Master's Thesis

Use of drones as a potential tool for managing conflicts with large grazing bird populations in agricultural landscapes

for attainment of the academic degree Master of Science (M.Sc.)

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Course of Study: Sustainable Resource Management

Contents

Abstract

Recent decades have seen substantial growth in goose populations throughout Europe and North America brought about by advances in agriculture and warming global temperatures. Superabundant goose flocks can cause wide-spread crop damage on farm fields due to grazing and foraging, creating the need for new research focused on improved management and mitigation methods. Current solutions are generally labor intensive, lack long term effectiveness, cause unintended disturbances, or provoke controversy in the public eye. This study aims to investigate the potential for drones as a new scaring tool that can remedy these management issues and help agricultural land owners address the escalation of wildlife conflict with geese and other large grazing waterfowl. The experimental design makes a comparative analysis between the effectiveness of drones and a previously well-established scaring technique that employs walking human bird-scarers. Differences in flight initiation distance (FID) and reductions in goose presence after a scaring event were examined in two separate Swedish populations at Lake Hornborgasjön and Kvismaren Nature Reserve. FID data at each location varied, with drones exhibiting significantly lower efficacy at Hornborgasjön, but comparatively similar effectiveness at Kvismaren. Drones also performed on par with walking in reducing goose presence after a scaring event at Kvismaren. The results suggest that location, previous exposure, and frequency of use could have an impact on efficiency of drones as a scaring device. However, due to promising outcomes at Kvismaren Nature Reserve, drones warrant continued research and development to identify additional methods of implementation that could strengthen their effectiveness as a management tool.

Chapter 1: Introduction

1.1 History of Conflict

In many parts of the world, wild birds offer a great many benefits and provide important resources for food, clothing, subsistence, fuel, medicine, fertilizer and cultural significance (Macmillan & Leader-Williams, 2008). Industrial and post-industrial societies increasingly value these animals for contributions to our well-being in terms of recreational activities, such as bird watching and hunting (Macmillan & Leader-Williams, 2008). However during the first half of the 20th century, Europe and North America saw catastrophic declines in many wildfowl species, including geese, due to over exploitation and economic development of wetland habitats across the continent (Fox & Madsen, 2017).

In the 1950s, this radically changed when research and legislative efforts sought to avoid the collapse of entire populations of threatened species (Fox & Madsen, 2017). Although decades of protective measures saw resounding success in conservation endeavors of many previously endangered large grazing birds, there are situations where this achievement has cultivated conflict. Superabundant flocks bring with them a plethora of problems that include damage to natural vegetation, risk to aircraft safety, and eutrophication via nutrient transfer to aquatic ecosystems (Bradbeer et al., 2017; Buij et al., 2017; Dessborn et al., 2016; Fox & Madsen, 2017; Hessen et al., 2017; Tulloch et al., 2017).

Perhaps the most significant conflict related to superabundant populations of waterfowl concerns wide-spread crop damage on agricultural lands due to grazing and foraging. The nature of this conflict and its associated costs often falls on relatively small groups of society in rural areas and can heavily impact livelihoods that rely on agricultural production (Macmillan & Leader-Williams, 2008). Geese in particular have been at the forefront of this wildlife conflict in recent decades. Farmers increasingly clash with geese as modern agricultural methods continue to develop new techniques that allow for improved livestock pastureland and higher yield cereal crops (Patterson, 1991). However, it is this advancement in farming practices -- combined with protective legislation, restoration of wetlands/protected areas, and climate change -- that have caused the problem to intensify throughout Europe and North America as populations of many goose species have dramatically increased in recent decades (Fox & Madsen, 2017; Patterson, 1991).

When migrating, geese and other large grazing birds group together in considerable numbers at staging sites along flyways, which are often located near agricultural areas close to protected wetlands (Jankowiak et al., 2015; Jensen et al., 2008; Kleijn et al., 2014; Lovisa Nilsson et al., 2016; Vegvari & Tar, 2002). The wetlands are used as roosting sites at night, while the surrounding farms are easily accessible foraging grounds during the day (Jankowiak et al., 2015; Jensen et al., 2008; Lovisa Nilsson, 2016). Today's agricultural landscapes offer geese ideal foraging conditions, as the nutrient and energy content of crops are as good or even superior to natural foods and tend to be available in far greater abundance and accessibility (Fox & Abraham, 2017). This creates a multifaceted challenge with mitigating damage to crops while concurrently managing stability of both the conservation area, and potentially, multiple species with varying population levels and degrees of protected status (Lovisa Nilsson, 2016; Redpath et al., 2013; Singh & Milner-Gulland, 2011).

1.2 Study Species: Greylag Goose *Anser anser*

Greylag goose (*Anser anser*) has a wide breeding distrubtion from Iceland to the eastern coast of Asia (L. Nilsson & Persson, 1994). Breeding populations in Europe are primarily located in the central and northern countries, and migration patterns of Nordic greylag geese have been studied by means of neck-collaring/banding throughout Norway, Sweden, Denmark and Finland since the 1980's (Andersson et al., 2001; Pellegrino et al., 2015). In southern and central Sweden, neck-banding has formed an integral basis for various studies involving greylag breeding ecology, population dynamics, habitat selection and wing moult (Leif Nilsson, 2018). Traditional migration routes used to bring most of the geese to southern Spain during winters after staging in the Netherlands. However recent years have seen a higher proportion of the population wintering further north (i.e. Germany and the Netherlands) and spending a shorter period of time away from breeding areas in Sweden and the rest of Scandanavia (Leif Nilsson, 2018). Higher average winter temperatures caused by climate change probably explain this increasing tendency for geese to winter closer to breeding grounds (Pellegrino et al., 2015).

Because greylag geese are no longer required travel such vast distances to arrive at suitable wintering grounds, they are now spending greater periods of time in fewer locations along flyways. This phenomenon exacerabtes conflict scenarios with agricultural landowners that must bear the burden of shifting migration routes. Previously, crop damage was spread out over multiple countries at numerous staging sites, whereas now it is highly concentrated in a few select areas.

1.3 Population Status

Estimating populations of migrating birds involves intensive monitoring programs, with many hours of human labor undertaken largely by networks of experienced volunteers and supplemented by relatively few professionals (Fox et al., 2010). Because of the mobile nature of these species, there are often short windows of time to obtain accurate counts of large populations spread out over extensive areas. Systematic counting of geese did not begin in Europe until around the 1950s, emphasizing the importance of considering limitations of historical population data for making inferences about legitimate changes in abundance (Fox & Madsen, 2017). Even with this lack of historical context, marking and monitoring programs initiated over the latter half of last century show that the majority of goose populations across western and northern Europe have increased dramatically over the last several decades (Fox et al., 2010; Fox & Madsen, 2017; Leif Nilsson & Haas, 2016).

Swedish surveys reveal that all goose species except the Lesser White-fronted Goose *Anser erythropus* and Bean Goose *Anser fabalis* have increased since national counts were introduced in the 1970s (Haas & Nilsson, 2019; Hake et al., 2010). Greylag goose *Anser anser* populations (Figure 1) grew more than twelvefold (20,000 to 250,000) from 1984-2017 (Haas, F. & Nilsson, 2019; Hake et al., 2010). The substantial rise in Swedish (and European wide) goose populations have resulted in a parallel increase in conflicts between the birds and farmers (Hake et al., 2010).

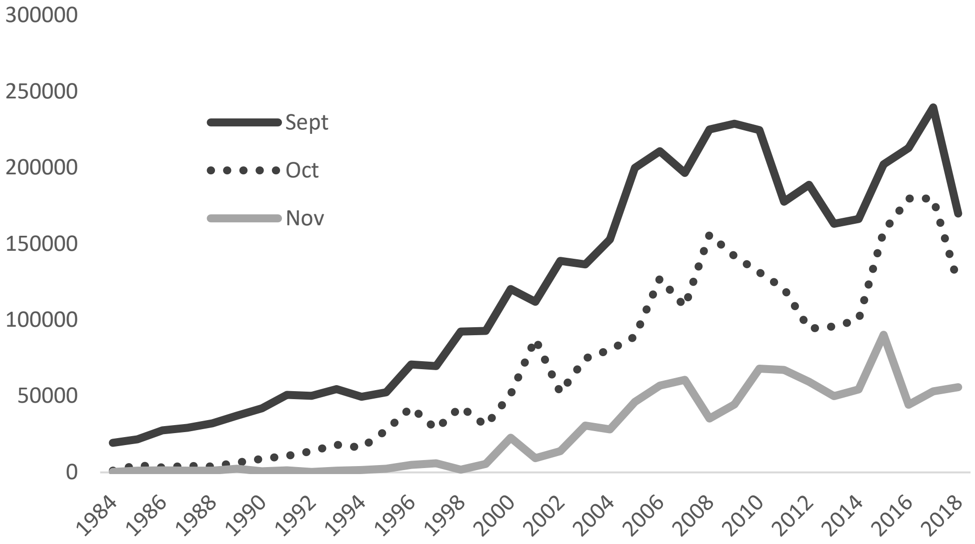


Figure 1. Annual greylag goose population numbers taken from September to November each year in Sweden 1984-2018 (data adapted from Haas and Nilsson 2019).

1.4 Crop Damage

In agricultural landscapes, geese primarily forage on grasslands used for hay production and newly sprouted cereal fields (Amano et al., 2007; Lovisa Nilsson, 2016). As populations of geese and other waterfowl increase, so have the costs for harvest losses, government compensation prorams, and preventative mesasures (Frank et al., 2016; Lovisa Nilsson, 2016). In 1995, the Swedish government developed a system to compensate farmers for crop damage induced by large grazingbirds (Montràs-Janer et al., 2019). Agricultural land owners can report harvest losses to local County Administrative Boards and receive assistance in estimating damage values, although there are likely many losses that go unreported (Lovisa Nilsson, 2016). Despite this, in 2015 the Swedish government reported over €800,000 in total costs resulting from large grazing bird damages (Figure 2).

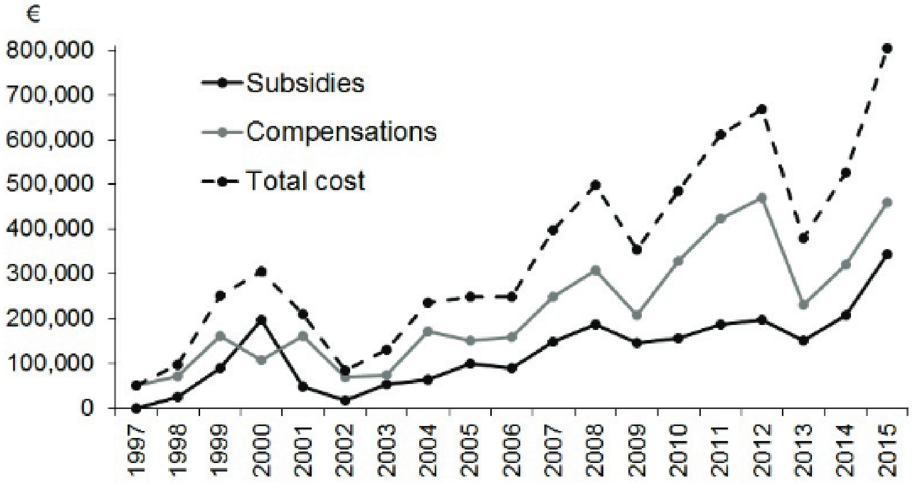


Figure 2. Compensation and subsidies paid for crop losses and damage prevention measures caused by geese, cranes and whooper swans in Sweden from 1997-2015 (graph sourced from Lovisa Nilsson 2016, original data from Frank, Månsson, and Zetterberg 2016).

1.5 Management Tools

Prevention of crop damage against geese and other waterfowl falls primarily into three categories: 1) use of scaring devices that create visual and/or audible stimuli 2) providing "sacrificial" fields for the birds as alternative feeding areas away from economically sensitive crops or 3) lethal scaring (i.e. shooting some of the birds foraging on crops) (Månsson, 2017; Simonsen et al., 2017). Utilizing a combination of these methods to form a "push/pull" strategy that aims to scare birds off vulnerable fields, and towards alternative feeding areas where they can graze undisturbed has become a model approach (Hake et al., 2010; Månsson, 2017).

