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Maize stubble as foraging habitat for wintering geese and swans in northern Europe

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Abstract

Agricultural crops have become increasingly important foraging habitats to geese and swans in northern Europe, and a recent climate-driven expansion in the area of maize fields has led to a rapid increase in the exploitation of this habitat. However, due to the novelty of maize foraging in this region, little is known about the abundance and energetic value of this resource to foraging birds. In this study we quantify food availability, intake rates and energetic profitability of the maize stubble habitat, and describe the value of this increasingly cultivated crop to wintering geese and swans in the region. Our results indicate that the maize resource varies considerably among fields and years, but also that the energetic returns from maize foraging is substantial. As such, fields with extensive spill allow foraging birds to fulfill their daily energetic demands in 4 hours of active foraging. Both the area of cultivated maize fields and the importance of this habitat to foraging birds are expected to increase in years to come. This may alleviate conflicts with other more vulnerable crops such as winter cereals, and have the potential to affect migratory decisions, site use and population dynamics of geese and swans wintering in northern Europe.

Keywords: Waterfowl; habitat use; intake rates; assimilation; Barnacle Goose; Pink-footed Goose; Bewicks' Swan

1. Introduction

During the last decades, wintering waterfowl across the northern hemisphere have increasingly exploited agricultural areas as foraging habitats (Abraham *et al.*, 2005; Fox and Abraham, 2017). The shift in habitat use from natural wetlands to farmed croplands has mainly been driven by differences in the accessibility and quality of available foods (Madsen, 1985; Béchet *et al.*, 2004; Nolet *et al.*, 2014; Fox and Abraham, 2017), and has likely been a driving factor of recent population increase in many waterfowl species (Van Eerden *et al.*, 1996; Fox and Madsen, 2017). Early evidence of waterfowl foraging on crops can be traced back to the medieval period (Kear, 2001), but it was not before the twentieth century when large areas of wetlands were reclaimed and inorganic fertilizer developed, that many waterfowl went through the transition to forage mainly on agricultural land (Van Eerden *et al.*, 2005; Fox and Abraham, 2017). Nowadays, the phenomenon has spread to cover many swan and goose species and a wide array of different exploited crops (Madsen *et al.*, 1999; Chisholm and Spray, 2002; Nolet *et al.*, 2002).

In the U.S. and Southeast Europe waterfowl exploitation of maize (*Zea mays*) stubble fields has taken place for many years (Glazener, 1946; Alisauskas *et al.*, 1988; Sutherland and Crockford, 1993), but only recently, in response to a global warming-induced increase in maize cultivation in northern Europe, has this food resource been exploited by waterfowl wintering in this region (Kenny and Harrison, 1992; Odgaard *et al.*, 2011). The first observations of swans on maize in Northwest Europe were reported in Germany in the mid-1990s (Degen *et al.*, 1996) and the first substantial numbers of geese on maize stubble was made in the Netherlands in 2008 (Cottaar, 2009) and in Denmark and Poland in 2009 (Rosin *et al.*, 2012; Madsen *et al.*, 2015). Since then, the use of maize stubble has increased considerably in this region, in parallel to a steep increase in the available area of maize stubble habitat (Clausen *et al.*, in press).

Due to the novelty of this food source in northern Europe little is known about the amount of food available on harvested fields and the profitability of this habitat to wintering geese and swans in this region. Studies from the U.S. suggest that waste maize can be a highly valuable food resource to waterfowl (Alisauskas *et al.*, 1988; Gates *et al.*, 2001), but in northern Europe where maize is cultivated close to its northern thermal limit, and used mainly for silage produced from immature cobs and vegetative parts, energetic gains might be less profitable (Kenny and Harrison, 1992; Andersen, 2000). In this study we investigated the profitability of maize stubble fields as a food resource to wintering waterfowl in northern Europe. This was achieved by 1) Assessing the amount of food available on harvested fields, 2) Investigating intake rates of wild birds foraging on maize stubble habitat and 3) Examining the energetic profitability of maize consumed by captive birds. Collectively, this enabled us to evaluate the value of maize stubble as a food resource in the north European agricultural landscape.

