Geese grazing grasslands

Managing the impact of geese on agricultural grassland

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Publication date
2023

Chapter 1

General introduction

From mice to elephants, wildlife often comes into conflict with humans. This is not surprising, as the growing human population keeps encroaching on natural habitat, resulting in habitat loss and fragmentation. In the last 60 years agricultural land has increased by nearly 2 million km^2, taking up over 40% of the earth's land surface (Winkler et al., 2021). When natural areas are inadequate to sustain wild populations, animals may have no choice but to forage on cultivated land. However, even when there is enough natural habitat, some wild herbivores may prefer to forage on agricultural land (Bleier et al., 2012). To many species, this cultivated land represents an attractive foraging habitat, with highly nutritious food readily available (Fox & Abraham, 2017; Fox & Madsen, 2017; Nilsson, 2017; Watve et al., 2016), and some species have been able to thrive and increase in number by utilizing this new habitat (Fox & Abraham, 2017). Unfortunately, this leads to conflict with farmers, since wild herbivores grazing on agricultural land can cause substantial damage to crops, with subsequent economic losses (Bleier et al., 2012; Conover & Kania, 1995; Düttmann et al., 2023; Hofman-Kaminska & Kowalczyk, 2012; Koffijberg et al., 2017; Montràs-Janer et al., 2019; Schley et al., 2008; Watve et al., 2016).

Half a century ago goose species were decreasing in number as a consequence of habitat destruction and degradation, and hunting pressures (Fox et al., 2017; Fox & Madsen, 2017). However, the switch to forage on agricultural land combined with hunting regulations allowed not only recovery but exponential growth in many species (Ebbinge, 1991; Eichhorn et al., 2012; Fox & Abraham, 2017; Fox & Madsen, 2017). While this can be considered a great conservation success, it in turn poses new conservation issues. For 18 out of 25 recognized goose populations, increasing population size is now leading to increasing societal conflicts ("Outcomes of the International Conference 'Goose Management: Challenges 2015,'" 2015).

When a population has grown to such an extent that they threaten ecosystem functioning or survival of humans, favored species, or the species itself, they may be considered overabundant (Alisauskas et al., 2011). Much like humans, an overabundance of geese has been related to habitat degradation, population decline in vulnerable species, decreases in local biodiversity and increases in emissions of greenhouse gasses, both in (sub) arctic (Abraham et al., 2005; Buij et al., 2017; Pedersen, Speed, et al., 2013; Pedersen, Tombre, et al., 2013; Peterson et al., 2014; van der Wal et al., 2007) and temperate regions (E. S. Bakker et al., 2018; Buij et al., 2017; Demarchi, 2006; Taylor & Kirby, 1990). Population sizes of snow geese (*Chen caerulescens*) and Ross's geese (*Chen rossii*) have grown to such an extent that management efforts to reduce their number appear ineffective (Alisauskas et al., 2011; Calvert et al., 2017), but these are not the only goose species that may negatively affect their environment due to their large numbers (E. S. Bakker et al., 2018; Buij et al., 2017; Pedersen, Speed, et al., 2013; Pedersen, Tombre, et al., 2013).

Addressing the problems posed by geese can be challenging, considering these are migratory species that where once rapidly declining. To add to this challenge, several goose species have changed their migration pattern. Pink-footed geese (*Anser brachyrhynchus*) are starting their migration earlier, spending more time in stopover sites (Bauer, Gienapp, et al., 2008; Bauer, van Dinther, et al., 2008). Barnacle geese (*Branta leucopsis*) migrating to Svalbard started using more northward stopover sites (Tombre et al., 2019), while part of the population migrating to the Russian arctic have extended their stay in wintering areas and skip their traditional stopovers in the Baltic (Eichhorn et al., 2009; Jonker, Eichhorn, Langevelde, et al., 2010). To ensure that survival of these species does not become a conservation concern again, management actions should be well justified and based on sound scientific research. It is also important to consider not only the local impact of management approaches, but also effects that may continue into different regions. For example, hunting and scaring may result in a local reduction in farmer-goose conflict, but may also aggravate the effects on a larger scale and shift the problem to a different region (Bauer et al., 2018; Klaassen et al., 2006).