1.5.1 Scaring Devices

The wide variety of scaring devices available to agricultural land owners can be animal activated (i.e. via motion or thermal sensors), random, or set at periodc time intervals (Gilsdorf et al., 2002; K. A. Steen et al., 2014; Kim Arild Steen et al., 2015). Research and development of new scaring devices is primarily driven by efforts to reduce habituation – the process by which animals adjust to and ignore new sounds, sights and smells over time (Gilsdorf et al., 2002). Multiple studies indicate that animals tend to habituate to external stimuli after relatively short periods (Gilsdorf et al., 2002; Nolte, 1999). The presence or use of novel items with audible and visual stimuli does aid in deterring wildlife, but can quickly lose effectiveness after only a few days unless the device/method is paired with negative reinforcement (Gilsdorf et al., 2002; Koehler et al., 1990; Nolte, 1999).

Continued efforts to counteract habituation effects of scaring devices can be seen in the extensive assortment of options available to agricultural land owners. A 2002 review paper from Gilsdorf, Hygnstrom, and VerCauteren compiled comprehensive reviews of the most common scaring device types employed by farmers in conflict with large grazing bird populations, which includes:

Pyrotechnics (fireworks)

These consist of bird bangers, shell crackers and screamers. Effectiveness varies with frequency of harassment, and primary disadvantages of this method involve high costs, potential for public disruption, and the need for a human operator.

Gas Exploders

One of the most common scaring devices used by farmers, these cannon-like tools use propane-powered gas guns to produce periodic explosions over 150 decibels loud that mimic the noise of a 12-gauge shotgun. A drawback could be disturbance of non-target animals and nearby residents.

Reflective Objects

When strung and twisted between posts, strips of reflective tape with red and silver colors on opposing sides (mylar ribbons) reflect sunlight and create a slight buzzing noise in the wind. White plastic flags also have reflective features and make a flapping noise, generating a similar combination of effects. This mix of light reflection and noise-making properties can prove to be effective deterrents for short periods, but lose efficacy in as little as a few days.

Alarm/Distress Calls (bioacoustics)

Audio devices that create avian alarm and distress calls warning other birds nearby danger is present, which typically causes them to flee or reduces the liklihood of landing on a field in the surrounding area. This mechanism is typically combined with other methods to maximize effectiveness (i.e. pyrotechnics), however by itself results can be varied.

Effigies

Scarecrows, inflatable pop-up man, and predator mimicking devices (i.e. hawk or owl shaped kites) can provide visual deterrents that reduce bird presence. These can also be combined with audible stimuli to increase effectiveness, but tend to decline in potency if left unmoved for several days.

1.5.2 Sacrificial Fields

There is evidence that intensive disturbance of foraging geese and other large grazing waterfowl might actually escalate the amount of crop damage, as birds will need to offset caloric deficits from reduced grazing time and increased energy expenditure from flying (Fox et al., 2016; Nolet et al., 2016). This is paritcularly true in agricultural areas that have transformed surrounding wetlands into farmland, thereby reducing the encompassing habitat size and natural foraging capacity for many species (McKay et al., 2001, 1996; Rowell & Robinson, 2004). With few other nearby options, the birds might risk returning to the same sites and forage at increased rates despite continued deterrence efforts. A solution to this issue is the creation of alternative feeding areas, or "sacrificial fields“, by modifying existing habitat space.

Food grown within sacrificial fields is intended to draw individuals away from economically valuable crops (Wood et al., 2014). Sowing different plant species and varieties can be used to manipulate quantity and quality of food within alternative feeding areas to target and attract specific species based on foraging preferences (Wood et al., 2014). The effectiveness of this method is maximized when combined with scaring devices to "push“ birds off important fields and "pull“ onto sacrifical areas with enticing alternative foraging options (Hake et al., 2010; McKay et al., 1996; Rowell & Robinson, 2004). Additionally, this management method is popular with special interest groups as it reduces risk of harming species that carry legally protected status with minimal disruption of natural feeding patterns (Wood et al., 2014).

1.5.3 Lethal Scaring

Lethal scaring aims to prevent harvest losses by shooting some of the birds foraging on crops, thereby creating a deterrent effect on the remainder of the flock (Månsson, 2017). This method differs from culling a specific species to reduce population or hunting during open season, as the objective is solely to prevent damage and reinforce the effects of non-lethal scaring measures (Conover, 2002; Månsson, 2017). Lethal scaring is allowed year round for some species (i.e. greylag goose *Anser anser* and Canada goose *Branta canadensis*) if they are not legally protected and known to cause crop damage (Månsson, 2017). For other species, there are a variety of restrictions ranging from full protection where landowners always need to apply for permission to perform lethal scaring; to specific seasons and sites when and where authorization to shoot is approved without need for a license (Månsson, 2017).

While this management method has proven effective at the local level, it can actually aggravate and shift the conflict to other sites further along the migratory flyway (Bauer et al., 2018). A 2018 study used behavior-based migration models to analyze consequences of hunting and lethal scaring at single or multiple locations along a flyway and found that intensive use of these methods at one location can cause an increase in consumption and crop damage in agricultural areas at later stages on the migration route as birds attempt to compensate for energy losses due to excessive disturabance (Bauer et al., 2018). There is also the added risk of incidental harm to a protected bird, as it is not uncommon for foraging flocks to contain multiple species grouped together on the same field. Accordingly, the ramifications of lethal scaring on migratory bird species are still not entirely understood and considered one of the more controversial management tools when dealing with conflict situations.

1.6 A New Type of Scaring Device

As technology becomes an increasingly vital component in nearly all aspects of agriculture, harnessing the growth and transformative potential of new developments in this area offers immense opportunities for addressing challenges imposed by climate change and growing world populations (Sylvester, 2018). Over the last decade, drones have seen a rapid rise in development and their popularization in both the consumer and commercial sectors. Agriculture in particular has embraced the possibilities of this versatile technology as a tool for evidence-based planning and spatial data collection (Sylvester, 2018). Applications include soil health scans, crop health monitoring, irrigation planning, fertilizer treatment, weather analysis, and yield data estimation – market value worth an approximate USD 32.4 billion (Sylvester, 2018).

Drones also offer capacity as a new tool for regulating large grazing bird populations in agricultural areas. Current solutions for minimizing crop grazing damage all have one primary deficiency – habituation effects after repeated expsoure over relatively short periods of time. Exploration of new techniques that prevent or negate this eventuality are urgently needed. The aerial mobility of drones that very closely simulate natural predatory threats (i.e. hawk or eagle) combined with continued advances in technology could finally provide practical solutions to the problem of habituation.

Additionally, traditional scaring devices include potential for excessive audible disturbance of locals and non-target wildlife. Drones present a relatively "low noise“ solution when compared to pyrotechnics, gas exploders, and alarm calls. This innovative concept would provide a long range scaring device capable of covering vast distances with minimal time, effort and cost.

1.7 Research Questions and Objectives

The goal of this research is to make a comparative analysis between drones and a previously well established scaring technique that employs walking human bird-scarers to assess the effectiveness of drones as potential scaring devices. There is currently little to no scientific research or evidence analyzing the efficacy of such a method. Primary research questions considered by this study are: 1) Do drones and walking differ in regards to effectiveness in scaring geese off farm fields? 2) Can drones be used as a tool to manage problem populations? Secondary research questions include: 3) How quickly do geese habituate for each method? 4) Do external and environmental factors impact effectiveness for either tehnique? 5) Do goose behavioral responses differ by region? 5) What are implications for management? These research questions will be addressed by pursuing the following objectives:

- Measure the difference in flight initiation distance and reductions in goose presence after scaring events for drone and walking
- Measure the impact of exposure/frequency, time, field location, flock size, starting distance and individual goose behavior on scaring method effectiveness
- Compare the results of field trials between two separate goose populations in different parts of Sweden
- Provide drone effectiveness assessments and recommendations for future research, development, and management plan integration

Chapter 2: Material & Methods

2.1 Study Areas

Field trials were conducted in agricultural areas adjacent to two protected areas in South-Central Sweden: Lake Hornborgasjön Nature Reserve and Kvismaren Nature Reserve from May to August 2019 (Figure 3).

2.1.1 Lake Hornborgasjön Nature Reserve

Lake Hornborgasjön (58°19´N/13°33´E) sits 150 kilometers northeast of Gothenburg in southern Sweden (Figure 4). This nature reserve spans an area of more than 4,000 hectares and consists primarily of the lake itself, the surrounding shore meadows, and part of the agricultural landscape east of the lake (Västra Götaland County Administrative Board, 2019). This agricultural zone is still within the bounds of the protected area, and therefore farmers are not allowed to disturb birds grazing on these fields. However, a government subsidy program reimburses landowners for damages accrued from grazing if property lies within the protected area. The remaining farms, mainly located up and down the eastern shoreline, regularly utilize various disturbance methods to minimize grazing damage to fields.

In January 2002, the county board took over management of Hornborgasjön Nature Reserve from the Swedish Environmental Protection Agency and has since overseen the completion of one of the largest wetland restoration projects in Europe (Västra Götaland County Administrative Board, 2019).

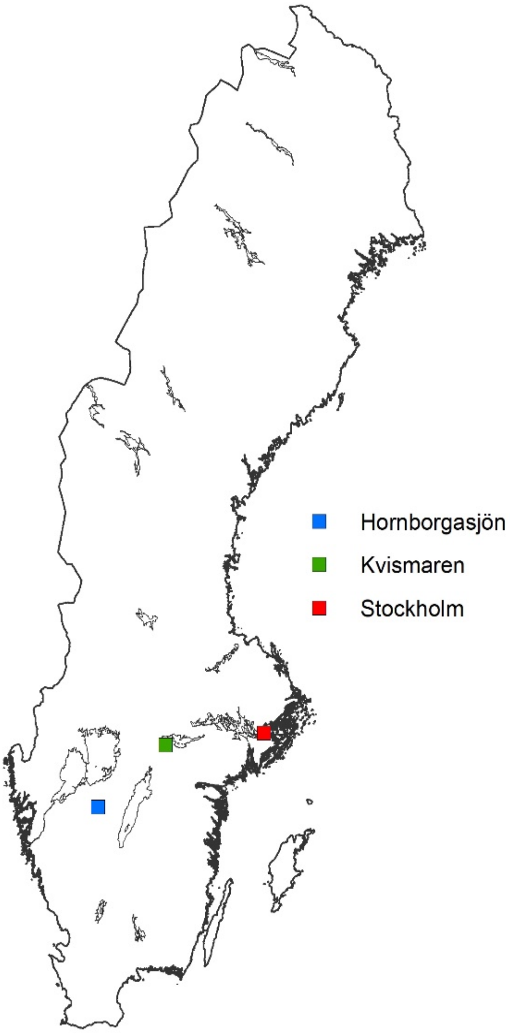


Figure 3. Experimental trials took place at Lake Hornborgasjön Nature Reserve (HNR) and Kvismaren Nature Reserve (KNR) from May to August 2019.

The lake repeatedly lowered, during previous centuries, for agricultural use in the surrounding region. In the 1930's, Hornborgasjön began to transform from a beautiful bird lake into a muddy swamp filled with reeds. Following a decision from the government in the latter half of the 1980's, restoration work began to restore the lake to its former beauty and functionality (Västra Götaland County Administrative Board, 2019). The successful completion of that project has seen birds return to the area in steadily increasing numbers, but bringing with them the grazing conflict with farmers.