2. Methods

2.1 Food availability and its relationship with goose usage

Availability of spilled maize was investigated in Denmark at the three study sites Drengsted (55.08 N, 8.86 E), Stadilø (56.17 N, 8.16 E) and Lund Fjord (57.10 N, 9.03 E, Table 1, Supplementary appendix, Picture 1) in the autumns of 2015, 2016 and 2017. Drengsted was visited in all three years to test for annual differences. Food availability was estimated by counting the number of maize cobs in areas of 10 x 10 m on harvested maize fields. Each field was randomly sampled several times (5 to 10 plots depending on size) to obtain an overall average estimate of cob density. In two fields where the maize crop had been downed by an October storm and subsequently harvested, the resource was manifold bigger compared to all other fields. Due to time constraints food availability in these fields was assessed by estimating the number of cobs in 5-10 samples of 9 m^2 (equivalent to the area between two rows of crops for 10 m).

Ten full cobs were collected at random to determine the mass of available maize grain on individual cobs. The number of grain on individual cobs was determined, and 10 grains from each cob dried at 80°C to constant weight to obtain the dry mass. The mass of available grain per cob was calculated by multiplying the number of grains on individual cobs with the average dry weight of individual grains. Fields were visited up to two weeks after harvest was completed, and on a few fields that had already been visited by geese (seen by the presence of droppings), we accounted for the already exploited resource by including empty cobs in our estimate of cob numbers (see Supplementary appendix, Picture 2). This ensured that preceding exploitation by birds and small mammals was likely to only have had a limited impact. However, both roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*) may remove entire cobs from harvested fields. The initial resource just after harvest might therefore have been slightly larger.

In 2015 some of the fields in Drengsted were heavily used by Pink-footed Geese (*Anser brachyrhynchus*) and Barnacle Geese (*Branta leucopsis*). On these fields we counted the number of droppings and cobs in randomly placed circles with radius 1 m. These data were used to investigate whether there was a relationship between food availability and goose usage of the maize stubble habitat.

2.2 Intake rates of maize-foraging wild birds

Intake rates of free-ranging birds were inferred from video recordings of foraging birds in actual maize stubble fields at Stadilø in November 2015. We used a wireless surveillance system (ABUS TVAC 16000B modified to our needs) to record the number of geese and time spent foraging in three sampling areas of 40 m^2 (8 x 5 m). The rectangular sampling areas were outlined with 4 small bamboo sticks, and baited with a pre-determined amount of maize forage (from 25 to 90 entire cobs) to attract foraging geese (Supplementary appendix, Picture 3). The small recorders were placed at one end of the sampling areas on thin iron poles, and camouflaged with a few intact maize stems. The power supplies (car batteries) were buried on the field beneath the video recorders. The setup was inspected at intervals of 2-3 days, and when clear signs of foraging were observed data on ingested mass and foraging time were collected. Ingested mass was derived by judging the proportions of each maize cob eaten and the knowledge of grain mass per cob derived above. Foraging time was determined by assessing the number of geese present on the video footage at intervals of 1 minute, and summarising across the entire foraging event to estimate the total number of “goose minutes” spent foraging. Geese were always actively foraging when on the sampling area, but our definition of “foraging time” includes finding and handling the food, in addition to occasional aggressive encounters with conspecifics. We used our knowledge of ingested food mass and goose foraging time to derive intake rates in the following way:

$$Intake\ rate\ (g\ dw/min)\ = \frac{Mass\ of\ maize\ grain\ eaten\ (g\ dw)}{Foraging\ time\ (min)}$$

2.3 Energetic profitability of maize forage

Energy content of the maize forage at Stadilø was measured using a bomb calorimeter (C-5000, IKA, Staufen). Assimilation efficiency was investigated using three wild-caught adult Bewicks' Swans (*Cygnus columbianus*) held at Netherlands Institute of Ecology (NIOO) in Heteren, The Netherlands. The swans had been acclimated to the experimental set-up by 7 – 9 identical measurements with other carbohydrate-rich food sources prior to the maize measurements. Each swan was held in a two-chamber metabolic cage with maize forage for four consecutive days in early December. Maize forage and water was supplied ad libitum and weighed at 09:00 and 17:00 each day. A control food supply was also weighed to correct for possible desiccation or water absorption. In order to minimize stress, the swans were not handled during the trial. The swans were weighed each morning at 09:00 by allowing them to step into a mobile weighing cage with an electronic balance (IB-34, Sartorius, Nieuwegein) underneath the floor. The swans were then transported to the adjacent, clean chamber. The excreta in the first chamber were collected from the tray below the grid floor (70 x 70 cm) and together with a sample of the maize forage stored at -24°C until further analysis. The food sample and a 100 g sample of the excreta were freeze dried at -80° C, the rest of the excreta was dried to constant weight at 70°C. For each day gross energy intake (GEI, kJ/day) and excreted energy (EE, kJ/day) were calculated as the product of dry weight (ingested or excreted per day) and the energy content as measured by the bomb calorimeter. Because the calculation assumes energy balance, days with a body weight difference > 2% and with a GEI < 500 kJ were omitted, leaving data of three trial days for each swan, for which GEI and EE were averaged. The assimilation efficiency (AE) was calculated as:

