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Foraging and movement patterns by geese in agricultural landscapes

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Contents

Abstract

When a variety of foods or habitats is available to an animal, some are avoided in favor of others. Preference of certain foods can be assessed by comparing usage with availability, in relation to different factors that may influence the selection process. Maximization of nutrient quality while still obtaining sufficient quantity and minimization of energy expenditure, are the main factors affecting habitat and food selection of most animals in general, and herbivores specifically.

Geese are large, social birds and highly selective grazers. Outside the breeding season geese generally feed during the day, mainly on agricultural crops and grasslands, and return to open waters during the night to roost. Besides nutrient maximization, access and proximity to roosting areas, and minimization of predation risk and inter- and intraspecific competition are important factors in the selection process of geese. Europe has experienced a recent population increase of geese, mainly due to changes in the agricultural landscape that increasingly offers abundant food resources of high quality. This has caused geese to abandon natural and semi-natural wetlands and grassland to increasingly forage on farmland. Rapidly increasing and expanding goose populations are causing major conflicts, and economic losses for individual farmers and society. In this review, existing research on movement patterns, and food and habitat preferences of geese on agricultural land in Europe is summarized, and potential knowledge gaps are identified.

When measuring preference of animals, study designs that measures both usage and availability on an individual basis are desirable as they allow for a finer resolution of analysis of resource selection. To this date, very few studies related to foraging and movement patterns of geese in Europe, have measured both usage and availability at an individual level, and only four of these were based on telemetry data. These few studies are mainly focused on movement patterns, and not on the selection processes behind goose movements.

Studies in which both usage and availability are measured at an individual level are much called for, as are studies in which larger spatial and temporal scales are considered, so that general patterns can be identified and used at a larger scale. Understanding, and being able to predict, the behavior and movement of geese is important for crop damage prevention, and for developing future management strategies. The recent advances in technology of telemetry devices has greatly increased the possibilities of performing goose studies ranging from a very precise spatial level, e.g. foraging sites, to larger spatial scales such as movements at a flyway level, that can provide new knowledge for increasing and expanding goose populations and for mitigating the associated conflicts with agriculture.

Introduction

When a variety of foods or habitats is available to an animal, some are preferred while others are avoided (Krebs, 1999). There are some factors affecting habitat and food selection that are consistent amongst animals in general, one being energy maximization and another being minimization of energy expenditure (Mac Arthur and Pianka, 1966, Senft et al., 1987). Energy maximization is especially important amongst herbivores as they are usually constrained by body size, gut type and capacity, and available foraging time, that limits their ability of consuming larger amounts of food in a short amount of time (Senft et al., 1987). For herbivores specifically, the nutrient quality are of further importance, as they often face a surplus of food, often of low or varying nutrient quality (Senft et al., 1987). Other important factors affecting foraging behavior, which are more specific for herbivorous birds such as geese and swans, include access and proximity to roosting areas, and minimization of predation risk, as well as inter- and intraspecific competition (Fretwell and Lucas, 1970, Schoener, 1979).

Selection can be made at different spatial scales, where the selection may influence the movement patterns of the animals to a various extent depending on the distribution and abundance of resources. The regional scale involves the geographical range of the species, which may change on a temporal scale for example by means of migration (Johnson, 1980, Senft et al., 1987). The spatial scales also includes a more local range, such as landscape and field levels, where the landscape level involves the home range of an individual, and the field level comprises particular feeding sites within that home range (Johnson, 1980, Senft et al., 1987). Food selection can further be made on an even smaller scale, namely between different food items (e.g. plants, or plant parts) within a feeding site (Johnson, 1980, Senft et al., 1987). At the smaller scales, energy and nutrient maximization are often the main factors influencing selection and movements, while at the landscape or regional scale the selection and movement patterns are affected not only by strategies of optimized feeding, but also by environmental factors such as climatic conditions, physical barriers and topography, or by genetically coded traits such as migration initiated by changes in the photoperiod (Senft et al., 1987). Minimizing predation risk, and having access to water may cause animals to avoid otherwise attractive habitats or feeding areas and could further increase movement distances, thus greatly affecting the energy expenditure and habitat or food availability (Senft et al., 1987). At a larger scale, habitat selection and movement patterns are further influenced by the energy cost of travel, and the loss of feeding time while moving between roosting and feeding sites (Senft et al., 1987).