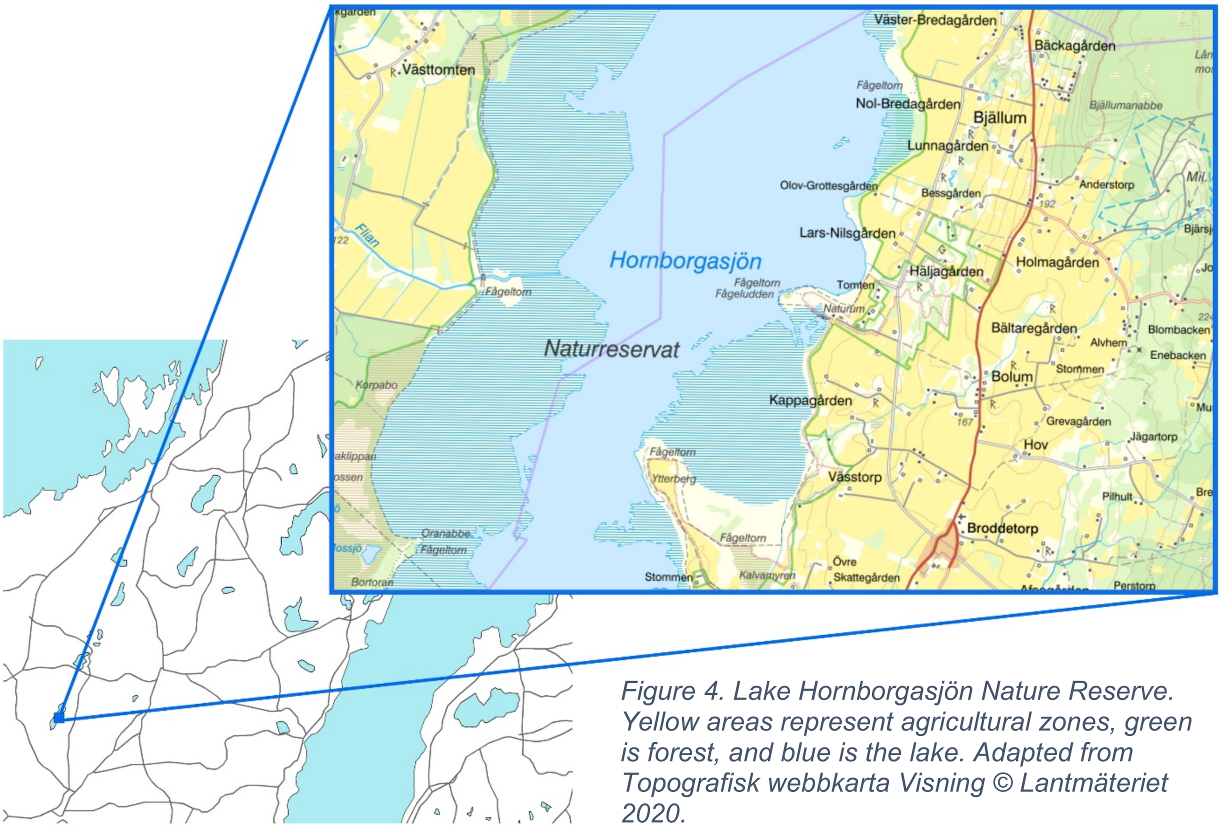


Figure 4. Lake Hornborgasjön Nature Reserve. Yellow areas represent agricultural zones, green is forest, and blue is the lake. Adapted from Topografisk webbkarta Visning © Lantmäteriet 2020.

The reserve itself is an important wetland habitat for over 300 breeding and migrating bird species in the spring and summer months. The Västra Götaland County Administrative Board estimates up to 30,000 cranes arrive in April to rest for 1-2 weeks before traveling north to nesting sites in western Sweden and Norway, creating a major tourist attraction in the area during this time. A 2017 survey estimated around 150 breeding pairs of greylag geese nest on the lake, and from May until July an additional 22,000 greylag migrated to the lake during wing molt season (Västra Götaland County Administrative Board, 2018). This combination of abundant migrating waterfowl in spring and summer months, and the proximity of the reserve to nearby agricultural areas has created an intense conflict between the birds and local farmers.

Agricultural crops in the area consists mostly of cereal (wheat or barley), and grass for the production of livestock feed. Farms throughout the region included in the field study were chosen by asking permission from local landowners to conduct experimental scaring. Help in locating goose flocks and determining which fields had the highest concentrations of geese was given by Kristian Kroon, the full-time bird scaring consultant for the Västra Götaland County Administrative Board.

2.1.2 Kvismaren Nature Reserve

Established in 1978, Kvismaren Nature Reserve (59°10´N/15°22´E) covers an area of 732 hectares and is situated about 14 kilometers outside the city of Örebro in south-central Sweden (Figure 5). Two shallow, eutrophic lakes (2.5 kilometers apart) surrounded by narrow belts of grazed wetlands comprise the core area of the reserve (Lovisa Nilsson, 2016). The landscape is flat and encompassing farmland (~66%) produces mostly cereals, grass and potatoes (Lovisa Nilsson, 2016). Each year approximately 200 bird species visit the area.

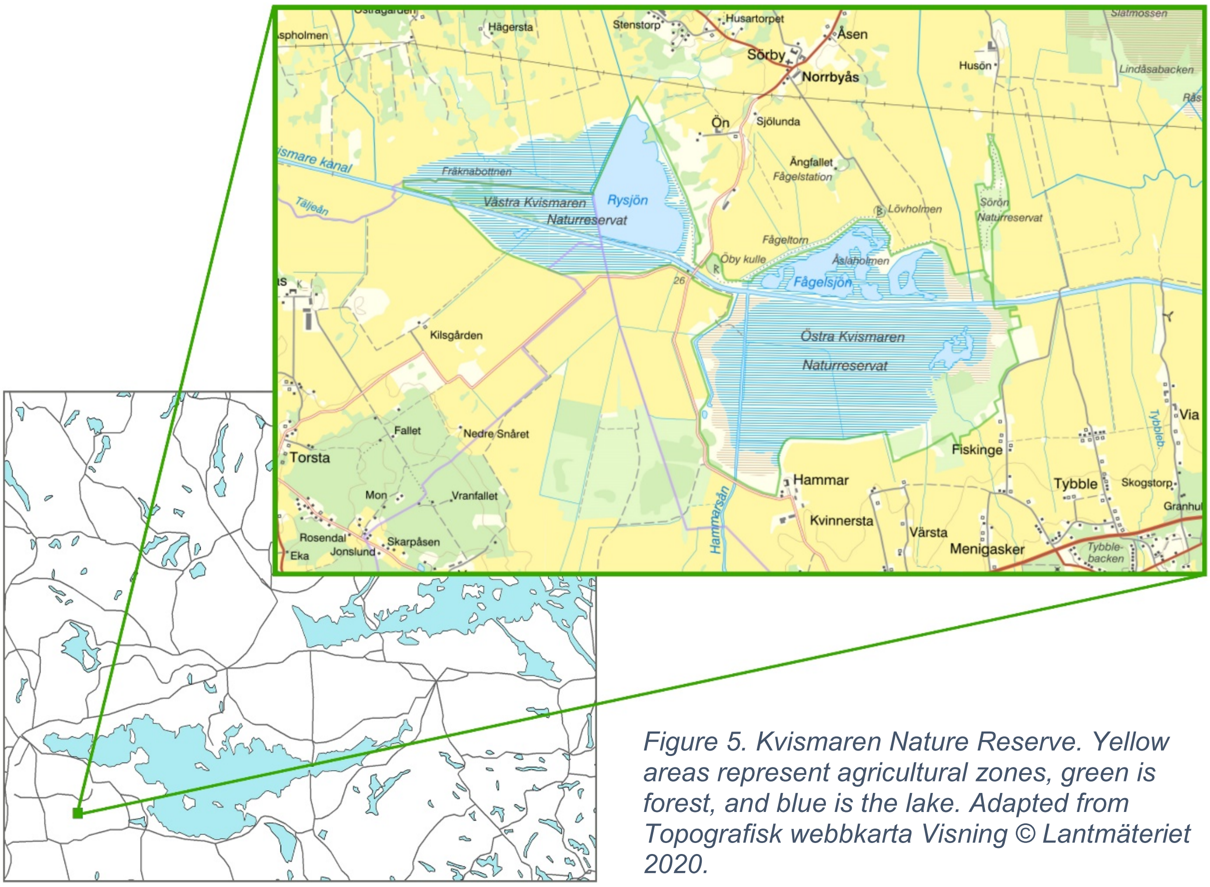


Figure 5. Kvismaren Nature Reserve. Yellow areas represent agricultural zones, green is forest, and blue is the lake. Adapted from Topografisk webbkarta Visning © Lantmäteriet 2020.

Decades of extensive use for agricultural irrigation saw the east and west lakes heavily depleted before the end of the 19th century, after which they slowly started becoming overgrown with common reeds (Örebro County Administrative Board, 2019). In the 1920s, ornithologist Erik Rosenberg discovered the areas rich bird life, and government decisions were made in the 1950s to build an embankment and Kvismare Canal to control the annual floods (Örebro County Administrative Board, 2019). Management measures by the Örebro County Administrative Board have since restored natural ecosystem functioning by removing reeds and regulating water levels to simulate natural variation (Örebro County Administrative Board, 2019).

2.2 Experimental Period

The flight response of greylag geese to both drone and walking scaring methods was measured between May 15, 2019 and August 20, 2019. Over 47 days spent in the field, a total of 25,015 geese were counted. Fieldwork in each location was split into three separate periods. The first period of 67 trials was conducted at HNR between May 15, 2019 and June 4, 2019. This field session began within a week of the arrival of greylag geese to the area and ended at the start of the wing molt period. During wing molt, the birds are flightless and it is not possible to test flight responses. The second field period (post wing molt) consisted of 76 trials and was again at HNR from June 25, 2019 to July 11, 2019. The final 75 trial fieldwork session was between July 23, 2019 and August 20, 2019 at KVR. Drone and walking scaring trials totaled 98 and 97 each for all sites combined.

2.3 Experimental Design

2.3.1 Measuring Effectiveness

A well established method of assessing the efficacy of new scaring devices and management techniques examines the escape behavior, or flight initiation distance (FID), of the target species. FID is defined as the distance between predator and prey at which an animal flees (Kalb et al., 2019). An early anti-predator response can provide prey with a selective advantage, although it comes at the cost of increased energy expenditure and lost foraging opportunities (Møller & Erritzøe, 2014). Consequently, it might be beneficial for prey to assess approaching predators to determine likelihood of attack before fleeing (Møller & Erritzøe, 2014). These responses are primarily associated with perceived predator characteristics and distance to refuge, but can also be influenced by time of day, amount of ground cover, and degree of fitness (Winchell et al., 2020). This behavioral reaction to humans or scaring devices is often used as a proxy to determine effectiveness of a disturbance technique. Longer FID values translate into higher threat levels, and theoretically, a more effective scaring method. For the purposes of this study, a combination of FID measurements and goose presence after a scaring event were used to analyze the efficiency of drones as a management tool.

2.3.2 Field Selection

Field selection in Hornborgasjön and Kvismaren was decided day to day based on the location of the goose flocks. Scaring trials could only be conducted in fields that did not lie within the bounds of the reserve zones. At Hornborgasjön, untagged geese were used in field tests. Prior to beginning the scaring trials, a staff member of the county administrative board provided a tour of farms in the area where flocks were previously seen grazing. The birds would generally have “favorite” fields and return to the same handful of sites, allowing for a pre-determined driving route to be taken daily in order to efficiently locate flocks. However, external factors (ex: crops growing too high, farmers harvesting a field, active scaring and hunting, over grazing, etc…) could cause a flock to discontinue foraging at a particular field. When geese changed sites to a new field, the owners of those farms were generally very quick to notify the county administrative board and ask for assistance in managing the problem population. This allowed for continual daily updates of flock locations and maximized time utilization for scaring trials instead of locating the geese.

Field trials at Kvismaren Nature Reserve allowed for the scaring of GPS collared geese that had been tagged over the last several years. Using a web based software system and iPad, geese could be located in real-time and eliminated the “guesswork” in finding flocks each day based on previous grazing patterns. Flocks at both sites tended to show preference for certain field locations. This was most likely attributed to distance of the field from roost site, crop height/size/type, and environmental factors discouraging the use of alternative fields. Factors might include proximity to heavily trafficked areas, poor visibility of the surrounding area, frequent disruption of grazing from land owners, and field size (Henle et al., 2008).

2.3.3 Scaring Trials

A comparative baseline of previously developed scaring methodology needed to be established in order to evaluate the effectiveness of the drone as a tool for managing grazing goose populations in agricultural settings. It was decided that comparing the scaring efficacy of a human walking in a straight line towards the flock to that of the drone flying at the flock in a straight line would provide the standard for comparative analysis. Success of each method would be measured through testing both flight initiation distance (Hornborgasjön and Kvismaren) and goose presence after a scaring event (Kvismaren). Scaring technique was determined randomly except in special circumstances, such as high winds impeding drone use and fences hindering direct walking routes.

2.3.4 Walking Protocol

After locating a flock from the car general information was recorded (date, time, weather), and the geese were then counted via binoculars and any additional species other than greylag were also noted and totaled. Once flock size was calculated, a one euro coin was flipped to randomly select either walking or drone as the scaring measure. If walking was selected, a straight line from the car to the flock was determined and coordinates were recorded at the start of the walk using a handheld GPS (Start person x y). A compass was used to calculate the walking direction, and then movement towards the flock at a steady, normal walking pace (with no additional activity or sound) began. Walking continued until all birds in the flock had taken off. At this point, a second GPS location was recorded (Stop person x y). Walking then continued in a straight line to the approximate location of the flock before takeoff, and a third GPS point was logged (Take off flock x y). The distance between the second and third GPS coordinates provided the FID. At the flock takeoff location (third GPS coordinate), additional measurements were recorded to account for potential environmental factors and variables, including: wind speed, wind direction, flight direction, crop type and crop height.