$$AE\ (\%) = \frac{\text{GEI} - \text{EE}}{\text{GEI}} * 100$$

The maize forage used in the swan assimilation measurements originated from a field in the Netherlands similar to the ones where intake rates were measured at Stadilø, and we assumed the results to be transferrable.

3. Results

3.1 Food availability

Available maize forage was assessed in a total of 141 plots covering 17 fields. The average amount of spilled maize on harvested fields varied substantially. On normally harvested fields the average (mean ± SE) was 3.42 ± 0.64 g dw/m^2, and the minimum and maximum amounted to 0.37 and 6.52 g dw/m^2 respectively (Table 1). The two fields with downed crops and suboptimal harvest had a maize resource > 100 times higher averaging 358.53 ± 41.69 g dw/m^2. Within the normally harvested fields the resource was very patchily distributed, and at the level of individual 10 x 10 m plots food availability ranged between 0 – 20.1 g dw/m^2 (corresponding to 0 – 38 entire cobs). Repeated assessments of plots in Drengsted during 2015, 2016 and 2017 revealed annual differences in food availability ($F_{2,101} = 34.934$; $P < 0.001$). These were also significant when omitting the fields downed by wind in 2017 ($F_{2,85} = 11.252$; $P < 0.001$), and presumably related to differences in harvest conditions (Brian Bech, pers. comm.).

Density of droppings on the exploited fields in Drengsted correlated positively with the number of spilled cobs ($F_{1,40} = 42.782$; $P < 0.001$), indicating that goose usage reflected the available amount of resource (Fig. 1).

3.2 Intake rates of maize-foraging wild birds

Maize-foraging at Stadilø was observed for several species of waterfowl, including Pink-footed Geese, Barnacle Geese, Whooper Swans (*Cygnus cygnus*) and Bewicks' Swans. Because the available area of good quality habitat (maize and cereal stubble fields) was large, it proved difficult to capture actively foraging birds on the small sampling areas at the site. As a consequence, a total of 4 foraging events were recorded inside the sampling areas during the period with large waterfowl numbers at Stadilø – all of Barnacle Geese (Table 2). Intake rates varied between 0.82 – 1.17 g dw/min depending on available maize forage, and seemed to indicate a classical type 2 functional response. Waterfowl foraging on grains and plant storage organs generally exhibit type 2 functional responses (Nolet *et al.*, 2002; Amano *et al.*, 2004; Béchet *et al.*, 2004), and because our limited data seemed consistent with this pattern, we fitted a Holling's Disc Curve (Holling, 1959) to the available data (Fig. 2). However, given the relatively few data points, this curve should be interpreted with caution.

The footage revealed that geese foraged on individual cobs by tearing of the husk (sometimes cooperating in pairs), and gnawing on the exposed grains. The gnawing led to an almost complete removal of grains (Supplementary appendix, Picture 2). In addition to foraging on the cobs, Barnacle Geese were seen pecking on the emerging undersown grass crop.

3.3 Energetic profitability of maize forage

Energy content of the maize from Stadilø where intake rates were investigated was 16.791 ± 0.114 kJ/g dw (mean ± SE). Assimilation efficiency (AE) of individual Bewicks' Swans varied between 79.4 % and 83.9 %, with an overall average of 81.4 % (Table 3).

4. Discussion

In agreement with studies on maize in other parts of the world (Alisauskas *et al.*, 1988; Gates *et al.*, 2001), our results indicate that in terms of energetic profitability maize stubble is high-quality food in line with other carbohydrate-rich food sources (e.g. Nolet *et al.*, 2002; Fox and Abraham, 2017). The metabolizable energy of maize in our study during late autumn amounts to 13.7 kJ/g, which is relatively large in comparison with grass diets (6.7 - 7.5 kJ/g) and winter cereals (7.3 – 10.6 kJ/g) during the same season (Prop & Vulink, 1992; Therkildsen and Madsen, 2000; Fox and Abraham, 2017). Although maize is currently cultivated near its northern limits in northern Europe, energetic returns from maize foraging is therefore very high. In addition, with current agricultural practice in this region, it is together with cereal stubble fields quantitatively much more important than other agricultural crops.