Preference (e.g., of a habitat or a crop) can be measured by comparing usage with availability, in relation to different factors that may influence the resource selection process (Johnson, 1980, Krebs, 1999). When measuring preferences of animals, there are three general study designs that can be applied. In the first, all measurements are made at the population level, without taking into account individual animals (Krebs, 1999). An example of this study design is when the amount of droppings are compared, in terms of presence/absence, among fields or sites with different food types (Krebs, 1999). In the second study design, usage is measured at an individual level, while the availability of resources is measured for the entire population; for example, when stomach contents of individual animals are compared to the food types available within the study area (Krebs, 1999). The third study design measures both usage and availability on an individual basis, one example of this is when marked or radio-collared individuals are studied in relation to food availability within the home range of each individual (Krebs, 1999). In general, the second and third study design are desirable, as they allow for measurements of resource selection at an individual level, and although there are different statistical treatments and data requirements depending on the study design chosen, the second and third design allow for a finer resolution of analysis of resource selection. However, when discussing biological relevance, the second study design is not to be recommended, as usage and availability are measured at different levels, and consequently therefore not comparable. Results based on the second study design could hence be misleading.

Geese are large, social birds and obligate herbivores (Fox and Abraham, 2017, Fox and Madsen, 2017, Fox et al., 2017). The main breeding grounds for most geese are located far north, in tundra and taiga habitats, but they spend the rest of the year farther south where they congregate in large flocks and feed on farmland or grasslands near lakes and wetlands (Fox and Abraham, 2017, Fox and Madsen, 2017, Fox et al., 2017). When selecting foraging sites, and food items, geese are expected to maximize intake rates of high quality foods, whilst at the same time minimizing energy expenditure, inter-and intraspecific competition, and predation risk from a fitness perspective (Mac Arthur and Pianka, 1966, Fretwell and Lucas, 1970, Schoener, 1979).

Outside the breeding season geese generally feed during the day, mainly on agricultural crops and grasslands, and return to open waters during the night to roost, safe from terrestrial predators (Ave et al., 2017, Fox et al., 2017). Feeding on agricultural crops allows geese to meet their daily energy requirements with less foraging time, but due to the relatively low nutrient quality in plant foods in general, it is important for herbivorous birds to maximize their nutrient intake by selecting for foods with the highest nutrient concentrations (Sedinger, 1997, Fox et al., 2017). Although flight enables geese to exploit a wide range of food resources within flight distance from the roost, food quality is especially important to avian herbivores due to the digestive limitations on food intake, since their relatively simple gut and small body size limit their ability to compensate for low nutrient concentration by eating larger amounts of food (Sedinger, 1997, Fox et al., 2017). Geese are therefore highly selective grazers, mainly preferring food with high digestibility and low fiber content (Sedinger, 1997, Vickery and Gill, 1999, Fox et al., 2017). Studies have further shown that geese select for food with high nitrogen content, especially crops subjected to nitrogenous fertilization (Sedinger, 1997, Vickery and Gill, 1999, Fox et al., 2017). Fertilization of grassland facilitates increased intake rate of nitrogen due to improved food quality and low diversity of plant species compared to natural grasslands, making managed grasslands more attractive to geese (Sedinger, 1997, Vickery and Gill, 1999, Fox et al., 2017).