In 2012 the first international species management plan (ISSMP) was developed for the management of the Svalbard population of pink-footed geese (Madsen et al., 2017), followed by ISSMP's for the barnacle goose, greylag goose (*Anser anser*) and taiga bean goose (*Anser fabalis fabalis*) in the subsequent decade. However, there are still a lot of questions and ongoing discussions regarding the impact of geese on their environment and effective goose management. In this thesis I address some of these questions, focussing on the management and impact of geese on agricultural grasslands. I will use the Barnacle goose as focal species, which is one of the most abundant species in Northern Europe. The aim is to improve the scientific basis for goose management, allowing more effective measures to be implemented, without causing unnecessary harm to wild geese. The following sections introduce a number of potential management approaches, give an overview of current questions and research gaps, and sketch the outline of this thesis.

1.1 Management options

Different management approaches can be utilized to reduce the impact of geese on agriculture and/or in natural areas, each with its own considerations and questions. In this thesis I address three methods that have been applied to geese in an agricultural setting: active population management, scaring and accommodation, and compensation payments.

Active population management. Here the aim is to maintain the population between a lower and upper threshold, with the lower well above the minimal viable population size (Madsen et al., 2012, 2017). This combines population reduction through hunting or other means (e.g. catching or trapping and killing) with close monitoring of changes in population size. Culling (the selective killing of a number of animals to reduce their number) of geese to reduce agricultural damage can also lead to conflict between farmers and nature conservation organizations (Mason et al., 2018). Furthermore, for species which are strictly protected, such as the red-listed barnacle goose, such measures are legally not allowed. However, even when not legally prohibited, the potential effectiveness of such measures should be clearly demonstrated and supported by scientific research. To justify such management, it needs to be clear that a reduction in the number of geese will also reduce the impact geese have on their environment. We thus need to understand the relationship between grazing pressure and the impact on the environment.

Scaring and accommodation. Also called *go-no-go* strategies, this is a combination of two management approaches, where potential foraging habitat is divided into scaring areas and refuges (Eythórsson et al., 2017; Koffijberg et al., 2017; Percival et al., 1997; Tombre et al., 2005; J. A. Vickery & Summers, 1992). In the scaring areas geese are actively chased away, for example by approaching the geese, shining a laser across a field, making loud noises, or by (licensed) shooting at the geese (called derogation shooting). The goal is to teach the geese that these areas are dangerous and should be avoided. The refuges form alternative habitat, where they can safely forage. Refuges can be created in natural areas, but also on agricultural land, where we refer to them as accommodation areas. This management effectively tries to influence the *landscape of fear* of geese, which is discussed more extensively in box 1.1. There can be different reasons to implement scaring and accommodation, for example to reduce risks of airplane collisions, protect areas with sensitive crops or species, reduce farmer-wildlife conflict, simplify compensation schemes (discussed below), or to reduce the overall impact on agriculture.

As with active population control, management through scaring and accommodation aims to change goose grazing pressures, with decreases in scaring areas and increases in accommodation areas. This again raises questions on the relationship between goose abundance and their impact on their environment. To determine whether the overall impact may be reduced, we need to know what the effect is of foraging in higher densities. We also need to consider temporal patterns in grazing activity. Geese may be present only part of the year, can switch between habitats (Bos et al., 2008; Madsen et al., 2021; Mckay et al., 1994; Pot et al., 2019; Prins & Ydenberg, 1985), and flock densities may change throughout the wintering period (Bos et al., 2004). Scaring could influence such temporal grazing patterns, especially when limited to a specific period. A final important consideration is the size, quality and location of refuge areas (Baveco et al., 2017). It has been suggested that scaring without adequate refuge area can negatively affect population fitness and survival (R. A. Jensen et al., 2008; Nilsson, 2017). Chasing a goose away repeatedly will increase its energy expenditure and foraging time (Nolet et al., 2016), but with no alternative habitat to move to, the animal will have to continue foraging in the scaring area (J. A. Gill et al., 2001). Rather than reducing the impact of geese, unorganized scaring could thus increase their effect on crops or natural vegetation while negatively influencing goose well-being and population growth.

