catch site	County	Year	$N_{x\text{-rayed}}$	$N_{crippled}$	Crippling rate	$N_{imbedded}$	Crippling ratio
Hudiksvall	Gävleborg	2019	60	7	0.12	1.43 (0.79)	1.09
Örebro	Örebro	2019, 2021, 2022	68	18	0.26	3.50 (3.75)	8.67
Nyköping	Södermanland	2019, 2021	48	12	0.25	2.08 (1.24)	3.13
All	Grand mean	2019, 2021, 2022	176	37	0.21	2.64 (2.82)	3.18

shotgun pellets. All detected pellets were found embedded, and none were found in digestive organs, including the gizzard, which indicates no recent ingestion of pellets. The clarity of bones, tissues, and the metal ring in these images was verified to ensure that any pellets would be detectable. If clarity was deemed insufficient for pellet detection, a new image was taken. Occurrence and number of pellets were noted for each x-rayed bird (Table 1).

Statistics

We used a logistic regression model to estimate the probability of crippling (the probability of occurrence of one or more imbedded shotgun pellets) across the three different regions. Region was added as a categorical and independent variable in the model. All analyses were performed using R ver. 4.2.2 (www.r-project.org), and results were considered statistically significant at $p < 0.05$.

Results

Overall, 21% of the 176 inspected greylag geese were carrying imbedded pellets (mean 2.33, range 1–16; Table 2). Crippling rate was twice as high in Örebro and Nyköping compared to the rate in Hudiksvall (Fig. 2). However, the probability of being crippled differed significantly only between Nyköping and Hudiksvall ($p = 0.04$; Table 2), not between Örebro and Hudiksvall ($p = 0.08$; Table 2) or between Nyköping and Örebro ($p = 0.86$; Table 2–3). The

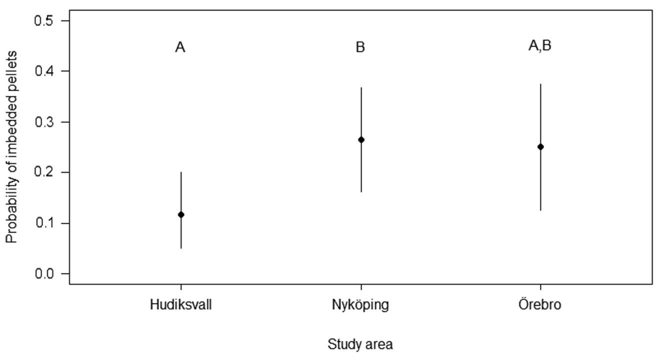

Figure 2. Probability (mean and 95% confidence interval) of carrying imbedded pellets (occurrence) in greylag geese *Anser anser* originating in three regions (subpopulations) in southern Sweden. Different letters indicate statistically significant differences ($p < 0.05$) based on pairwise comparisons (Table 2).

relative difference in crippling ratio was even larger than the difference in crippling rate, being eight times higher in Örebro compared to Hudiksvall and three times higher in Nyköping compared to Hudiksvall (Table 2).

Discussion

In this study we found a relatively high crippling rate in adult greylag geese (21%) but also variation among the subpopulations. Variation in crippling rate has previously been demonstrated over time and between populations and flyways, but rarely at finer spatial scales such as regions or subpopulations. Understanding spatial variation in crippling rate and the possible underlying mechanisms can help management in prioritizing regions in which to enhance awareness and implementing measures reducing crippling.

There are few previous studies available about crippling rate in greylag geese. A study of wintering greylag geese in southern Spain reported a crippling rate of 20% in birds trapped in 1994–2004 (a mix of adults and juveniles; Mateo et al. 2007). Similar crippling rates have been found in pink-footed geese surveyed in recent years (declining trend from 36% among adults in 1992 to 20% in 2015; Clausen et al. 2017). There are also studies showing both higher (bean goose *Anser fabalis* 60% in Sweden 1978–1979) and lower crippling rates (barnacle goose *Branta leucopsis* 13% in the Russian/Baltic population investigated in Denmark 2009 and 2011; Holm and Madsen 2013). Greylag goose, pink-footed goose, and bean goose have all long been subject to open hunting, whereas the barnacle goose cannot be hunted within the EU (according to the EU Bird Directive). This may explain the difference in crippling rate among these species. Barnacle geese may still be hunted in Russia, though, and crippled during derogation shooting in the EU countries. Even if our data and other crippling studies on waterfowl in Europe indicate lower crippling rates today compared to 30–40 years ago (Clausen et al. 2017, Liljebäck et al. 2023), one out of five adult greylag

Table 3. Parameter estimates and SE of logistic regression predicting the effect of study site (subpopulation) on occurrence of imbedded shotgun pellets in x-rayed greylag geese *Anser anser*. The categorical estimates are in comparison to the intercept (Hudiksvall).

	Estimate	SE	z-value	Pr(>|z|)
Intercept	−2.02	0.40	−5.03	< 0.001
Nyköping	1.00	0.49	2.06	0.040
Örebro	0.93	0.52	1.77	0.076

geese (present study) and pink-footed geese (Clausen et al. 2017) still carry imbedded shotgun pellets.