Europe has experienced a recent population increase of geese, mainly due to changes in the agricultural landscape that increasingly offers abundant food resources of high quality. This has caused geese to abandon natural and semi-natural wetlands and grassland to increasingly forage on farmland where their consumption of agricultural crops causes reduced yields and major conflicts with farmers (Fox and Abraham, 2017, Fox and Madsen, 2017, Fox et al., 2017). Inorganic fertilizer application, improved tillage techniques, mechanization, pesticides, and the use of increasingly efficient and high-yielding cultivars have extended the growing season, and enhanced the quantity and quality of biomass produced (Fox and Abraham, 2017). Consequently, the increase in large-scale and intensified agriculture in Europe has unintentionally created seasonally abundant and highly attractive food resources for geese (Fox and Abraham, 2017, Fox et al., 2017). These large-scale changes within the agricultural landscape have acted as important drivers of goose population growth and shifts in their distribution, expanding their winter range northwards, and to stay longer periods of time in the latter (Therkildsen and Madsen, 2000, Clausen and Madsen, 2016, Fox et al., 2017). Elevated reproductive success as a result of more profitable foraging and by increased winter carrying capacity have had a positive effect on goose populations in Europe (Fox and Abraham, 2017, Fox and Madsen, 2017, Fox et al., 2017). Rapidly increasing and expanding goose populations are causing conflicts not only with agriculture, but also with airport security, and with the public through littering of recreational areas (Fox and Abraham, 2017, Fox and Madsen, 2017, Fox et al., 2017).

Objectives and limitations

Due to climate change and population growth, geese are now present on European farmland in higher numbers and for longer periods of time, resulting in increased conflicts and economic losses for individual farmers and society. Spatial and temporal distribution of geese are a result of their behavior, and in turn by landscape characteristics. Knowledge about the behavior of geese, and the factors influencing movement patterns and habitat use, are crucial for the understanding of the spatio-temporal variation of distribution, and provide crucial information for management decisions and improving methods for reducing crop damage.

The objectives of this review are to summarize existing research on movement patterns, and food and habitat preferences of geese on agricultural land in Europe, and identify knowledge gaps. Based on previous research, this review will further evaluate what factors affect landscape attractiveness, food preferences and field selection of geese on farmland.

This review includes studies addressing habitat selection, related to availability in all goose species. It does not include arctic or tundra based research, or temporal and spatial patterns of migrating geese, i.e. timing of migration and selection of routes. When reviewing the literature, emphasis is put on empirical studies of individually marked birds through telemetry devices or neck bands, although relevant and recent literature reviews and results from other study designs are also considered. The literature search was mainly conducted in the database Web of Science using the key words “geese” or “goose” and “selection/feeding/ecology /preference/movement/utilization/agriculture/crop”, and by looking up original references in review articles on the subject.

Selection of habitat and food

Goose movements and distribution at landscape and local levels are mainly a consequence of habitat and food selection. There are several factors involved in this selection process, some of which are covered in this section.

Spatial and temporal variations – Seasonal change

There are seasonal variations in the nutritional demands of geese, affecting their food selection and foraging behavior. In early spring, they rebuild flight musculature and fat stores for the upcoming migration and breeding season, and they are therefore in need of a high supply of food rich in protein and energy (Giroux and Patterson, 1995, Sedinger, 1997, Fox et al., 2017). During this time of year the majority of geese shift to mainly feeding on agricultural grasslands, utilizing the period of rapid plant growth (Giroux and Patterson, 1995, Sedinger, 1997, Fox et al., 2017). In autumn and early winter, when the geese have returned to their winter quarters, they tend to select especially for foods rich in protein and fat, in order to repair and rebuild damaged tissues after the migration flight, and to replenish fat stores for upcoming winter demands (Giroux and Patterson, 1995, Sedinger, 1997, Fox et al., 2017). During this time, geese are highly selective for spilled grain left from cereal harvest in stubble fields, when available (Giroux and Patterson, 1995, Sedinger, 1997, Fox et al., 2017). During mid-winter, food quality and abundance is often lower, day length for foraging is shorter, and energy expenditure is higher due to increased thermoregulation (Giroux and Patterson, 1995, Sedinger, 1997, Fox et al., 2017). Therefore, geese typically switch to foods higher in carbohydrates and lipids, and lower in protein, compared to in summer and early autumn (Giroux and Patterson, 1995, Sedinger, 1997, Fox et al., 2017).