Compensation schemes. To reduce farmer-goose conflict, compensation payments or subsidies can be provided to farmers experiencing yield losses due to goose grazing (Klaassen et al., 2008; Koffijberg et al., 2017; Montràs-Janer et al., 2019; Simonsen et al., 2017; Tombre et al., 2013; J. A. Vickery et al., 1994). There can be different methods to pay compensation. One approach is to pay a specific subsidy to farmers who allow geese to forage on their land, potentially with different levels reflecting expected goose densities in the area (Tombre et al., 2013). A second approach links compensation directly to yield reductions by geese, assessed after grazing has occurred by comparing grazed and ungrazed areas (Koffijberg et al., 2017). The first approach leads to the same questions on the effect of density and timing of grazing posed for management through scaring and accommodation, which complicate estimates of fair subsidies based on the number of geese present. The second requires an understanding of the effect of grazing on crop development. It has been suggested that the difference in yield loss may change with time since grazing (Groot Bruinderink, 1989; Summers & Stansfield, 1991), which indicates that the timing of damage assessment is very important. Furthermore, it may be difficult to find a suitable ungrazed reference when grazing occurs across a large area. Overall, it is not easy to come to a fair compensation scheme (Fox et al., 2017).

1.2 Current discussions and research gaps

1.2.1 Grazing pressure and yield loss

The first question that might be asked regarding the impact of grazing geese on agricultural grassland, is whether their grazing truly results in yield loss. One reason to question whether yields are truly decreased by goose grazing is the potential for grass to recover its biomass if enough time is available between grazing and harvest (Groot Bruinderink, 1989). Another reason is the ability of geese and ducks to increase their own harvest (Mayhew & Houston, 1999; van der Graaf et al., 2005). Studies in natural systems show that grazing by geese may stimulate continued production of protein rich biomass. It has also been suggested that limited grazing by geese under the right circumstances might stimulate seed production in rye grass (Clark & Jarvis, 1973) and in winter wheat (Clausen et al., 2022; Petkov et al., 2017). Yet it is unclear whether these beneficial effects also translate to a reduced impact on grass biomass harvested for hay or silage. Furthermore, while low grazing pressures under favourable conditions may not reduce winter wheat losses, yield losses have been established with higher grazing pressures, especially under less suitable growing circumstances or at specific stages of crop development (Clausen et al., 2022; Kahl & Samson, 1984; Petkov et al., 2017; Summers, 1990; Wallin & Milberg, 1995). Quite a number of studies have established negative effects of goose grazing on grassland harvest (Bedard et al., 1986; Bergjord Olsen et al., 2017; Bjerke et al., 2013, 2021; Colhoun & Day, 2002; Conover, 1988; Groot Bruinderink, 1989; Mayhew & Houston, 1999; Montràs-Janer et al., 2019; Patton & Frame, 1981; Percival & Houston, 1992; Summers & Stansfield, 1991) illustrating that a reduction in grassland yields can indeed follow from goose grazing.

A subsequent question is how the amount of yield loss changes with goose grazing pressure (Fox et al., 2017). The effect of different aspects of grazing on grassland yields has been studied in a number of exclosure studies (Bedard et al., 1986; Bjerke et al., 2013, 2021; Colhoun & Day, 2002; Conover, 1988; Groot Bruinderink, 1989; Mayhew & Houston, 1999; Olsen et al., 2017; Patton & Frame, 1981; Percival & Houston, 1992; Summers & Stansfield, 1991). In these studies grass height or biomass is measured inside and outside of fenced areas or cages meant to prevent goose grazing. Several studies related the difference between these treatments to goose grazing pressure, established either through goose counts or using dropping densities (Bedard et al., 1986; Bjerke et al., 2021; Colhoun & Day, 2002; Groot Bruinderink, 1989; Olsen et al., 2017; Percival & Houston, 1992; Summers & Stansfield, 1991). Dropping densities are considered a good representation of the grazing pressure, since geese produce droppings at a regular interval of 3 to 5 minutes (Owen, 1971; Prop & Spaans, 2004).

These studies generally find that higher grazing pressures result in larger yield loss, though some were unable to find a significant correlation (Bjerke et al., 2021; Groot Bruinderink, 1989). This may be attributed to low overall grazing pressures or variation in weather conditions and field quality. Few of these exclosures studies address the shape of the relationship, though some suggest that there may be a threshold density, below which the effect on yield is negligible (Bjerke et al., 2021; Olsen et al., 2017). Furthermore, there are some indications of a non-linear relationship. A study relating yearly goose counts and assessed damages in Sweden found a non-linear relationship for barnacle geese, where damages increase more slowly at higher grazing pressures (Montràs-Janer et al., 2019). However, this relationship did not hold when correcting for trends over time. It thus remains unclear how yield loss changes with goose numbers or grazing pressure.