2.3.5 Drone Protocol

Field protocol for drone scaring trials followed nearly identical steps as the walking protocol. After taking down general information, counting the geese and flipping a coin for randomized selection of the scaring method, the drone was then placed on the ground in direct line of site of the flock and a GPS location was recorded (Start drone x y). The drone was then piloted vertically to a height of 10 meters and flown directly at the flock in a straight line at normal velocity setting. After the last bird had taken off, the drone was stopped and the GPS location of the drone noted (Stop drone x y). A visual estimation of the flock position before takeoff was noted, and a third and final GPS coordinate at this point was recorded via handheld GPS (Take off flock x y). Final field measurements concluded with documentation of wind speed, wind direction, flight direction, crop type, and crop height. After completing all field trials, geo-location metadata from drone images was obtained via the Opanda IEXIF 2 software program, providing the second GPS measurement (Stop person x/Stop person y) during drone trials. FID was calculated using the distance between the second and third GPS coordinates.

2.3.6 GPS Position Data

A total of 17 GPS tagged (neck collar) greylag geese were included in the experiment at Kvismaren nature reserve. Individual birds were selected each day based on location and frequency of previous scaring attempts. Geese were only scared if they were in agricultural fields outside the bounds of the protected area. A specific goose was not targeted more than once every third day to be able to study behavior of the disturbance over three days, and scaring of birds within visual proximity on the same day was avoided. However, due to the nature of goose grazing behavior, it was extremely difficult to meet this standard and avoid contact with any bird that had been targeted in the previous three days. Individuals that had been scared within this three day window were often foraging in the same flock as the target bird for that particular scaring trial. In several instances, nearly all of the tagged geese could be found grazing in the same flock comprised of up to 1,500 individuals. To account for this in the analysis, non-target tagged geese that grazed in the same flock as the target goose for a specific trial were also recorded during data collection. This allowed for analysis of both “target” and “non-target” scaring frequencies.

Transmitters on the GPS collars were set to position every 5 minutes at least 4 hours before and 4 hours after a scaring trial. This allowed for exact, real-time positioning of geese using the online OrniTrack Control Panel via iPad. Considering GPS collars were solar powered, minimizing power usage on cloudy days by adjusting transmission settings required significant attention to battery levels during fieldwork and strategizing beforehand which individuals would be scaring targets the following day. The number of GPS recordings for each goose was determined by the healthiness of the solar powered batteries in individual collars. While location frequencies were standardized a minimum four hours before and after a scaring event, some devices were older than others, which required a reduction in frequency to maintain power levels outside this specified time period.

A total of 77,855 GPS positions were recorded during the Kvismaren trial period. The average number of total positions two days before and after a scaring event was 541 and 563 respectively with drone trials; for walking 543 and 535. Using protocol established by Johan Månsson (Månsson et al., 2011), inaccurate GPS data without coordinates and dilution of precision >7 (n=255 of 77,855) were excluded from the data set. Analysis included all positions of the target goose two days before and two days after each scaring trial (i.e. five days total). Additionally, only validated positions were indexed and used. Scaring trials at Kvismaren focused on behavioral responses of a target specific, radio collared goose. Therefore it was necessary to obtain exact positioning of the target goose during each scaring attempt. Handheld GPS recordings taken in the field were limited to marking overall flock location and not useful for identifying exact locations of target geese at the time of each trial, as flocks could often be quite large and spread out over a few hundred meters. Esri ArcMap version 10.6.1 was used to isolate the last recorded GPS location of the goose on a given field before the scaring attempt took place. This position identified the "scaring event" and was used as the focal point for spatial analysis.

Figure 6. Buffer zones created around each scaring event were used to group GPS positions for spatial analysis. Positions falling inside the 100, 300, and 500 meter ranges were used in models to predict probability of return within that distance after a scaring trial had taken place. Adapted from Topografisk webbkarta Visning © Lantmäteriet 2020.

Goose positions were derived by measuring the number of GPS recordings of the target goose within a 500 meter radius around the scaring event 48 hours before and after the trial (four days total). 100 meter buffer zones were created around the scaring event (five zones) to analyze probability of return within that distance to account for varying sizes of farms (Figure 6). Average field size of farms (17.2 ha) where scaring trials were conducted was calculated using ArcMap. 100, 300, and 500 meter buffer zones were used in the analysis to represent field areas of 3, 28, and 79 hectares.

2.4 Statistical Methods

Data analysis and statistical models were performed in R version 3.5.3 (R Core Team, 2019) with the 'lme4' (Bates et al., 2015) and 'arm' (Gelman & Su, 2018) packages. All statistical tests used significance level of $p < 0.05$. Random effects were included due to repeated observations ('goose ID' for probability of return and 'field ID' for flight initiation distance). Explanatory variables were tested for correlation using chi-squared tests and top-ranked models were selected based on Akaike Information Criterion (AIC) in accordance with recommendations from Guthery et al. 2003 (Guthery et al., 2003).

2.4.1 Probability of Presence

Linear mixed models with normal distribution error structures and logit link functions were used to analyze probability of goose presence before and after a scaring trial. Response variables, or 'probability of presence', were derived by dividing the number of GPS positions for a target goose in each buffer zone by the total number of positions for the trial. This ratio was used as the response variable to account for variance in the data caused by the differences in battery healthiness of GPS collars. GPS recordings that did not meet criteria for normality were transformed (x+1) when zeros were present in the data set (Zuur et al., 2010). The calculated response variable value was increased proportionally. Explanatory variables included 'scaring technique', 'scaring exposure', 'time' (before/after scaring event), the interaction between 'time' and 'scaring technique', and 'goose ID' as a random factor (Table 1). After model simulations, inverse logit functions were used to derive probability of goose presence within a given distance of the scaring event before a trial commenced; and after drone and walking scaring trials respectively.

Table 1. Description of explanatory variables included in the linear mixed models for predicting scaring technique impact on probability of goose presence.

Explanatory Variables	Type	Measure
Scaring technique	Fixed effect	drone or walking
Scaring exposure	Fixed effect	number of times exposed to drone and walking
Time	Fixed effect	before or after scaring event
Goose ID	Random effect	1 – 17 unique ID's

The model for all response variables $f(x)$ can be shown as:

$$\log f(x+1) = f\,(technique + time + technique * time + exposure + |goose\ ID|)$$

Using the estimates from the model results after simulations (Table 4), predicted probability of presence was calculated within each buffer zone for drone and walking (Figure 8) by applying inverse logit functions. Probability of presence was predicted before a scaring trial commenced; and after drone and walking trials respectively. Predictions were then multiplied by five and ten to show how repeated scaring trials impacted probability of presence over time.

2.4.2 Flight Initiation Distance

As a secondary metric for the effectiveness of drone and walking scaring techniques, flight initiation distance (FID) was compared for each method at Hornborgasjön before and after the molt period (HBM/HAM) and Kvismaren (KVI). Longer FID suggests a higher threat level (Bernard et al., 2018; Fernández-Juricic et al., 2005; Guay et al., 2016; Rodgers & Schwikert, 2002; Rodgers & Smith, 1995); shorter FID a lower threat. "Other" incidental scares (n=19) with the car (i.e. flock takes off while still in the car) and scares where the geese took off while in preparation for a trial (i.e. counting goose numbers from the car) were not included in the data, as the purpose of the study is to compare only drone and walking.

Linear mixed models with normal distribution were used to model the effects of disturbance techniques on the flight initiation distance (FID) of goose flocks in both Hornborgasjön and Kvismaren. FID was derived by calculating the distance from the scaring trial starting location to the flock location before takeoff. As the geese in Hornborgasjön were untagged, these models used a different set of explanatory variables that allowed for analysis of group behavior rather than individual behavior. Four different models were created to analyze scaring trials at Hornborgasjön before and after the molting period, at Kvismaren, and finally with all trial locations/periods combined. Explanatory variables included scaring technique, flock size, starting distance, site location, and field ID as a random effect.

Table 2. Description of explanatory variables included in the linear mixed models for predicting impact on flight initiation distance.

Explanatory Variables	Type	Measure
Scaring technique	Fixed effect	drone or walking
Flock size	Fixed effect	1 - 1500
Starting distance	Fixed effect	40 – 764 (m)
Site location	Fixed effect	Hornborgasjön before/after molt (HBM/HAM), Kvismaren (KVI)
Field ID	Random effect	1 – 69

The model for response variables $f(x)$ at individual sites can be shown as:

$$f(x) = f\ (technique + flock\ size + starting\ distance + |field\ ID|)$$

The model for response variables $f(x)$ at all sites combined can be shown as:

$$f(x) = f\ (technique + flock\ size + starting\ distance + site + |field\ ID|)$$

Chapter 3: Results

3.1 Flock Size

The largest number of geese on any one field was 1,100 (Kvismaren), and the mean total flock size for all sites combined was 128 (SD=186.4). Flock sizes at KVI (M±SD=256±258.3) were significantly larger than those at HBM (M±SD=56.3±70.6) and HAM (M±SD=68.9±84.1). Combined average flock size for Hornborgasjön (HBM+HAM) totaled 63.1 (SD=78.1).

3.2 Goose Presence

The percent change in average number of positions present within buffer zones (100, 300, 500m) before and after a scaring event did not differ significantly between techniques (Table 3). Waking reduced presence after scaring by an average 30.0% compared to 27.0% for drones. However the average percent of goose locations after a trial decreased for each method within all buffer zones, showing both drone and walking had an impact on reducing goose presence following scaring events. High numbers out outliers were present in the data sets for each method (Figure 7).

Table 3. Average percent change (Δ) of goose GPS collar locations within each buffer zone two days before and two days after scaring events after adjusting for zero inflation (n=average number of positions).

	Drone						**Walking**					
	100m		*300m*		*500m*		*100m*		*300m*		*500m*	
	M ±SD (Δ)	*n*	*M* ±SD (Δ)	*n*	*M* ±SD (Δ)	*n*	*M* ±SD (Δ)	*n*	*M* ±SD (Δ)	*n*	*M* ±SD (Δ)	*n*
Before	5.5 ± 4.3	28.3	9.8 ± 7.3	51.1	13.0 ± 11.0	67.3	4.4 ± 4.0	24.42	8.1 ± 6.1	44.85	12.2 ± 11.2	65.67
After	3.4 ± 6.3 (**-38%**)	16.6	7.6 ± 12.2 (**-22%**)	38.2	10.3 ± 15.7 (**-21%**)	51.9	2.7 ± 6.1 (**-39%**)	11.61	5.8 ± 9.3 (**-28%**)	28.39	9.4 ± 13.4 (**-23%**)	48.49