Compared to natural habitats, residual grain, waste from root crops, reseeded and managed grasslands, and increased availability of winter-green cereal crops, have together greatly improved the availability and abundance of high quality food for geese, and enable greater food intake rates during most parts of the year (Fox and Abraham, 2017, Fox et al., 2017). There are nevertheless temporal variations in terms of food quality and availability, affecting food selection by geese. In the majority of the wintering areas, grass ceases to grow in winter, so when the stubble fields have been depleted geese tend to feed mainly on agricultural root crops, and autumn-sown crops (Gill, 1996, Sedinger, 1997, Therkildsen and Madsen, 2000, Fox et al., 2017).

Geese select for fields with food that is locally highly abundant, thus some of the seasonal variations in distribution and habitat selection of geese are directly due to changes in food biomass and availability (Fox et al., 2017). Geese can compensate to some extent for a depletion of food resources by increased peck rates and feeding time, but a reduction of food abundance will ultimately result in a shift to the next most profitable feeding resource (Mac Arthur and Pianka, 1966). Examples of seasonal changes in availability of food resources are the highly digestible and nutritious grass during the first sprouting in spring, and the short-term availability of spilled harvested crops in the autumn. Deep snow and ground frost have been shown to affect feeding selection of geese, forcing them to abandon crop types such as root crops and winter cereals which they normally select during winter, and switch to foods that protrude the snow (Fox et al., 2017).

Some studies have also suggested that during spring, when geese feed mainly on grasslands, they tend to follow the "green wave" of renewed plant growth on their migration towards breeding areas further north (Fox et al., 1994). A response to a spatio-temporal gradient of plant growth, triggered by increasing temperature, where geese profit from the high protein content in these plants associated with the onset of growth (Fox et al., 1994).

Disturbance

Various types of disturbances are often responsible for birds leaving a field or area, sometimes being responsible for more than 50 % of flight take-offs (Giroux and Patterson, 1995), and for affecting the overall behavior of birds during rest and foraging by inducing head-raising or calling (Owens, 1977). Disturbances increase the energetic costs, leave less time for feeding, and alter the movement patterns of geese, causing temporary displacement in the distribution towards less optimal habitats or foraging areas (Giroux and Patterson, 1995, Adam et al., 2016, Fox et al., 2017). Hunting, for example, directly affects goose populations through killing, but also indirectly through the disturbance caused by shooting and human presence (Adam et al., 2016). Besides intentional scaring and presence of predators and other animals, human infrastructure such as buildings, roads and windmills, and environmental attributes like hedgerows, forest patches and tall vegetation, are associated with perceived increased predation risk by geese (Giroux and Patterson, 1995, Jensen et al., 2017). Thus, geese tend to select foraging habitats with less disturbance and lower predation risk (Giroux and Patterson, 1995, Jensen et al., 2017). Larger, more heavily used roads are believed to constitute a smaller disturbance effect, as geese tend to get used to the constant disturbance, compared to smaller roads where traffic is more irregular (Giroux and Patterson, 1995, Jensen et al., 2017). Although there are large variations among species, individual populations, seasons, sources and levels of disturbance, a disturbance effect of human infrastructure have been observed at distances up to 500m (Vickery and Gill, 1999, Jensen et al., 2017). The majority of geese move more than 100m after being disturbed, seeking new feeding areas with less disturbance. However, the return time after disturbance is usually shorter in fields that are highly preferred by geese, whereas the return time is longer in relation to less preferred fields (Giroux and Patterson, 1995, Jensen et al., 2017).