1.2.2 Factors influencing yield loss

The amount of yield loss associated with goose grazing on agricultural grassland appears to depend on a number of other factors. These can be external, such as the grass species, soil type, climate, and weather conditions (Bjerke et al., 2021; Fox et al., 2017; Merkens et al., 2012; Olsen et al., 2017; Percival & Houston, 1992), but can also be directly related to the process of grazing. For example, different temporal aspects of grazing have been found to relate to the amount of yield loss. A higher frequency of grazing may stimulate more biomass production than a single grazing event (Fox et al., 1998), autumn grazing appears to cause less damage than spring grazing (Fox et al., 2017), and yield losses may decrease, provided enough recovery time between the moment of grazing and harvest (Groot Bruinderink, 1989). However, while some studies have looked at these aspects individually, there has been no direct study of their interaction. Furthermore, we do not know how these effects change with the number of grazing geese.

In addition to the temporal patterns of grazing, there may also be differences between species that can influence their effect on grassland yields. Geese differ in their migration patterns and preferred foraging habitat. Due to differences in bill size, small goose species such as brent geese (*Branta bernicla*) have a higher food intake rate on short grass compared to larger species, such as the greylag goose (Baveco et al., 2011; Durant et al., 2003). The larger goose species prefer taller grass, and can also digest more fibre rich grass species such as reed (E. S. Bakker et al., 2018). They may also be more likely to forage on other agricultural crops or harvest remains, such as beets or tubers (Nilsson & Persson, 2000). There are also differences in temporal grazing patterns between goose species, with pink-footed geese spending more time at stopover sites (Bauer, Gienapp, et al., 2008; Bauer, van Dinther, et al., 2008), barnacle geese extending their stay in the wintering areas (Düttmann et al., 2023), brent geese aggregating in large numbers in spring time (Bos et al., 2004) or greylag geese moving to natural habitat in spring to breed (E. S. Bakker et al., 2018; Kleijn et al., 2012). Overall, we need a better understanding of the impact of the intensity and timing of grazing on yield loss, as well as how this impact may differ between species.

1.2.3 Effect of scaring on goose behaviour

In addition to questions about the effect of grazing on grassland yields, there are also questions about the effect of management on goose behaviour. Several studies show that on a small scale, scaring can reduce grazing pressures in specific locations or at specific times (Evans & Day, 2002; Fox & Madsen, 1997; Frederick et al., 1987; Heim et al., 2022; Madsen, 2001b; Månsson, 2017; Simonsen et al., 2016; J. A. Vickery & Summers, 1992). However, whether it can also work on a large scale remains questionable. Scaring and accommodation has been implemented in different regions, with varying effects. In Scotland, grazing pressures could be reduced in some areas, but not in others (Percival et al., 1997). A study in New Mexico suggested that a small percentage of geese might be convinced to continue migration earlier than usual by well-timed scaring practices (Taylor & Kirby, 1990). In the Netherlands there was no effect of scaring efforts on the distribution of geese across scaring and accommodation areas (Koffijberg et al., 2017), and in Denmark scaring twice a day could not reduce yield loss on winter wheat fields when grazing occurred in winter and spring, but a decrease was observed when grazing was limited to the winter period (Clausen et al., 2022).

There are different reasons why scaring and accommodation may fail to change grazing pressures. One has already been mentioned: when there is not enough alternative foraging habitat, geese have no choice but to continue grazing in scaring areas. Alternatively, it may not be clear to geese which areas are safe, and which are not. Scaring needs to be well organized and occur frequently for geese to perceive an area as dangerous (Koffijberg et al., 2017). An experimental study found that scaring only decreased grazing pressures on a field when repeated more than twice a day (Simonsen et al., 2016). The difference in perceived predation risk between scaring and refuge areas can also become smaller if there is more natural predation or accidental human disturbance in the refuge areas. It has been suggested that increased natural predation in Baltic stopover sites contributed to a longer stay of barnacle geese in wintering areas (Jonker, Eichhorn, van Langevelde, et al., 2010). Furthermore, even when not aiming to scare, frequent recreational or agricultural activity can result in a high perceived predation risks by animals (Frid & Dill, 2002). Bélanger and Bédard (1989) found that frequent unintentional disturbance could almost half the number of greater snow geese (*Anser caerulescens atlanticus*) present the next day. Finally, there may be edge effects on the borders between scaring and accommodation areas, reducing the amount of habitat perceived as 'safe' (Koffijberg et al., 2017). This is especially problematic when accommodation areas are small and irregularly shaped.