A previous study has shown that campaigns, e.g. by promoting ethical awareness among hunters and/or developing training programs, have decreased the crippling rate in a population of pink-footed geese (Clausen et al. 2017). However, unlike the management strategies for pink-footed geese, management of the European greylag goose population is divided among several distinct populations, or management units. The latter are defined based on the geographical origin of geese and their migration patterns (Bacon et al. 2019). The European population of greylag geese also covers a wider distribution range and embraces many more countries than is the case for pink-footed geese (Madsen et al. 2017, Powolny et al. 2018). In parallel with the rapid population growth of greylag geese in Europe, prolonged hunting seasons and possibilities for derogation shooting have been implemented with the intention to prevent crop damage and conservation conflicts. However, even though recent goals have been set to halt population growth, there are still indications that present harvest levels do not prevent a continued population increase of greylag geese (Powolny et al. 2018; Liljebäck et al. 2021). As the harvest increases, so does the likelihood of a higher crippling rate, assuming that hunter performance remains the same (Clausen et al. 2017). It is therefore crucial to gain a deeper understanding of how current and future management strategies may influence crippling rates. It is essential to ascertain whether there is a need for measures to mitigate crippling, and whether this need varies across different regions as indicated by the present study.

Confounding factors affecting our data prevent us from delving deeper into the underlying mechanisms, possibly leading to differences in crippling rate among the regions. As a case in point, imbedded pellets are the result of a cumulative hunting effect over the lifetime of each individual. Also, the age of geese at the time of x-raying is unknown. Furthermore, it is unclear how regional differences in harvest rate, for example (Table 1), actually relate to crippling risk in individual birds. We therefore did not include these factors in the analysis. Nevertheless, there are some interesting aspects that may shed light on the needs for further research. Given that the sub-populations in our study exhibit similar migration patterns and wintering habits in terms of timing and areas used (Månsson et al. 2022, Nilsson et al. 2022), it is plausible that the differences in crippling rate may be attributed to variation in local hunting practices (i.e. close to the capture sites), such as harvest rate and hunters' performance (Clausen et al. 2017). As shown in previous studies, crippling rate is expected to be positively related to harvest rate (Clausen et al. 2017). However, the harvest rate seems to be higher in Hudiksvall (our data suggest 8–10 times higher than in Örebro and Nyköping; Table 1), which is the region with the lowest crippling rate. Furthermore, the relative index of individuals crippled per each successfully bagged bird, mirrored by the crippling ratio (Table 2), was also by far the lowest in Hudiksvall. One plausible explanation for the variation in crippling rate among the subpopulations may therefore be differences in behavior or performance among hunters. We speculate that variation among the regions in crop damage by greylag geese may be correlated to differences in performance of hunters (Montràs-Janer et al. 2020; Table 1). For example, extensive crop damage may diminish farmers' perceived ability to influence the situation and hence reduce tolerance towards geese (Eriksson et al. 2022). This may in turn affect ethical considerations during hunting, e.g. shooting at birds flying too fast or at too great a distance.

The above reasoning is speculative. To draw any conclusions for future research and management about mechanisms behind the observed regional differences, better resolution of data is needed. For example, it is necessary to know when individuals become crippled, i.e. repeated x-ray examinations are needed, preferably of birds of known age, such as those marked as juveniles. Furthermore, knowledge about each individual's migration and staging patterns is required to estimate the risk in terms of hunting pressure for each individual. Moreover, a hunting bag system that differentiates between open hunting shooting, lethal scaring (during open season), and derogation shooting is needed to interpret the purpose of the shooting and possible emotions behind it. In this context, social–ecological studies are also needed to learn more about potential differences in the perception of geese and hunting experiences among farmers and hunters involved in shooting.

As previously mentioned, our study cannot pinpoint mechanisms behind the observed regional variations in crippling. Despite this, the results show that it is important to highlight the crippling rate at different geographical scales, as it is an obvious challenge for management. Future research should be aware of regional differences (one cannot simply x-ray in one site for a general picture of crippling rate over larger areas) and management needs to recognize that different areas may require different priorities to reduce crippling (for example, education and/or conflict mitigation measures). We recommend that future research initiatives delve deeper into these aspects. Understanding such potential relationships could improve strategies aimed at reducing crippling during hunting.

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Permits – Handling of birds and x-raying were done according to permits from the Animal Ethics Committee of Central Sweden (no. 5.8.18–03584/2017).

Author contributions

Johan Månsson: Conceptualization (equal); Data curation (equal); Formal analysis (lead); Funding acquisition (lead); Investigation (equal); Methodology (equal); Project administration (lead); Resources (equal); Writing – original draft (lead); Writing – review and editing (lead). **Niklas Liljebäck**: Conceptualization (equal); Data curation (equal); Funding acquisition (supporting); Investigation (lead); Resources (equal); Writing – review and editing (equal). **Ralph Buij**: Resources (supporting); Writing – review and editing (equal). **Sander Moonen**: Investigation (supporting); Writing – review and editing (equal). **Johan Elmberg**: Funding acquisition (equal); Investigation (supporting); Project administration (supporting); Resources (equal); Writing – review and editing (equal).

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Data availability statement

Data are available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.63xsj3vbg (Månsson et al. 2024).

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