Disturbance causes individual geese to use significantly larger areas for feeding, and is also associated with increased flight distances between roosting and feeding sites. Disturbance therefore has a significant impact on the movements of geese on field and landscape levels, and it influences the availability of feeding sites (Giroux and Patterson, 1995, Adam et al., 2016). Geese also tend to avoid heavily disturbed areas and those with restricted visibility, or only utilize them when resources have been depleted at less disturbed areas, in order to minimize perceived predation risk, sometimes at the expense of food quality or abundance (Owens, 1977).

Access to water

Open water bodies offer geese fresh drinking water and refuge from terrestrial predators, and access to such is needed within the landscape in order for an area to be suitable for geese. The average size of water bodies used for roosting by geese ranges between 50 and 60 hectares, although there are some variation depending on species and region (Adam et al., 2016). As geese congregate at roosting sites for the night, the distance, or rather the energy use, of the flight from the roost site to the feeding area affects field selection (Fox et al., 2017, Jensen et al., 2017). Even if the feeding range in some goose species may be larger at certain sites, the distance between roost sites and feeding areas is usually 1-10km, where the majority of the geese feed within 5 km of the roost site (Giroux and Patterson, 1995, Vickery and Gill, 1999, Si et al., 2011, Adam et al., 2016, Jensen et al., 2017). The importance of distance to the roost is driven by minimizing the energetic loss of increased flight distances (Schoener, 1979). Therefore, feeding sites closer to roost sites are preferred, and tend to become exploited and depleted by foraging geese before comparable feeding resources at greater distances from the roosts (Schoener, 1979).

Distance to water seems to be increasingly important for geese occurring in agricultural landscapes during the breeding season, affecting density and habitat choice of breeding adults and their goslings (Olsson et al., 2017). In the study by Olsson et al. (2017), all breeding geese were observed less than 800 m from the shoreline of the roost, a considerably shorter distance compared to those observed in other studies performed outside of the breeding season. This could be seen as a potential anti-predator strategy, as breeding Greylag geese are vulnerable to terrestrial predators as gosling and their parents are flightless during this time of year (Olsson et al., 2017).

Field size

Geese select large fields over smaller fields of the same crop, mainly to reduce predation risk and other disturbances, although the selection for larger fields may also be influenced by the fact that larger fields can sustain more geese (Fox et al., 2017, Jensen et al., 2017). The average size of fields selected by geese is about 10 ha, although they rarely use fields smaller than 5 ha (Vickery and Gill, 1999). Field size tend to be an increasingly important variable in terms of selection during the hunting season, when geese are more sensitive to disturbance (Jensen et al., 2017). There has been suggestions of an "edge effect" as a possible explanation to the tendency of geese to avoid smaller fields, as the edges of the field are usually closer to human infrastructure or environmental attributes associated with increased perceived predation risk by the geese (Vickery and Gill, 1999).

Sward height

There is a difference in preferred sward height of grasslands depending on bill size, where goose species with larger bills tend to select taller swards compared to geese with smaller bills (Fox et al., 2017). Nevertheless, most geese select for relatively short swards since they provide the highest quality in terms of high nutrient and low fiber content, and as such swards also have an active regrowth (Durant et al., 2004, Fox et al., 2017). This is one of the reasons why recently harvested ley fields in general are selected by geese compared to fields with tall grass (Vickery and Gill, 1999, Si et al., 2011, Fox et al., 2017, Olsson et al., 2017). The relationship between sward height and nitrogen content can however be reversed in fertilized grasslands, where the nitrogen content is often high in general, and across swards of all heights, compared to unfertilized grasslands that usually show increasing nitrogen content with decreasing sward height (Riddington et al., 1997, Vickery and Gill, 1999, Fox et al., 2017). Thus, due to higher nitrogen content, fertilized grasslands are often more attractive to geese than unfertilized or natural grasslands (Hassall and Lane, 2001).

Movement patterns

Movements of geese at different spatial scales have so far been discussed in this review as a consequence of food and habitat selection, but there are further factors that can affect goose movements to various extents. The latter are covered in this section.