A better understanding of the scaring intensity and the amount of refuge area needed to effectively change grazing pressures is crucial to effective goose management. Some modelling work has already been done to allow estimates of the required amount and optimal location of accommodation areas (Baveco et al., 2011, 2017). However, we still lack a good understanding of the effect of scaring on a larger scale. Furthermore, the scaring intensity and size of refuge area may interact, with scaring being more effective when more alternative habitat is available. There are also questions regarding the potential increase in energy expenditure by geese following scaring. Geese may need to forage more due to scaring efforts (Béchet, Giroux, & Gauthier, 2004; Bélanger & Bédard, 1990; Frederick et al., 1987; Nolet et al., 2016). which could potentially increase overall agricultural damage.

There are also costs involved in management through scaring and accommodation. In one study the cost of hiring someone to chase geese from a field did not weigh up against the decrease in yield loss (Percival et al., 1997), though another study did find it could be cost-effective (J. A. Vickery & Summers, 1992). Other studies make reference to the costs of different scaring practices, though do not weigh these against the potential benefits (Heim et al., 2022; Simonsen et al., 2016). However, overall there is little reference to the cost associated with different scaring methods. Similarly, there can be costs involved in appraising agricultural damages and maintaining accommodation areas. Some compensation schemes also increase in cost with the size of the accommodation areas, such as offering subsidies that are not dependent on the amount of yield loss (Tombre et al., 2013). To determine the effectiveness of scaring and accommodation as a management practice, such costs should be taken into account.

1.3 Thesis outline

This thesis has been divided into two parts, in which some of the above research gaps are addressed. In the first part of this thesis I focus on the impact of geese on spring yields of agricultural grassland. **Chapter 2** provides a review of existing theory and terminology on the effects of biomass removal on plant development. It examines different mechanisms that allow plants to compensate loss of biomass, and identifies different factors that are likely to affect the amount of yield loss that may follow biomass reductions. **Chapter 3** and **4** address the relationship between goose grazing pressure and spring yield losses on agricultural grassland. In **chapter 3** we estimated grazing pressures in accommodation areas in Fryslân, the Netherlands, using existing data from detailed monthly goose counts, gathered by Sovon (the Dutch Centre for Field Ornithology), which we linked to reports on assessed damages from BIJ12 (who handle compensations for fauna damages in the Netherlands) using GPS-data collected for this study and from several earlier projects. This allowed us to determine the relationship between goose numbers and assessed yield losses for different goose species, namely the barnacle goose (*Branta leucopsis)*, white-fronted goose (*Anser albifrons*) and greylag goose (*Anser anser*). Furthermore, we examined differences and interactions between these different goose species. **Chapter 4** describes an exclosure study on intensively managed grassland fields with a gradient of grazing pressures, conducted in Fryslân. Goose grazing was prevented in two exclusion treatments, from November or from early April until the first harvest. Two weekly grass development in spring was compared between the exclosure treatments and grazed plots, and related to grazing pressures established on a two weekly basis through dropping counts. This allowed us not only to look at the shape of the relationship between grazing pressure and potential yield loss, but also to account for certain temporal aspects of grazing.

The second part addresses how management through scaring and accommodation can affect goose behaviour and subsequently spring yield losses on agricultural grassland. **Chapter 5** presents an individual/agent-based model, simulating foraging behaviour of barnacle geese on grassland in Fryslân under different scaring intensities and accommodation area sizes. We parameterized the model using field observations and GPS-data, using detailed monthly goose counts for validation. The model allows evaluation of the effect of different management scenarios on goose survival and their impact on agricultural grassland, both in terms of the number of fields affected by grazing and the amount of yield loss which can be expected. It places these results in light of the potential costs associated with the management scenario, allowing estimates of the potential cost-effectiveness of different combinations of scaring intensity and accommodation area size.

In the **chapter 6** I bring together the different theories developed in the preceding chapters, to come to a more complete picture of how geese can affect agricultural grassland yields and how management may reduce the conflict between farmers and geese. Furthermore, the discussion of the different chapters will lead to new hypotheses and directions for future study.