The field work in this study was limited to Denmark, but we see no reason why the results should not be representative of other north European countries where maize cultivation is likewise expanding. The current northern boundary of maize cultivation coincides with Danish boarders, and the energetic value of this food resource in countries further south might, if anything, increase with a warmer climate. We therefore expect maize stubble to be a valuable resource in the neighboring countries as well.

In theory, our estimation of intake rates could be affected by foraging of wildlife other than Barnacle Geese during the period between two visits to the sampling areas. However, such events would also have been captured by the video recorder. Our footage revealed active maize foraging by hare (*Lepus europaeus*), roe deer and red deer, demonstrating that the resource was shared with other wildlife as well. However, none of these events took place in time windows with foraging geese, why any impact from foraging by other animals can be ruled out.

Baldassarre *et al.* (1983) found that waste maize availability varied greatly between fields in Texas (roughly 5 - 120 g dw/m^2), and showed that the amount of waste correlated inversely with crop moisture. This is in good agreement with findings from our study, suggesting that maize stubble fields may vary considerably in their value to waterfowl species depending on the effectiveness of the preceding harvest. In a dry autumn with early harvest, very little spill will be available. However, delayed harvest and, in particular, stochastic events like autumn storms before harvest may cause downing of maize fields on a regional scale. As shown, this can lead to an enormous spill. Being highly mobile and exploratory, geese are able to quickly identify and exploit such areas (Clausen and Madsen, 2016).

The area of cultivated maize is increasing in the agricultural landscape of northern Europe (Fig. 3), and in light of the expected further warming of this region in the coming decades, there is every reason to believe that it will increase even further (Odgaard *et al.*, 2011). Herbivorous waterfowl can therefore be expected to intensify their use of maize stubble habitats, although the available resource relies heavily on the efficiency and circumstances of the harvest (Baldassarre *et al.*, 1983; Krapu *et al.*, 2004). In northern Europe maize is cultivated mostly for silage production as forage for livestock, and the increasing maize area has therefore replaced especially cultivated grasslands and to some extent sugar beets. The attractiveness of these two crops varies between waterfowl species and across the non-breeding season, but during autumn and winter, when maize is exploited, most species generally prefer carbohydrate-rich forage. The increase in maize on the expense of grasslands has therefore likely resulted in higher food availability at northern latitudes (Clausen *et al.,* 2018). Because foraging on maize stubble is generally unproblematic in terms of waterfowl-agriculture conflicts, the potential increase in maize habitat use may ease the pressure on more vulnerable crops such as winter cereals (Summers, 1990). Clausen *et al.* (2018) found that the availability of maize habitat may be able to drive changes in wintering strategy and migratory decisions of Pink-footed Geese, indicating that a northward expansion of maize crops might ultimately lead to an equivalent northward shift in wintering site use of birds exploiting this resource.

The value of maize as a food resource to waterfowl is further enhanced by the temporal accessibility of this crop. In northern Europe, maize is generally harvested from mid-September to mid-October, i.e. 2 – 3 months later than other cereals such as wheat and barley. As a consequence, the maize resource emerges at a time when other preferred food sources are increasingly depleted or decomposed (Madsen, 2001). Moreover, the combination of a cool autumn environment and the protective husk around the grains allow cobs to last for very long on harvested fields. As such, Baldassarre *et al.* (1983) found that the nutritional quality of waste maize remained unchanged throughout an entire winter. Both sugar beets and potatoes are potential food crops characterized by the same late-autumn harvest and winter availability to birds. In a north European context however, the cultivated area of these crops is relatively small (in Denmark 0.2 and 1.7 % of total arable land, Source: Statistics Denmark), and hence less important.