Geese tend to be limited to a certain area, or home range, in their movements during non-migration periods. The short-term home range size tends to vary greatly among sites, species, and seasons, ranging between about 400 and 84 000 hectares (Phillips et al., 2003, Adam et al., 2016). There seems to be an overall pattern where geese tend to expand their feeding range in late winter, as grazing on preferred sites may have depleted the food supply and thus possibly increased competition for food resources (Phillips et al., 2003). Unpaired geese are also more likely to use larger feeding areas than paired (Kruckenberg and Borbach-Jaene, 2004). The main movement activity within the home range of geese is usually that of moving between resting and feeding sites. Since movement requires energy, and is a trade-off with time spent foraging, it is often restricted also within the home range.

Site fidelity and social interactions

Geese exhibit site fidelity at several spatio-temporal scales, often returning to the same staging or breeding area for several years, restricting their movements and habitat choice to relatively few sites and often returning to the same area for feeding within a season, as well as returning to the same field after being exposed to disturbance (Fox et al., 1994, Giroux and Patterson, 1995, Phillips et al., 2003, Clausen and Madsen, 2016, Ave et al., 2017). Despite the fact that many sites at different spatial scales are suitable goose habitats, not all are utilized equally, meaning that some sites are simply more popular than others. Thus, site fidelity, or the return rate to a particular site, can be used as an indication of the quality of that site, even though the factors that affect the selection process may be unknown. Returning to an area with predictable, and stable availability of resources in terms of safe feeding areas with disturbance-free roosts, is one strategy of ensuring good chances of survival and reproductive success, and is shown by the majority of goose populations in most areas, although some geese are more sedentary than others (Fox et al., 1994, Fox et al., 2010). Thus, site faithful geese might not select the most optimal site, but instead return to a site with predictable resources of sufficient quality.

It has been shown in experimental studies that geese are capable of learning and has a long-term memory with the ability to distinguish between quantitative differences (Weiss and Scheiber, 2013). In the experimental study by Weiss and Scheiber (2013), geese showed that they were able to learn and differentiate between colors, where the higher ranked color was rewarded with food, and remember this for several months to a year. The results of the study were discussed in terms of geese using these abilities to optimize social interactions, but it may also be useful skills for geese in the process of food selection and could help to further understand and explain their foraging behavior. Juvenile geese have moreover been shown to be capable of recognizing and discriminate between individual group members of the same species (Scheiber et al., 2011). As geese are social birds, capable of both learning and remembering, it is possible that tradition and social learning between juvenile and parental birds plays an important role when geese return to the same site year after year.

Paired birds seem to be more site faithful than unpaired adults, which can be explained by the high energy demand during the breeding season, and the correlation between breeding success and acquisition of body reserves during spring (Kruckenberg and Borbach-Jaene, 2004). Accordingly, favorable feeding conditions during late winter and spring may increase breeding success the same year, and it is therefore profitable for paired birds to return to well-known sites for feeding during spring migration (Kruckenberg and Borbach-Jaene, 2004). Non-breeders, young birds and older birds without breeding partners can afford and may gain experience by being more mobile and testing new feeding areas while simultaneously looking for new roost sites (Kruckenberg and Borbach-Jaene, 2004).

In a study by Ave et al. (2017), about 40 % of the habitat choice in spring and summer was explained by the rearing conditions of the geese. The geese consistently returned to the same site, or sites that resemble the rearing conditions they experienced themselves, to rear their young and to forage (Ave et al., 2017). Between years, site fidelity has been shown to vary with breeding success, with higher return rates in birds that produced many goslings the previous year (Kruckenberg and Borbach-Jaene, 2004). Two possible explanations for this has been proposed; one being that long-term site-faithful geese have a high breeding success, because they know the area well and can choose optimal feeding sites, thus making the number of returning geese an indirect measurement of the quality of the site (Kruckenberg and Borbach-Jaene, 2004). The other explanation relates to increased survival rates rather than breeding success, indicating that birds with high return rates are more successful in choosing sites with low predation and hunting pressure (Kruckenberg and Borbach-Jaene, 2004). Another possible explanation, based on the fact that young geese from more favorable rearing conditions seem more likely to feed on high quality food such as residual corn and grain, is the competitive advantage over geese reared in less favorable conditions due to superior body condition (Ave et al., 2017).