Box 1.1 Theories on predation risk

Management through scaring and accommodation is an attempt to influence the foraging behaviour of geese by increasing the risk which they experience in an area (the *perceived predation risk*). The perceived predation risk is not necessarily a reflection of the true risk of getting killed; there are many non-lethal factors that may influence the risk which an animal experiences. Furthermore, the decision to forage in an area is not only affected by the perceived risks, but also by the expected gains (Bednekoff, 2007; Brown & Kotler, 2004; Gaynor et al., 2019). Understanding these different factors is key to understanding how scaring and accommodation may be employed to influence the distribution of geese. Here I discuss some theories on predation risk to provide further background to the general discussions in this thesis.

Defining disturbance

A key concept in this box is ‘disturbance’. It is therefore important to start out with clarifying what I mean with this term. There are several different definitions possible. What they have in common is that disturbance is some type of event or activity that deviates from the normal order. For Fox and Madsen (1997) this event only included human activity, where the effect was the disruption of normal activity or distribution of an animal. Riddington et al. (1996) had a much broader definition, considering any event that alters ecosystem, community or population structure or available resources. Here I will use the term in a similar way to Bélanger and Bédard (1989, 1990): anything that can lead to a response of alarm in geese. The thing leading to the response is the source of a disturbance, and can be natural or anthropogenic. Geese can express alarm in different ways, ranging from simply looking up to flying back to their roost.

Encounter, attack and capture

To a goose, each disturbance it experiences could be a potential predation attempt. However, to fly away at every little disturbance caries a hefty cost in terms of energy spent and foraging opportunity lost (Brown & Kotler, 2004; Díaz et al., 2013). It is therefore important for the animal to assess the danger associated with disturbance and balance the need for safety with the need for food.

Bednekoff (2007) describes three stages in any predation attempt: encounter, attack and capture. To be certain of evading any predation attempt, an animal could attempt to avoid encountering predators, by choosing a foraging location where the risk of encounter is low. The probability of encounter can be estimated based on signs that indicate the presence of a predator (Bednekoff, 2007). If such signs occur more frequently, the probability of an encounter is also larger. The high prevalence of signs of human activity on agricultural land may increase the perceived predation risk associated with agricultural land. Animals can also learn were predation risks are higher through direct experience, namely by surviving an encounter with a predator. Since geese forage in flocks, a large number of them will generally survive an attack by a predator, and will subsequently learn about the risk in an area. Geese avoid areas were tourism is high (Stock, 1992), and several studies have found that geese can learn to avoid areas during the hours in which hunting is allowed (Béchet, Giroux, & Gauthier, 2004; Madsen & Fox, 1995; Owens, 1977).

In addition to predation risk, there are several other factors that influence the choice of foraging location, such as the quality or availability of food, and these may push an animal to forage in more risky environments (Gaynor et al., 2019). In these situations emphasis shifts to avoiding attack once encounter occurs. One way to achieve this is to remain more alert in areas with a higher chance of encountering a predator (Bednekoff, 2007). Geese have been found to change their behaviour in response to increased hunting by increasing vigilance and taking off at a much larger distance from disturbance (Béchet, Giroux, & Gauthier, 2004; Madsen & Fox, 1995; Owens, 1977). Furthermore Owens (1977) found that simply approaching geese several times over the course of an hour would lead them to respond much quicker the second and third time.

However, in a human dominated landscape there are many disturbances, each of which may represent a potential attack. A goose cannot afford to respond to all of these and needs to determine the risk of attack associated with the disturbance. One way to do this is by differentiating between different sources of disturbance. Geese are more sensitive to some disturbances such as sounds of motorized vehicles or guns (Bélanger & Bédard, 1989; Kölzsch et al., 2022), likely because these are associated with hunting. Snow geese were also found to respond significantly stronger to purposeful disturbance compared to accidental disturbance (Béchet, Giroux, & Gauthier, 2004; Bélanger & Bédard, 1990). Both brent geese and snow geese were found to give a longer response to the presence of eagles compared to other sources of disturbance (Davis & Wiseley, 1974; D. H. Ward et al., 1994). Furthermore geese can habituate to some types of disturbance that are not aimed at them, such as trains or even shooting sounds from military practice or factories (Owens, 1977).