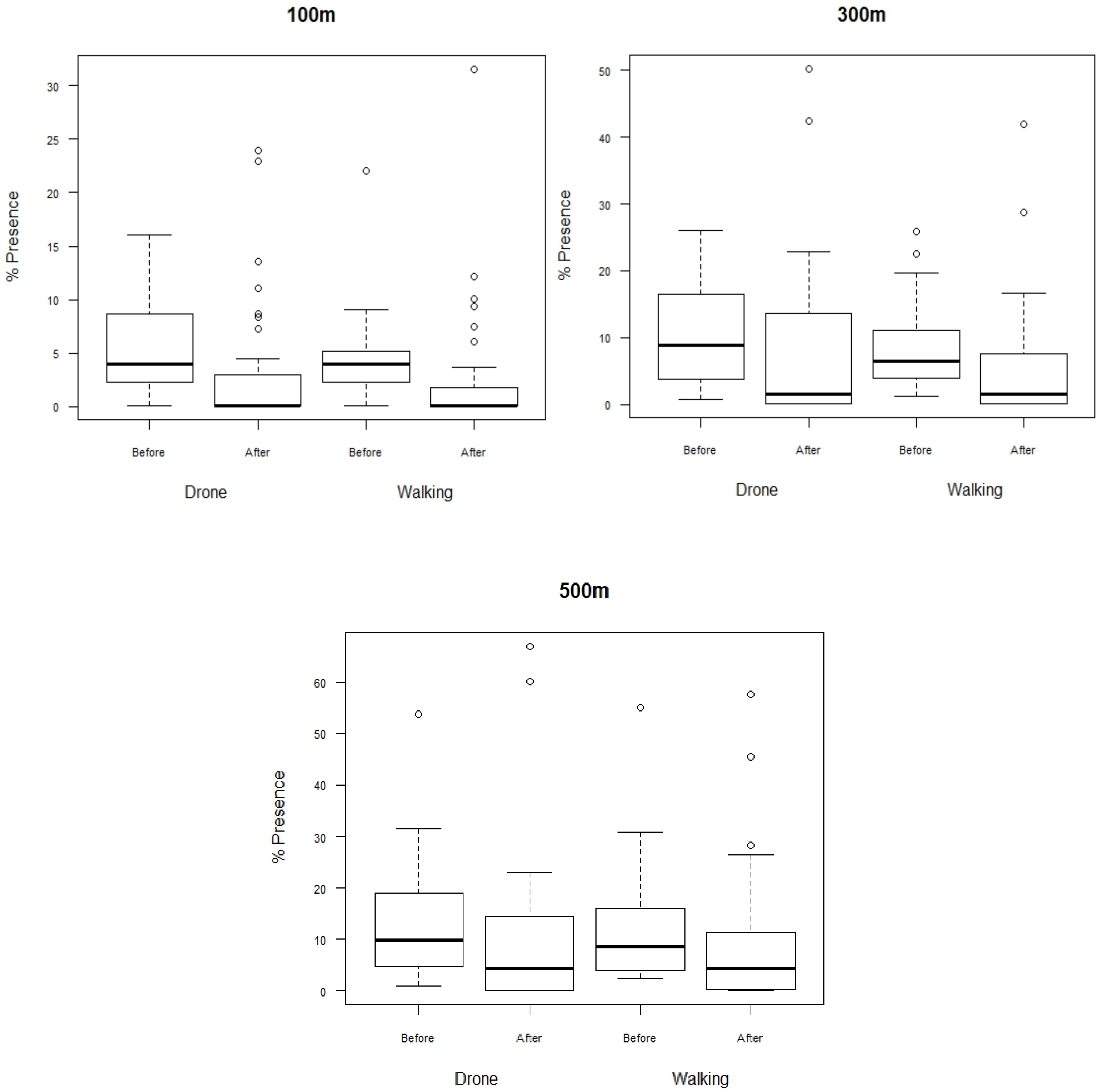


Figure 7. Boxplot diagrams showing percent of goose GPS collar locations within each buffer zone out of the total amount of recorded locations two days before and two days after scaring events (after adjusting for zero inflation). The box represents the middle 50% of goose presence and the middle marks the median. The upper and lower whiskers represent the top and bottom 25% and outliers are represented by circles. Reductions in percent of goose presence after a scaring event were greatest within the 100m buffer zone. Overall, both techniques showed similar effectiveness in lowering goose presence after a scaring trial.

3.2.1 Model Results: Impact of Technique and Exposure

The model output predicting technique and exposure impact on goose presence confirms walking and drone scaring techniques had a significant impact on reduction of goose presence after a scaring event within the 100m buffer zone (estimate=-0.94, p=0.029), and marginally significant impacts within the 300m (estimate=-0.84, p=0.064) and 500m (estimate= -0.86, p=0.070) zones (Table 3). There were not significant differences in effectiveness between drone and walking techniques at any distance, which corresponds to the raw data (Table 3, Figure 7).

The number of times individual geese were exposed to scaring (drone and walking combined) also showed a significant influence on goose presence within the 100m (estimate=-0.07, p=0.046), 300m (estimate=-0.17, p<0.001), and 500m (estimate=-0.18, p<0.001) buffer zones (Table 4). As the number of scaring exposures increased, goose numbers in each zone decreased. The interaction effect between technique and time did not show significance.

Table 4. Model results for predicting technique and scaring exposure impact on goose presence. No significant differences were found in the effectiveness between each method within any buffer zone. However, the effectiveness of both drone and walking did decrease as distances increased. Scaring exposure had a significant impact on goose presence at all distances.

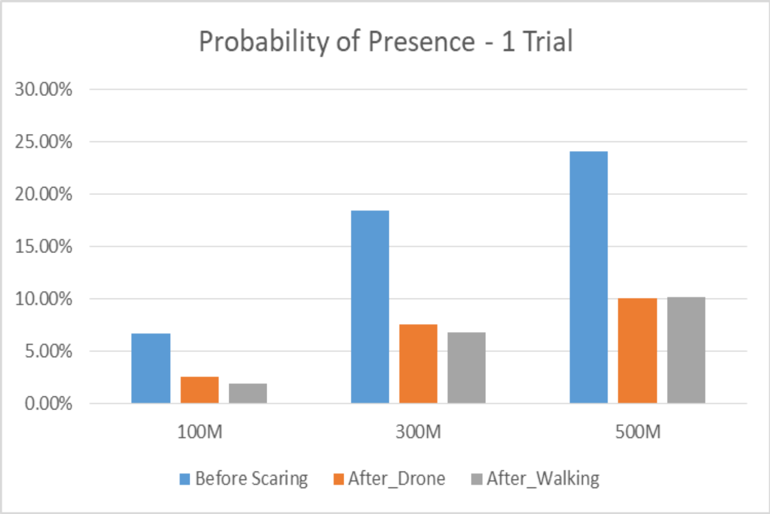
Variable	Distance	Estimate	Std. Error	*t*	*p*	CI (95%)
Intercept	100m	-2.63	0.66980	-3.926	**<0.001**	-3.94 – -1.32
	300m	-1.49	0.67616	-2.206	**0.027**	-2.82 – -0.17
	500m	-1.15	0.71587	-1.605	0.109	-2.55 – 0.25
Technique (Drone_Walking)	100m	-0.20	0.39427	-0.497	0.619	-0.97 – 0.58
	300m	-0.16	0.40564	-0.402	0.688	-0.96 – 0.63
	500m	-0.12	0.42816	-0.286	0.775	-0.96 – 0.72
Time (Before_After)	100m	-0.94	0.43145	-2.183	**0.029**	-1.79 – -0.10
	300m	-0.84	0.45369	-1.851	0.064	-1.73 – 0.05
	500m	-0.86	0.47683	-1.809	0.070	-1.80 – 0.07
Scaring Exposure	100m	-0.07	0.03693	-1.992	**0.046**	-0.15 – -0.00
	300m	-0.17	0.03734	-4.451	**<0.001**	-0.24 – -0.09
	500m	-0.18	0.03957	-4.487	**<0.001**	-0.26 – -0.10
Technique*Time	100m	-0.05	0.27262	-0.199	0.842	-0.59 – 0.48
	300m	0.04	0.28670	0.137	0.891	-0.52 – 0.60
	500m	0.13	0.30131	0.442	0.659	-0.46 – 0.72

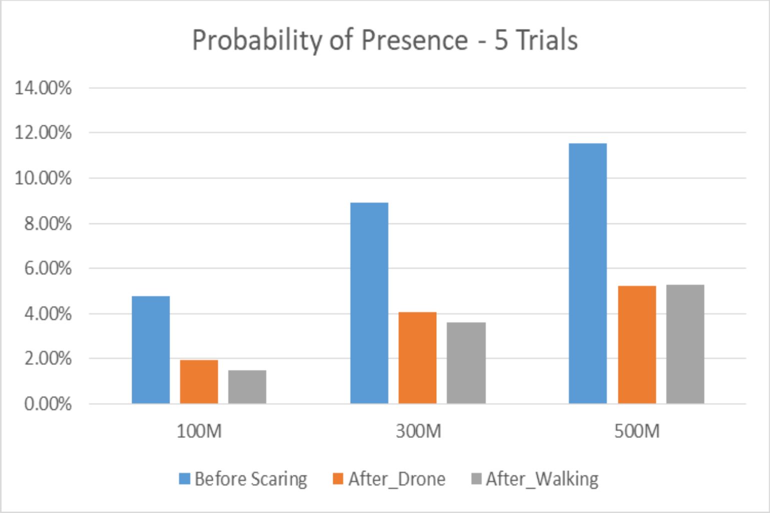
3.2.2 Probability of Presence

Probability of presence derived from the model estimates (Table 3) showed significant reductions in predicted goose presence for both drone and walking following a scaring event (Figure 8). After a single trial, drones reduced the probability of goose presence by an average 58.9% in all buffer zones combined. In comparison, walking predicted average declines of 61.5%.

After forecasting probability of presence for repeated exposures to each scaring method, walking continued to perform marginally better on average with 58.9% (5 trials) and 61.0% (10 trials) reductions, compared to 55.7% and 57.4% for drone.

In total, drones reduced the probability of presence after a scaring trial by an average 57.8% across all buffer zones, and walking displayed predicted declines of 60.7%.





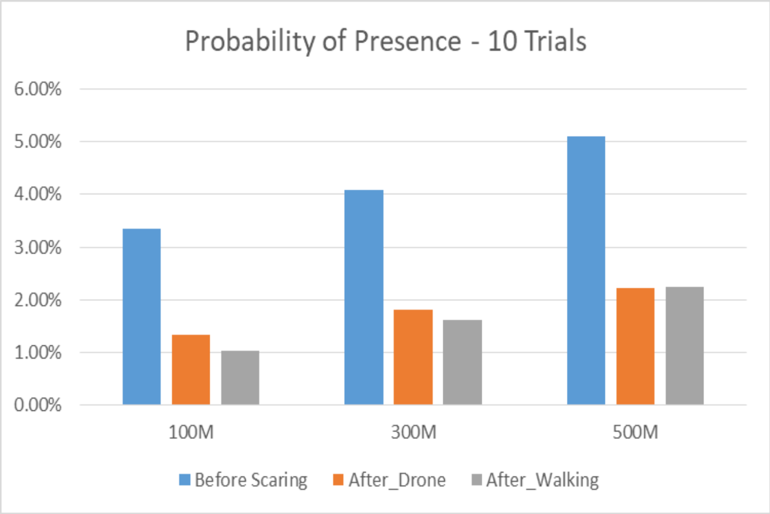


Figure 8. Predicted probability of goose presence before and after a scaring event for drone and walking techniques. On average, the greatest reductions in probability were seen in the 100m buffer zone for both methods.

3.3 Flight Initiation Distance

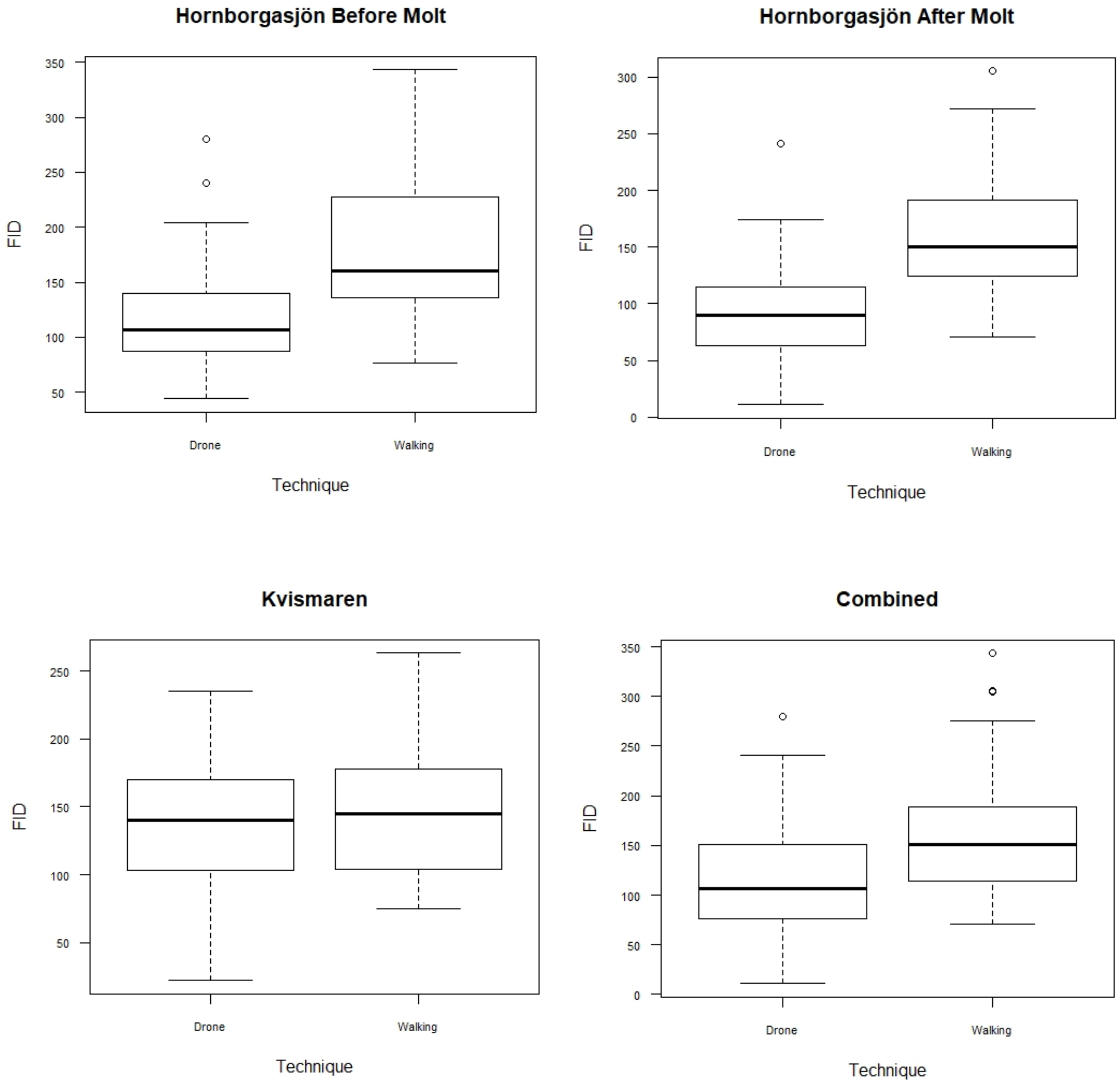
Walking had a longer FID in all categories with an average of 160.6 meters compared to 116.2 meters for drone (Table 4). The total walking FID was significantly greater at both HBM (M±SD=177.8±68.3) and HAM (M±SD=159.0±51.2), with walking averages 47.7% and 70.8% higher than drone (HBM M±SD=120.4±54.1, HAM M±SD=93.1±45.7). Combined Hornborgasjön (HBM+HAM) walking averages (M±SD=168.1±64.0) were a total 59.6% higher than combined drone averages (M±SD=105.3±51.1). There was a drop off in total FID averages for both drone and walking methods after the molting period in Hornborgasjön (HAM), with a 22.7% and 10.6% decrease respectively. Comparatively, Kvismaren (KVI) exhibited relatively close values for drone (M±SD=137.8±58.7) and walking (M±SD=146.2±52.5) scaring techniques.