Owen *et al.* (1992) reported a daily energy expenditure of Barnacle Geese in November/December of roughly 1000 kJ/day. As digestibility of grass is very similar for Bewicks' Swans and

Barnacle Geese (Ebbinge *et al.*, 1975; Van Gils *et al.*, 2008), we assumed that assimilation efficiency of maize was likewise comparable. This allowed us to calculate the daily consumption of maize forage needed to cover daily energetic costs of Barnacle Geese as approximately 1000 / (16.791 x 0.814) = 73 g dw. Under the assumption that our functional response is reasonable, this allows us to calculate the necessary foraging time for Barnacle Geese on maize stubble to fulfill daily energetic demands. Given a resource of 3.42 g dw/m^2 (average across normally harvested fields in our study) this can be obtained in approximately 6.8 hours of active foraging. However, in normally harvested fields with substantial spill (6.52 g dw/m^2) this can be reached in 4.0 hours of active foraging, and in fields downed by wind prior to harvest (358.53 g dw/m^2) in less than an hour. If energy acquisition is constraint by the digestive capacity of geese (a digestive bottleneck, cf. Black *et al.*, 2014), total time spent on the feeding grounds may be somewhat longer. This clearly demonstrates that access to the right fields may be worth very long flights, which may be a contributing factor to explain the far-inland foraging flights of maize-foraging waterfowl observed especially in Denmark in recent years. As such, Pink-footed Geese and Barnacle Geese have been observed to travel up to 40 km inland from their coastal roosts to forage on maize stubble fields (Madsen *et al.*, 2015; Clausen and Madsen, 2016).

Winter food availability is highly affected by snow cover in Northern Europe (Laubek, 1995), but even in snow free conditions the energetic quality of available foods is important for the ability of waterfowl to meet the energy demands associated with overwintering in this region. In this respect, the temporal and spatial increase in food availability associated with a growing area of maize cultivation in northern Europe is important, and might have the potential to drive further population growth among the geese and swans able to exploit this increasing resource (Fox and Abraham, 2017). This may especially be true if some of these species are presently limited by food availability during winter. It is currently unclear to what extent the use of maize stubble fields may affect overall fitness for these species, but the topic certainly merits further investigation.

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Table 1. The amount of available maize forage on harvested maize fields at three study sites in Denmark. In Drengsted the same fields were visited for three consecutive years. * indicates that these fields were downed by a storm leading to suboptimal harvest and substantial spill.

Field	Available forage (g/m^2)	Location	Year
1	6.04	Drengsted	2015
2	3.42	Drengsted	2015
3	5.03	Drengsted	2015
4	6.52	Drengsted	2015
5	1.80	Stadilø	2015
6	3.71	Stadilø	2015
7	3.47	Lund Fjord	2015
8	2.46	Lund Fjord	2015
9	5.61	Lund Fjord	2015
10	0.85	Drengsted	2016
11	0.37	Drengsted	2016
12	1.22	Drengsted	2016
13	0.74	Drengsted	2017
14	1.48	Drengsted	2017
15	8.58	Drengsted	2017
16	400.22*	Drengsted	2017
17	316.84*	Drengsted	2017

Table 2. The amount of maize forage eaten and the total feeding time for four foraging events of Barnacle Geese (*Branta leucopsis*) recorded in the sampling areas at Stadilø, Denmark.

Foraging event	Species	Ingested mass (g)	Total feeding time (min)
1	Barnacle Goose	1339.2	1199
2	Barnacle Goose	769.2	884
3	Barnacle Goose	788.3	774
4	Barnacle Goose	50.9	62

Table 3. Daily gross energy intake (GEI, kJ/day), daily excreted energy (EE, kJ/day) and assimilation efficiency (AE, %) of three maize-foraging captive Bewicks' Swans (*Cygnus columbianus*).

Swan	GEI (kJ)	EE (kJ)	AE (%)
1	3047	586	80.8
2	2116	435	79.4
3	3405	549	83.9
Average			81.4

Figure 1. Relation between number of spilled maize cobs and number of droppings on harvested maize fields exploited by Pink-footed Geese (*Anser brachyrhynchus*) and Barnacle Geese (*Branta leucopsis*) at Drengsted, 2015. Not all data points are visible due to overplotting, N = 42.

Figure 2. Type 2 functional response of maize-feeding Barnacle Geese (*Branta leucopsis*) at Stadilø, Denmark, assuming an intake rate of zero when no food is present. The dashed line and associated equation indicate the best fit (Holling's Disc Curve).

Figure 3. Development in the area of cultivated maize (thousands of ha) in Denmark during the period 1982-2016. Data acquired from Statistics Denmark.