Another way to avoid attacks from occurring is by ensuring predation risks can be detected at a larger distance, allowing a response before an attack occurs. Bednekoff (2007) mentions habitat structure and distance to safety as possible factors in this. Geese appear to prefer larger fields, which may provide a better view of oncoming predators (J. A. Gill, 1996; McKay et al., 1996; Rosin et al., 2012; J. Vickery & Gill, 1999), though not all studies find this (Merkens et al., 2012). They are more likely to use fields with some elevation (McKay et al., 1996; Rosin et al., 2012), avoid landscape structures that might obstruct predator detection (McKay et al., 1996; Rosin et al., 2012), and prefer fields closer to bodies of water, which represents safety against many types of predators (McKay et al., 1996; Rosin et al., 2012). When predator detection is limited due to weather conditions such as fog or heavy rain, geese have also been found to respond more quickly to disturbances (Bélanger & Bédard, 1989, 1990).

Once an attack occurs, an animal may still have a chance to escape, provided it can make a fast escape. Grazing on open grassland fields or wide mudflats, safety for a goose in the face of predation is in the air or on the water. The most important factor for its escape will generally be how fast it can get into the air and fly away. Anything that might influence this is likely to also influence how long a goose will wait before responding to disturbance. Taking flight will be more difficult under certain weather conditions such as heavy wind or rain, which have indeed been found to impact the response of geese to disturbance (Bélanger & Bédard, 1989, 1990; Blumstein, 2006). In addition, the body condition of a bird is relevant. High weights may hamper take off and thus increase predation risk to a bird (Bednekoff, 2007; Blumstein, 2006; Witter & Cuthill, 1993). When in a worse body condition, taking flight may be more difficult, but an animal will also have a higher need to forage, and may not respond to disturbance as soon (Beale & Monaghan, 2004; J. A. Gill, 2007).

Landscape of fear and management

The avoidance of encounter, attack and capture are related to the theory of the landscape of fear (Laundre et al., 2010). The landscape of fear of an individual or population can be described as a cognitive map overlaying the true landscape, with regions of low and high perceived predation risk (Gaynor et al., 2019). The peaks in the landscape of fear are areas where animals expect a high chance of encounter and attack, and where the chance of escape is lower. The valleys of the landscape of fear represent safer areas, where either the risk of encounter and attack is low, or it is relatively easy to escape if a predator appears. For geese the landscape of fear is likely influenced by natural predation risk on the one hand, and human disturbance and hunting on the other hand. Which disturbances occur, and how often, presents information about the risk of encounter and attack, and thus have an important role in forming the landscape of fear of geese. Escaping capture is mainly influenced by physical characteristics that limit view or hamper take off. The distance to the roost or another safe body of water can also play a role, provided these represent a safe, disturbance free environment. The relative importance of these different factors in determining the landscape of fear of geese likely varies between regions and between species.

We would generally expect animals to avoid the areas where they expect the highest predation risk. To prevent capture, animals need to be more vigilant when spending time in these areas, which lowers their foraging efficiency (Laundre et al., 2010). Furthermore, less energy is spend on digestion and stress levels are higher, as the animal needs to be ready to respond to a potential treat as soon as it occurs (Laundré et al., 2014). The response to disturbance also poses costs. The diet of geese is low in nutrients and hard to digest, thus requiring them to spend most of the day foraging (Owens, 1977; Riddington et al., 1996). Disturbance can cut into this foraging time, forcing geese to forage longer in order to compensate. Furthermore, disturbance leads to increased flight, which uses a lot of energy. This needs to be compensated by further increasing foraging time (Béchet, Giroux, & Gauthier, 2004; Bélanger & Bédard, 1990; Nolet et al., 2016; Riddington et al., 1996). Thus, increasing the perceived predation risk in an area through active scaring seems like a viable management option.

However, the choice of foraging location is not only influenced by perceived risk, but also by the expected gain and the need to forage (Gaynor et al., 2019). If food is of higher quality, more easily accessed or available in higher densities, an animal can achieve higher intake rates, and this may offset the costs of vigilance and disturbance (Brown & Kotler, 2004; Laundre et al., 2010). Animals in a worse body condition have a higher need to forage, which may force them to accept higher risks (Brown & Kotler, 2004; J. A. Gill, 2007). This will also cause them to spend less time on anti-predator behaviour, and will make them more difficult to chase away (Brown & Kotler, 2004; J. A. Gill, 2007). Geese may have a high need to forage at certain times of the year, such as mid to late winter, when daylight is limited and food availability low (Lameris et al., 2021; Tinkler et al., 2009), or in spring, when they need to build up fat-reserves for migration and reproduction (Lameris et al., 2021; Madsen, 2001a). The effect of scaring thus depends not only on factors influencing risk, but also on food availability and energetic requirements.