HBM (M±SD=150.0±67.8) and KVI (M±SD=141.9±55.5) had comparable total (i.e. drone + walking) FID averages overall (Table 5), however there were some differences in results between walking and drone methods at each site. Average FID drone values at KVI were 14.3% higher than those at HBM, and averages for FID walking results at HBM were 21.6% higher than KVI.

Table 5. Mean, standard error, and range FID measurements at HBM, HAM and KVI. Drone produced shorter FID's at all locations. There were reduced FID values at Hornborgasjön after the molt period for both drone and walking. Overall the difference in FID for both methods was much greater at HBM and HAM compared to KVI.

	Hornborgasjön Before Molt (HBM)			**Hornborgasjön After Molt (HAM)**			**Kvismaren (KVI)**			**All Measurements**		
	Mean (SE)	*Range*	*N*	*Mean (SE)*	*Range*	*N*	*Mean (SE)*	*Range*	*N*	*Mean (SE)*	*Range*	*N*
FID$_{drone}$	120.4 (10.0)	43.6 – 280.0	29	93.1 (7.6)	11.2 – 240.5	36	137.6 (10.2)	21. 9 – 235.3	33	116.2 (5.6)	11.2 – 280.0	98
FID$_{walking}$	177.8 (12.3)	76.0 – 343.0	31	159.0 (8.9)	71.2 – 305.5	33	146.2 (9.35)	75.4 – 263.3	33	160.6 (5.9)	71.2 – 343.0	97
FID$_{total}$	150.0 (11.2)	43.6 – 343.0	60	124.6 (8.3)	11.2 – 305.5	69	141.9 (9.8)	21.9 – 263.3	66	138.3 (5.8)	11.2 – 343.0	195

Figure 9. Boxplot diagrams showing drone and walking FID averages for HBM, HAM, Kvismaren and the total combined averages for all three. The box represents the middle 50% of goose presence and the middle marks the median. The upper and lower whiskers represent the top and bottom 25% and outliers are represented by circles. Significant differences can be seen between the methods at Hornborgasjön, with walking averages a total 36.85% higher at this location. Kvismaren produced similar results for both methods.



3.3.1 Model Results: Impact of Technique, Flock Size and Starting Distance

Model results (Table 6) show that both drone and walking had a significant impact on FID in the combined model (estimate=58.76, p<0.001), HBM (estimate=74.07, p<0.001), and KVI (estimate=79.35, p<0.001). Additionally, walking was found to have a significantly greater effect on FID for the combined model (estimate=47.18, p<0.001), HBM (estimate=55.88, p<0.001) and HAM (estimate=78.03, p<0.001). KVI did not show significance between techniques, which matches the raw data that displayed similar results for both methods (Table 5, Figure 9). Both drone and walking had a reduced impact on FID at HAM, and flock size did not have a significant impact on the results at any site.

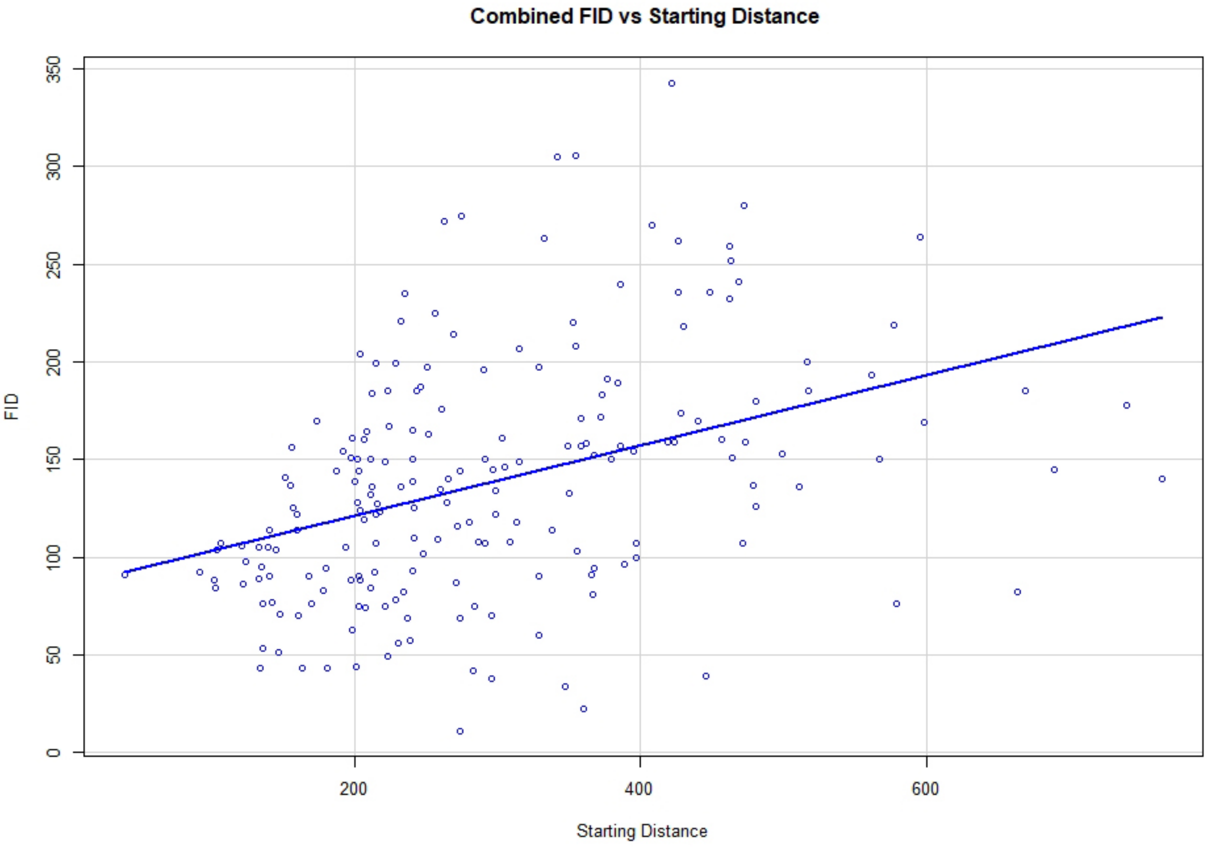
Table 6. Model results predicting technique, flock size, and starting distance impact on FID. Values that are bold indicate statistical significance. Significance was found between walking and drone scaring methods at HBM and HAM. Additionally, starting distance had a significant impact on FID at all sites.

Variable	Site	Estimate	Std. Error	*t*	*p*	CI (95%)
Intercept	Combined	58.76	12.25	4.80	**<0.001**	34.75 – 82.78
	HBM	74.07	20.40	3.63	**<0.001**	34.08 – 114.06
	HAM	8.64	19.45	0.44	0.657	-29.48 – 46.76
	KVI	79.35	18.76	4.23	**<0.001**	42.59 – 116.11
Technique (Drone_Walking)	Combined	47.18	7.12	6.63	**<0.001**	33.23 – 61.13
	HBM	55.88	13.89	4.02	**<0.001**	28.66 – 83.10
	HAM	78.03	9.24	8.44	**<0.001**	59.92 – 96.15
	KVI	12.64	12.62	1.00	0.317	-12.11 – 37.38
Flock Size	Combined	0.03	0.02	1.26	0.209	-0.01 – 0.07
	HBM	0.03	0.11	0.26	0.798	-0.19 – 0.25
	HAM	-0.07	0.06	-1.05	0.295	-0.19 – 0.06
	KVI	0.03	0.02	1.35	0.178	-0.01 – 0.07
Starting Distance	Combined	0.18	0.03	5.65	**<0.001**	0.12 – 0.24
	HBM	0.17	0.06	2.93	**0.003**	0.06 – 0.28
	HAM	0.37	0.07	5.69	**<0.001**	0.24 – 0.50
	KVI	0.14	0.05	3.05	**0.002**	0.05 – 0.24
Location (HBM)	Combined	16.51	11.08	1.49	0.136	-5.21 – 38.23
Location (KVI)	Combined	-7.61	12.45	-0.61	0.541	-32.02 – 16.80

3.3.2 Starting Distance Significance

Starting distance had significant influences on FID (Figure 10) in the combined model (estimate=0.18, p<0.001), HBM (estimate=0.17, p<0.003), HAM (estimate=0.37, p<0.001), and KVI (estimate=0.002, p=0.002). Average starting distances for combined drone and walking trials at all sites (n=195) were 296.85 meters (SD=133.6), and 294.07 meters (SD=135.7) respectively. Average HBM starting distances for drone (M±SD=295.6±171.0) and walking (M±SD=333.2±150.2) were 14.3% and 43.13% higher compared to HAM (drone M±SD=258.7±93.5, walking M±SD=232.8±65.0). KVI averages for drone (M±SD=339.6±124.1) and walking (M±SD=318.6±154.7) were comparatively similar. Figure 10 shows the upward correlation between FID and starting distance, however there are fewer trials involving starting distances at the high end of the spectrum (i.e. over 400m, n=39).

Figure 10. FID measurements for trials at all sites combined (n=195) compared to the starting distance. There is a clear upward trend relating longer starting distances to higher flight initiation distances. Circles represent individual trials and the regression line is in solid blue.



Chapter 4: Discussion & Conclusion

4.1 Scaring Exposure Impact on Goose Presence

As can be seen from the model results (Table 4), one of the most significant influences on goose presence was the scaring exposure, or the number of times a goose participated in scaring trials. Over time, an increase in number of trials an individual was exposed to resulted in predicted lower goose presence (Figure 8). However, previous studies have shown one of the major limitations of using scaring devices to deter wildlife from occupying specific areas is the risk of habituation (Gilsdorf et al., 2002; K A Steen et al., 2012a; Kim Arild Steen et al., 2015). The more an animal is exposed to a method without experiencing harm, the greater the chance they will begin to ignore the equipment altogether. Using this logic one would assume repeated exposure to a scaring method, particularly a non-human threat (i.e. drone), would reduce the effectiveness over time as the geese begin to realize the device does not pose a danger. There are several factors that could explain why increased exposure did not result in habituation and an increase in goose presence at this site.

Scaring trials at Kvismaren were conducted over a period of 28 days. If we look at the maximum number of times an individual goose was exposed to the drone scaring method (n=8) from the first trial to the last, it was spread out over a period of 23 days. Agricultural areas feature constantly changing landscapes as crops progress throughout a growing season. Crop type and crop stage play crucial roles in field selection of many foraging bird species (Amano et al., 2004; Anteau et al., 2011; Leito et al., 2008; Lovisa Nilsson et al., 2016).

During the experimental trials, geese were primarily found grazing on cereal (n=78) and grass (n=115) fields. The average for each type was 14.4 cm. Early in the season, geese showed more preference for cereal crops, but as the crops grew too high they would switch over to grass. Once the grass grew too high, this generally coincided with the timing for harvesting of cereal crops, and they would switch back over to the stubble fields when they became available. In this way, the height, availability and location of crops was a major factor in field selection of the geese. Over the course of several weeks, the variability of these combined factors most likely had an influence on the probability of bird presence on a particular field.