Geese are social birds, and often occur in large, mixed-species flocks, a behavior that is believed to have a positive impact on time spent on foraging, as alertness has been shown to decrease with flock size, and with presence of other goose species (Kristiansen et al., 2000). Due to the dilution effect, occurring in larger flocks may also be favorable to individual geese in terms of decreased predation risk (Kristiansen et al., 2000). Since geese often occur in groups, social interactions and the behavior of other birds influence the movements of the individual bird. For example, this can be seen for disturbance behavior, which is many times determined by the most sensitive individuals within a flock, as the sudden departure of a few individuals often causes the whole flock to follow (Owens, 1977). With increased numbers, and increased competition for high quality food and habitats, the more favorable sites are often occupied first, something that could force animals of lower social status, or birds less able to compete for preferred resources, to feed on less preferred sites (Senft et al., 1987). The effect of increased goose numbers on habitat selection, becomes increasingly important for goose movements when high quality sites approach their carrying capacity, due to depleted resources (Prop et al., 1998).

Landscape configuration and environmental change

Wetland restoration, implementation of nature reserves and availability of other disturbance-free refuges have also been shown to affect habitat selection by geese, and as an effect their movements and distribution at a landscape level. When there is no difference in food quality or quantity between habitats with more or less disturbance, geese tend to spend most of their grazing time in disturbance-free areas (Si et al., 2011). The level of human presence, as well as intentional scaring and other disturbances, influence the attractiveness of certain areas for geese, meaning that the location of disturbance-free refuges has an effect on goose distribution by pushing geese away from heavily disturbed areas towards areas with less disturbance (Si et al., 2011).

Major environmental changes can further alter the habitat choice of geese, as they are often capable of swiftly moving to new foraging or staging areas after a loss of a previously preferred site (Clausen and Madsen, 2016). Geese are thus able to respond very well to rapid changes to the environment, despite being site-faithful in general (Clausen and Madsen, 2016). Climate change has been shown to alter the migration patterns of some goose species at larger spatial scales, with a northward shift of wintering grounds and associated stop-overs sites during migration (Gauthier et al., 2005). There have also been temporal changes in large scale movement patterns of geese due to increased temperatures, with earlier goose migration in spring, and delayed fall migration (Gauthier et al., 2005).

Discussion

The objectives of this review were to identify and summarize existing research on movement patterns, and food and habitat preferences in geese on agricultural land in Europe, and to identify needs for future research. The initial aim was to focus the review on empirical studies of individually marked birds through telemetry devices or neckbands when reviewing the literature.

Available literature shows some consistent patterns of movement and selection of food items and habitat. Theories describing minimization of predation risk and energy expenditure, and maximization of energy and nutrient intake, are demonstrated by geese through studies where they are shown to generally prefer larger fields with plants of high quality and relatively short sward height, close to water bodies (Giroux and Patterson, 1995, Durant et al., 2004, Adam et al., 2016, Jensen et al., 2017). These general patterns can be used to predict spatial distribution of geese and to assess the probability of damage to certain agricultural fields or areas, and to guide the focus of preventative measures. The movement patterns of geese are influenced further by social interactions, landscape configuration, seasonal variations in food availability and abundance, and long-term environmental change (Si et al., 2011, Clausen and Madsen, 2016). To make the selection process even more complex, predictability of sufficient habitats or foods, and tradition, seem to play an important role for geese when choosing habitat or foraging site (Fox et al., 1994, Giroux and Patterson, 1995, Phillips et al., 2003). These are behaviors that may hinder efforts to actively attract geese to certain areas from another site utilized by geese, in order to reduce damage.