Given the restrictions of the methodology with attempting to limit over exposing birds to scaring trials over the short term (i.e. once every three days), a week or more could go by before an individual was targeted for another trial. This could suggest the geese simply moved to a different field with a more preferred crop type/height/location over that time span; and not necessarily because of increased frequency of scaring. In order to test this, additional studies would need to be undertaken to assess the average length of time a flock spends grazing on a field if left undisturbed. After acquiring this data, it would then be possible to compare scaring frequency to average field grazing time and examine the impact increased scaring exposures might have on goose presence.

4.2 Average Starting Distance Impact on Flight Initiation Distance

The model results for flight initiation distance (FID) show starting distance as a significant influence at all sites, suggesting scaring trials beginning further away from the flock resulted in a considerably higher FID (Table 6). The regression analysis confirms this, showing an upward trend relating longer starting distances to higher FID (Figure 10). However, it should be noted that additional trials focusing on long range starting distances should be conducted (above 400m) to strengthen the correlation, as there are fewer trials at the high end of the spectrum. The impact of starting distance on FID could be attributed to a combination of factors stemming from field location, habituation effects, and the food intake rate requirements for large grazing birds (Fox et al., 2016).

Geese and other herbivorous waterfowl are predicted to minimize predation risk while maximizing food intake rates with minimal energy expenditure (Fox et al., 2016; Mangel & Clark, 1986; McNamara & Houston, 1992). The amount of time an individual spends feeding per day can indicate how quickly birds attain daily food requirements, however disturbances on fields prompt more flying and thus the need for additional foraging to compensate for loss of energy reserves (Fox et al., 2016). A previous study showed when geese are intentionally disturbed during foraging, subsequent flights are twice as long (2 x 195 s), requiring additional foraging time of 3-7% per day (Nolet et al., 2016). The results demonstrate if the birds are intentionally disturbed more than five times per day, they will no longer be able to cover energy requirements for building fat reserves (Nolet et al., 2016).

This logic infers that the geese would only want to take flight when they are certain potential threats pose real physical risk. Both of the locations where scaring trials were conducted are nature reserves in addition to agricultural areas; meaning that tourists are frequently in close proximity to the farms and pastures where the geese prefer to graze. Decisions to avoid possible danger must then be made quickly and at short distances. As these people generally pose no threat (and it would be an inefficient use of energy reserves to take flight every time a car pulls into a nearby parking lot or a hiker walks by) the geese could quickly become habituated to foraging in close vicinity to the tourists.

Accordingly, if a scaring trial starts from further away and the person walking (or drone) continues in a straight line directly towards the flock, it would become apparent to the geese that it is not just a tourist. The decision to take flight and avoid the threat is easier and can be made from a safer range, producing longer flight initiation distances. Further spatial analysis of the data could be conducted to evaluate the potential influence of variables associated with individual field location (i.e. frequency of tourists, distance to parking lots, major roads, building infrastructure, remoteness, etc…) on FID.

Additionally, the average starting distance values for drone and walking at HAM saw significant declines of 12.5% and 30.1% compared to starting distances at HBM. This also coincides with a reduction in total FID averages of 22.6% and 10.52% during the same trial period at HAM. Wing-molt is a costly and energy intensive process that renders many goose species flightless for up to five weeks while flight feathers are regrown (Fox & Kahlert, 1999; Kahlert, 2002). During this flightless period, terrestrial feeding waterfowl are at their most vulnerable and tend to forage close to bodies of water as movements between feeding patches, drinking sites and escape routes from potential predators are undertaken on foot (Kahlert, 2002). While food intake rates remain the same as those before and after the molt, time spent foraging can fall by over 50% (Fox & Kahlert, 1999). A previous study on barnacle geese showed a body mass decrease of approximately 25% from the pre-molt value due to an increase in metabolism from feather synthesis and reduced time spent foraging as a predator avoidance behavioral strategy (Portugal et al., 2007).

Such a substantial reduction in body mass following wing-molt could potentially have an impact on feeding sites chosen to replenish energy reserves quickly in pursuance of continuing migratory routes. In selecting less remote fields closer to roost sites, geese would expend less energy traveling and be able to quickly gain back lost body mass. Incidentally, these fields could also be the ones closest to tourist sites; constituting lesser starting distances for scaring trials. This in turn would have a considerable impact on reducing FID. Furthermore, shortened FID might also be a consequence of the bird's diminished energy stocks. Repeatedly taking flight unnecessarily could greatly decrease the opportunity to restore body mass rapidly and continue migrations to mating sites. The geese might be more willing to let potential threats come closer before flying in order to minimize excessive disturbances resulting in take-off.

4.3 Hornborgasjön & Kvismaren Flight Initiation Distance Results

When comparing the overall average FID data of Hornborgasjön to Kvismaren, there are some differences to consider for further analysis. At Kvismaren, disparity in FID results for drone (M±SD=137.8±58.7) and walking (M±SD=146.2±52.5) were not statistically significant and produced relatively similar values (Table 5, Table 6). However, the combined Hornborgasjön (HBM+HAM) walking averages (M±SD=168.1±64.0) were a total 45.9% higher than combined drone averages (M±SD=105.3±51.1). This difference in results at Hornborgasjön indicates the geese were less threatened by the drone than a walking person, while Kvismaren geese displayed a nearly equal risk avoidance behavior for each method. Differences between the two locations could suggest external influences including habituation to local management methods and environmental factors (i.e. field size, average starting distance).

The county board staff at Lake Hornborgasjön includes a designated “goose management” professional responsible for daily surveyance of local farms and overseeing the disturbance of flocks causing damage to crops. Goose management scaring techniques involve kites, scarecrows, fireworks and drones. Having been previously familiar with drones, the significantly higher difference in Hornborgasjön FID values in comparison with Kvismaren could represent potential habituation effects for repeated exposures to the same scaring methods over a longer period of time (Díaz et al., 2015; Rees et al., 2005).

Average field size differentials between Hornborgasjön (5.9 ha) and Kvismaren (17.2 ha) could have also impacted the results for FID. Larger fields provide greater opportunity for a longer starting distance. If the flock is located on the far end of a field away from the access road, then the trial would begin from further away, and vice versa for smaller fields. As discussed previously, starting distance had a significant influence on FID. Larger fields would equate to longer average starting distances, and thus higher FID.

4.4 Flight Initiation Distance & Goose Presence

The two metrics used for determining effectiveness of drone and walking as scaring methods, FID and goose presence, offered varying results across each location. As there were no tagged geese at Lake Hornborgasjön, the study was unable to measure goose presence at this site. However, at Kvismaren it is possible to compare both variables since they were recorded simultaneously during each trial. The average FID values at Kvismaren for drone (M±SD=137.8±58.7) and walking (M±SD=146.2±52.5) displayed a relatively close 5.8% difference in results, exhibiting slightly higher FID outcomes for walking.

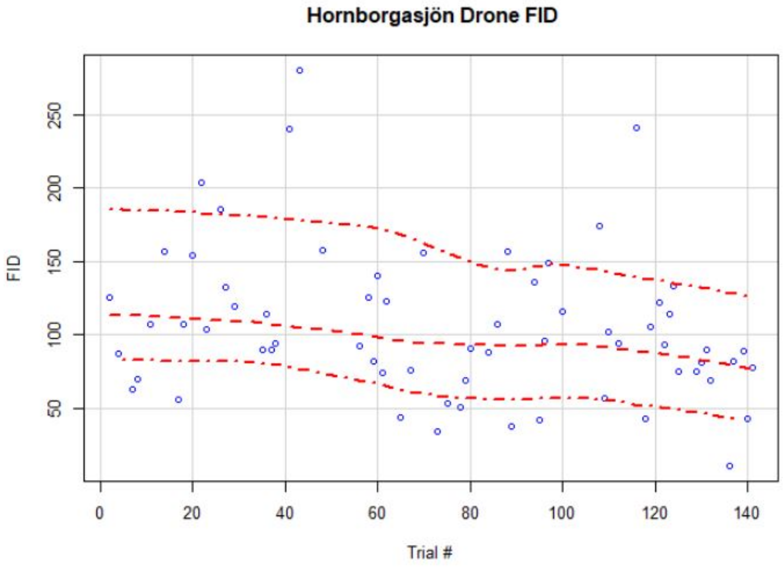
Correspondingly, the differential in average reduction of goose presence after scaring for drone (-27.0%) and walking (-30.0%) was only 3%. Overall there are far fewer outliers in the FID data (Figure 9) compared to the goose presence data set (Figure 7), which indicates less variability in the results (Dawson, 2011). Nonetheless, walking displayed slightly better scaring effectiveness in both metrics, but the difference was not statistically significant in either category. The similar results in performance for drone and walking in the FID and goose presence tests indicate the metrics might correlate at Kvismaren (i.e. higher flight initiation distance = lower goose presence, and vice versa). But there is not enough data from this experiment to conclusively say overall that longer FID correlates with declines in goose presence, as there was not an opportunity to test both variables at Hornborgasjön. For the purposes of this study, FID values should be viewed as a measure of short term effectiveness and reductions in goose presence as a long term metric.

4.5 Viability of Drones as Management Tools

Comparing the FID and goose presence data for each scaring technique provides insight into the effectiveness of drones as a potential management tool farmers can utilize to mitigate excessive crop damage from large grazing birds. A previous study examined the cost-effectiveness of scaring brent geese *Branta b. bernicla* from farm fields using a full-time human birder scarer (Vickery & Summers, 1992). The conclusion was that geese showed no signs of habituation to the human, and the method reduced crop damage from grazing by a greater margin than more conventional methods (Vickery & Summers, 1992). Scope of the effectiveness was determined by calculating average cost per hectare to employ the bird disturbance professional (i.e. £17.00ha) against net crop losses of previous years. However, this cost was spread out over 101.5ha of crops – more than double the size of the 43.1ha average farm size in Sweden (Eurostat, 2010). The per-hectare cost would be substantially higher for smaller fields, putting the cost-effectiveness of a full-time bird scarer into question for average farmers. Despite the financial limitations, this method proved to be the most potent weapon in a farmer’s arsenal. Simply put, geese (amongst most other wildlife) deem humans as a real and viable threat. Development of new bird disturbance techniques attempting to balance efficiency and cost need this baseline of comparison to evaluate their effectiveness as potential wildlife management tools.

After weeks of field trials, drones did display comparatively similar results to walking at Kvismaren Nature Reserve, in both FID and reductions in goose presence after scaring. However, there were significant differences in FID at Lake Hornborgasjön. Drone averages were a combined (HBM+HAM) 36.9% lower than walking, indicating the geese perceived this method as a lesser threat. Average starting distances for drone (277.2m) and walking (283.0m) at Hornborgasjön were also extremely close in value, which means this variable cannot account for the substantial difference in FID between the methods.

A possible explanation for variation in results between the two study sites could be habituation to the drone. As mentioned previously, Hornborgasjön does employ a full-time bird scaring professional that utilizes multiple management techniques; including drones. Previous exposure might have acclimatized geese by providing opportunity to become familiar with the device. While it is not possible to fully analyze the effect of habituation on drone performance without data on extent of use prior to official field tests, the results from scaring trials conducted for this study already demonstrate reduced effects over a period of several weeks (Figure 11).



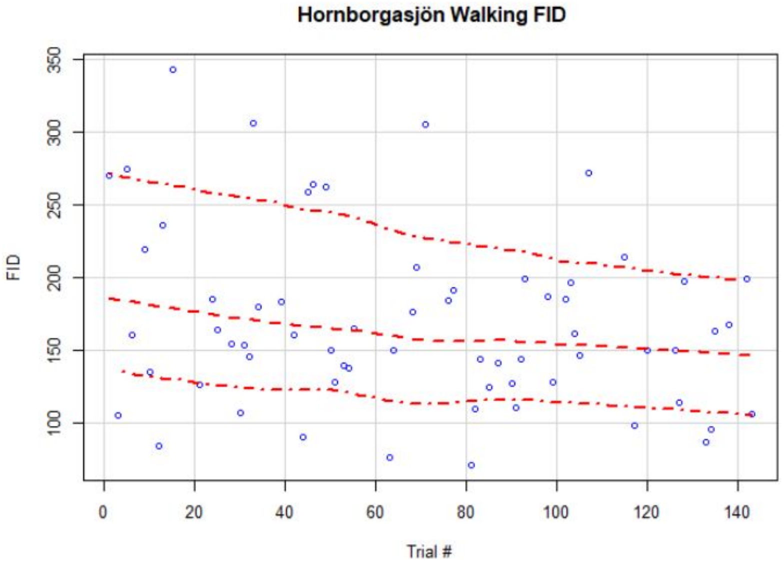


Figure 11. Comparison of flight initiation distance (FID) averages for drone and walking over the span of the entire field period at Lake Hornborgasjön. Circles represent scaring trials, and dotted lines represent the mean (middle) and variation (outer).