However, there is also variation among species, study areas, and across scales in the importance of different factors. Due to this variation it is for example important to consider site specific availability of resources when studying the selection process, to be able to assess the relevance and applicability of the results also to other populations and study areas. When studying previous research on selection by geese in agricultural landscapes, I found that very few studies have measured both usage and availability at an individual level (table 1 & 2), and there are only four European studies to this date that are based on telemetry data (table 2). Accordingly, studies which mainly address home range size, site fidelity, roost-feeding site flight distance, daily time budget, and the use of refuges, where focus is rather on movement patterns, and not on the selection processes behind goose movements. The studies of Giroux and Patterson (1995) and Si et al (2011) are the only telemetry-based studies where food selection in agricultural areas was investigated. In addition, the telemetry based studies were very restricted in terms of study areas and sample size, ranging from 8 to 18 individual birds, which limits the possibilities of drawing general conclusions relevant at population level and outside of the particular study area. When reviewing current knowledge about selection and movements of geese in agricultural landscapes, it is evident that there is a knowledge gap, and an urgent need for additional ecological knowledge to be able to guide current and future management, making the development of this field of high importance. This serious knowledge gap and the major management challenges associated with increased goose abundance and expanded ranges in northern Europe, and the related conflicts with agriculture, together with the difficulties of managing migratory bird species, constitute major challenges for future management. Moreover, due to the major changes in goose abundance and agricultural practices that have taken place in recent years, earlier goose research becomes less relevant under current conditions (Fox et al., 2017).

Table 1: Studies (N) listed by study design (1st, 2nd and 3rd) according to Krebs (1999) and relevant reviews articles. In the first study design, both usage and availability are measured at a population level. In the second study design, usage is measured at the individual level, while the availability of resources is measured for the entire population. In the third study design both usage and availability are measured at an individual basis. Studies based on the third study design is covered in table 2, where they are additionally categorized according to methods.

Design	N	Study
1st	8	Owens 1977, Fox et al 1994, Gill 1996, Riddington et al 1996, Prop et al 1988, Kristiansen et al 2000, Jensen et al 2017, Olsson et al 2017
2nd	None	None
3rd	12	(Table 2)
Reviews	13	Mac Arthur & Pianka 1966, Fretwell & Lucas 1970, Schoener 1979, Johnson 1980, Senft et al 1987, Sedinger 1997, Vickery & Gill 1999, Gauthier et al 2005, Fox et al 2010, Buij et al 2017, Fox & Abraham 2017, Fox et al 2017, Fox & Madsen, 2017

Table 2: Studies (N) based on the third study design according to Krebs (1999), listed according to methods. The experimental methods includes studies where domesticated geese have been used, or when wild geese have been exposed to altered environments. Studies where marked geese have been used are mainly based on geese with neckbands or color rings or with different types of telemetry devices.

	Experimental	Color marked	GPS / Telemetry
N	4	4	4
Study	Hassall & Lane 2001, Durant et al 2004, Scheiber et al 2011, Weiss & Scheiber 2013	Therkildsen & Madsen 2000, Kruckenberg & Borbach Jaene 2004, Clausen & Madsen 2016, Ave et al 2017	Giroux & Patterson 1995, Phillips et al 2003, Si et al 2011, Adam et al 2016,

Studies in which both usage and availability are measured at an individual level are therefore much called for, as are studies in which larger spatial and temporal scales are considered, so that general patterns can be identified and used at a larger scale. New knowledge about factors affecting landscape attractiveness, food preferences and field selection of geese on farmland is needed, in order to develop more efficient management practices and to address current and future conflicts with agriculture. Understanding, and being able to predict, the behavior and movement of geese is important for damage prevention, and for developing future management strategies, in the new (i.e. with more geese, intensified farming practices and milder climate) and changing agricultural landscape. I therefore recommend to make use of recent advances in technology of telemetry devices and the possibilities of performing more detailed ecological studies to learn more about the behavior of individual geese and their direct response to different management actions.

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