Both methods exhibit declining FID as the number of trials increase, which indicates the geese did become less fearful over time (Figure 11). However, the slope of the mean (i.e. middle dotted line) for drone shows a sustained downward curve at the tail end – even beginning to steepen further over the last few trials (Figure 11). In comparison, the slope for walking appears to start flattening out towards the end. This steady, constant decrease in drone FID implies a continued habituation taking place; and a stabilizing threat level for walking suggests the geese might have a threshold for minimum permissible distance in regards to human disturbances. Additionally, mean FID values for walking were significantly higher than drone from the very beginning, further emphasizing a higher perceived threat level from people compared to drones at Hornborgasjön (Figure 11).

A final variable to consider in the data variability between locations is the difference in number of trials and time and spent at each site. 143 scaring trials over 27 field days were conducted at Hornborgasjön against 70 trials over 20 field days at Kvismaren. It is possible a longer field period and higher frequency of scaring at Kvismaren would have provided more opportunity for habituation to the drone, and over time yielded higher separation between the results for each method similar to that of Hornborgasjön.

Because of the success seen at Kvismaren Nature Reserve, drones do exhibit potential as a management tool for farmers and warrant continued research. However at this stage, the long term effectiveness of drones as a scaring tool is still inconclusive and requires additional field trials to acquire more concrete data. Ideally, in order to gather enough information and arrive at a firm conclusion, geese would also need to be radio collar tagged at Hornborgasjön and additional field trials conducted simultaneously at both sites to adequately examine and associate results.

4.6 Future Implications

In terms of real world application, a weakness of the study was lack of variation in using the drone while conducting field trials. Flying the drone at the same height/speed and discontinuing flight trajectory once geese took off (instead of continuing pursuit until certain they have left the area) were necessary for data collection purposes and consistency, but did not provide a true representation of how drones would be employed by farmers. Repetitive use of scaring devices without altering application patterns can lead to faster habituation as animals become less wary over a short period. Simply altering the position and pattern of the devices can help to delay habituation and reduce crop damage (Belant et al., 1996; Gilsdorf et al., 2002; Koehler et al., 1990; Nolte, 1999; Whisson & Takekawa, 2000). Thus, in a real world scenario farmers would be manually piloting the drone creating unique scaring disturbances with every use (i.e. varied flight height, speed, angle of approach, etc…), which in turn would most likely reduce the rate of habituation.

With the continued advancement of modern technology, drones encompass possibly limitless capacity for variation of disturbance patterns as a fully automated scaring device. Several studies have attempted to develop adaptive scaring devices (i.e. altering the timing and frequency of disruptive bioacoustic stimuli) using machine learning algorithms to recognize behavior of specific bird species with video and audio-based detection systems (K. A. Steen et al., 2014; K A Steen et al., 2012b; Kim Arild Steen et al., 2015). While still in the early stages of development, these systems offer a glimpse at promising technologies that could be combined with drone systems. Hypothetically, drones could perform automated “patrols” around a field after strategically placed sensors have triggered detection algorithms for specific behaviors, such as foraging. The drone would then alter flight patterns (speed, height, auditory stimuli, etc…) around the conflicted area until detected wildlife were no longer in range of the sensors.

Although the commercial viability of an automated drone system is still a long way off, there are potential legal barriers that would need to be considered before investing resources into additional research and development. Regulatory ordinances that should have been developed alongside the quickly evolving technology are slow to catch up, leaving gaps in safety codes and societal guidance on appropriate use – particularly in regards to autonomous drone regulations. July 1st 2020 will see a new era of drone governance enter into effect within the European Union (European Union Aviation Safety Agency, 2020). According to Azure Drones, a pioneer in the advancement of commercial autonomous drone systems, the European Union Aviation Safety Agency (EASA) will provide 3 categories of operations with increasing levels of risk:

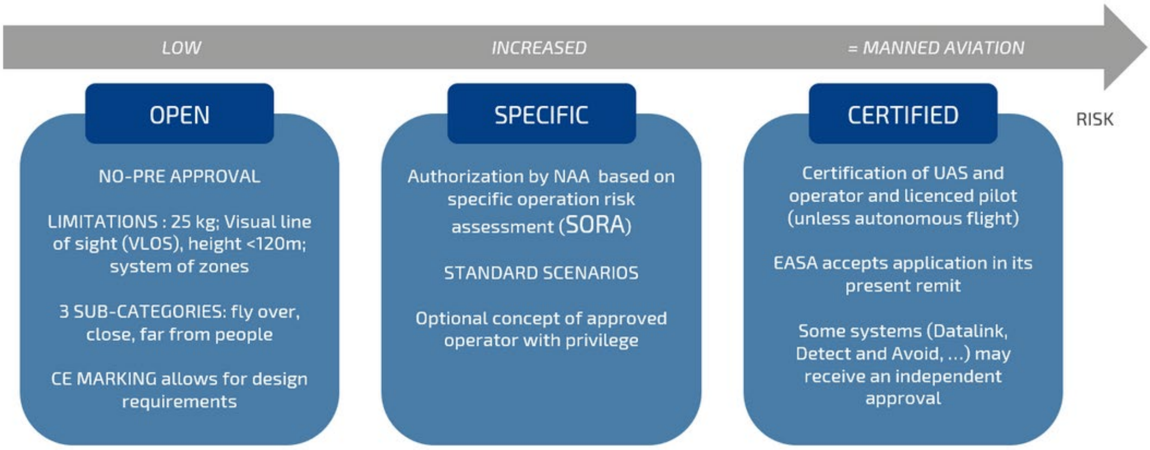


Figure 12. New EU wide drone regulations that will go into effect July 1st 2020. Primary authorization/pre-approval requirements for drone use will be based on size, height, area of use, and operations risk (sourced from Azur Drones 2020).

Since agricultural landscapes are generally in rural, less populated areas, it is possible an automated drone system used in the context of a farm management tool could fit into the “Open” category (Figure 12); eliminating the need for specific use authorization or additional licenses. Where the rules become a bit blurred involve visual line of sight requirements, as this would depend on the size of the farm and field layout. In order to understand the safety specifications and redundancies mandatory for such a system, government involvement and consultation during the initial development process would be prudent before heavy investment of resources.

4.7 Conclusion

Overall results at Kvismaren indicated each method had comparatively similar success in both FID and reductions in goose presence, while at Hornborgasjön the drone displayed significantly shorter FID values and was decisively was less effective in this metric. The study showed how efficacy of scaring devices can greatly differ between locations, and is dependent upon many external factors including potential previous exposure and habituation to disturbance techniques. Despite the large disparity in FID results between sites, the ultimate measure of success from any scaring device would be successful reduction of grazing damage done to valuable crop fields. While FID is a valuable metric for measuring the immediate threat level of a disturbance or environmental stimuli, the primary concern for agricultural land owners is reducing bird presence and minimizing crop damage.

In this context, the drone showed similar success to walking in lowering number of geese on fields after a scaring event at Kvismaren, and displayed potential as a non-lethal tool farmers can utilize to help manage large grazing bird populations. However due to the variation in FID results at Hornborgasjön and Kvismaren, additional field research should be conducted (ideally with multiple sites accommodating tagged geese) to acquire more data on the effectiveness of drones as a scaring device before incorporating them into conflict management plans. Nevertheless, future capacity for successful development of a drone system that resists long term habituation effects could reside in legal and technological advancements related to flight automation. Subsequent research should reflect this potential with continued scientific rigor and enthusiasm.

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Cheers,

Wade Million

Declaration of Originality

I declare that this thesis is an original report of my research, has been written by me and has not been submitted for any previous degree. The experimental work is almost entirely my own work; the collaborative contributions have been indicated clearly and acknowledged. References have been provided on all supporting literature and resources.

M. Wade Million
30 June 2020, Freising

Appendix A: Field Protocol

Scaring geese

		Trial __	Trial __	Trial __	Trial __	Trial __	Trial __	Trial __
General information	Date							
	Time							
	Name							
	Weather/ precipitation							
	Scaring measure							
Geese	Nr of geese							
	Greylag							
	Barnacle							
	Bean							
	Canada							
	Gr. White front							
Fleeing response distance	Start person x							
	Start person y							
	Stop person x							
	Stop person y							
	Take off Flock x							
	Take off Flock y							
Direction and wind	Wind speed							
	Wind direction							
	Flight direction							
	Walking direction							
Field scaring	Field type							
	Crop height/stage							
	Visibility							
Notes								

Appendix B: Crop Damage Images

These images taken from a drone demonstrate extreme crop damage (left side) from goose grazing at Lake Hornborgasjön. The entire field was planted at the same time, however management efforts to reduce goose presence was minimal and resulted in 75% crop loss. It is interesting to see where the birds stopped foraging on the right side of the field presumably because this was the closest they were willing to go near the farm house (Image 2).

Image 1

Image 2

Appendix C: Lake Hornborgasjön Images

Drone images taken at various locations around Lake Hornborgasjön. Image 1 shows only a fraction of the population that migrates here every year for wing-moult. A small number of breeding pairs can also be found at his site (Image 6).

Image 1

Image 2

Image 3

Image 4

Image 5

Image 6

Appendix D: Kvismaren Goose Tagging Images

Images from a goose capture and tagging excursion at Kvismaren Nature Reserve. Greylag geese have been radio collared every year at this site since 2016 (Image 4). A research team from the Netherlands was also collecting data using new mobile x-ray devices. The aim was to scan the birds for gun pellets resulting from hunting expsore (Image 6).

Image 1

Image 2

Image 3

Image 4

Image 5

Image 6

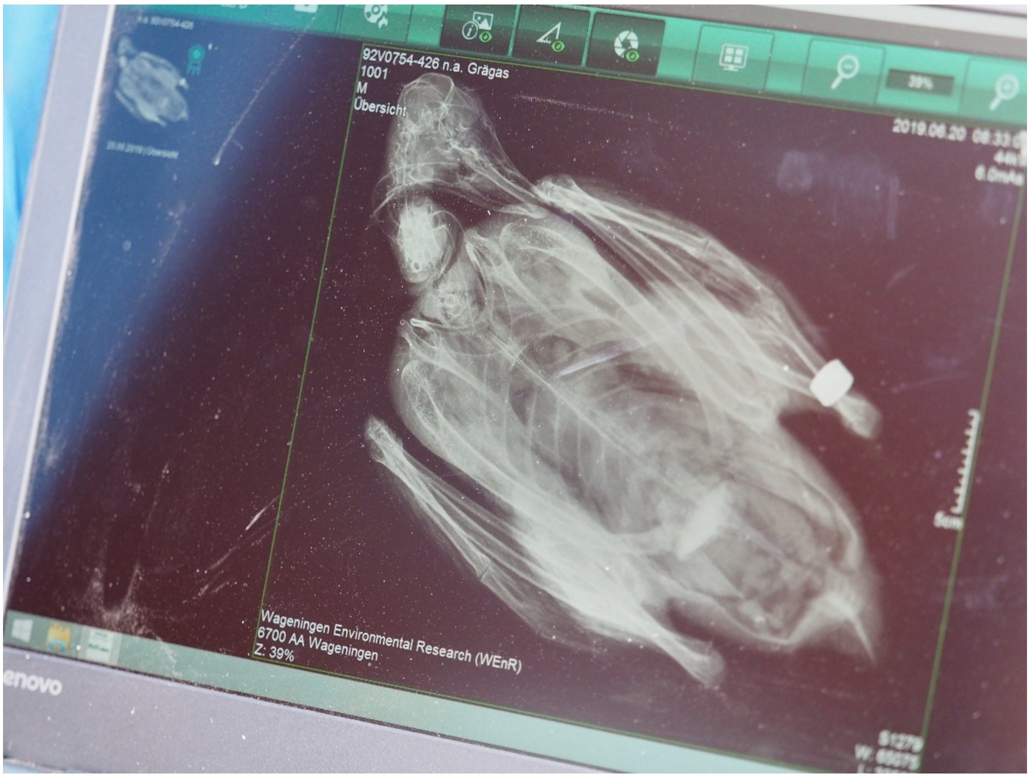

Image 7

Image 8