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REPORT

Animal behavioral adaptation to changing landscapes: spring-staging geese habituate to wind farms

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Abstract Wind farms are positioned in open landscapes and may cause loss of wildlife habitat due to disturbance, fragmentation, and infrastructure development. Especially flocking geese, swans, ducks and waders are regarded as vulnerable to wind farm development. We compared past and current displacement effects of two onshore wind farms and a line of land-based turbines on spring-staging pink-footed geese (*Anser brachyrhynchus*) to see if there was evidence of habituation. In one wind farm area, geese previously (1998) (Larsen and Madsen 2000) kept a distance of c. 200 m (the distance at which 50% of peak densities is reached) and they did not go between the turbines; today (2008) they keep a distance of c. 100 m, but do still not enter the wind farm area. In another wind farm, where foraging geese previously (2000) kept a distance of more than 100 m and did not enter the wind farm, they now (2008) forage between the wind turbines and keep a distance of c. 40 m to turbines. In 1998, geese kept a distance of 125 m to a line of turbines, compared to 50 m now. We conclude that geese have behaviorally adapted to changing landscapes created by wind farms. The difference in avoidance between the sites may be due to the sizes of the turbines which in this study were small in both rotor-swept area and in height compared to more recent "industry standard" of 2.5 and 3.0 MW turbines. The study points to the need for longer term studies to properly assess the impact of wind farms on wildlife, including consequent increased risks from inclement weather events of feeding, rafting, and migrating waterfowl.

Keywords *Anser brachyrhynchus* · Disturbance · Habitat loss · Habituation · Landscape connectivity · Pink-footed goose · Wind facility · Wind turbines

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Introduction

The rapidly increasing development of wind energy production by means of wind turbines (onshore as well as offshore) has raised concerns about impacts on wildlife populations, especially birds and bats (the latter not addressed in this study), due to collision risks and loss of habitat caused by disturbance, fragmentation, and infrastructure development (see reviews by Hötker et al. 2004; Stewart et al. 2004, 2007; Percival 2005; Drewitt and Langston 2006; Fox et al. 2006). With regard to disturbance effects, especially flocking geese, swans, ducks and waders are considered vulnerable to wind farm development, since they generally avoid wind farms at a distance of more than 100 m. On a wider scale, the issue of avoidance also raises questions about functional connectivity of landscapes, defined as the degree to which the landscape facilitates or impedes movement among resource patches (Taylor et al. 1993; Bélisle 2005; Baguette and Van Dyck 2007). Hence, avoidance may incur additional travel costs (extra energy costs and predation risks associated with the travel, e.g. due to hunting) and cause a fragmentation of the potential area to a degree affecting the overall quality of the area. Onshore wind farms are typically positioned in open coastal landscapes where the highest wind speeds prevail, largely overlapping the habitats of waterfowl and waders, and wind farms can potentially consume a considerable amount of the potential suitable habitat (Larsen and Madsen 2000).

The majority of studies of effects of wind farms have been brief, and the longer term effects have rarely been addressed. Hence, there is little evidence of habituation by birds to wind farms (Hötker et al. 2004), and there is even a suggestion of increased negative effects of wind farms on bird abundances over time (Stewart et al. 2004, 2007). Consequently, with the explosive growth of wind farms in Europe, North America, India and elsewhere, cumulative impacts, including both direct and indirect effects, are growing concerns.

In 1998 and 2000, we studied the displacement effects of wind farms on field utilization by spring-staging pink-footed geese (*Anser brachyrhynchus*) in west Jutland, Denmark (Larsen and Madsen 2000; J. Madsen unpubl. data). We found that geese kept a distance of 100–200 m to the wind farms and that they did not utilize the area inside the wind farm areas. In the spring of 2008, we repeated the study in the same wind farm areas to see, if there was a change in the response by the geese. If geese had habituated, i.e. reduced their behavioral response to the wind farms, we expected to find a reduced distance to the wind farms. In this paper we present the results of the comparison. We discuss the implication for wind farm designs and planning.

Methods

Study areas

The study was carried out in three land-based wind farm areas investigated in 1998 and 2000. All three areas are used by large flocks of spring-staging pink-footed geese, primarily foraging on cultivated grasslands, supplemented by winter cereals (Madsen 1984; Larsen and Madsen 2000). The specifications of the wind farms and the layouts of the wind farms can be found at the website of the wind turbine master register by the Danish Energy Authority (http://www.ens.dk/sw34512.asp).

1) Klim Fjordholme, NW Jutland (57°02′N, 09°08′E). A land-based cluster of 35, 600 kW turbines, established in 1997, with a hub height of 45 m, rotor diameter of 44 m, arranged in four rows with a distance of 172 m between turbines and 240 m between rows. The wind farm area is primarily cultivated grassland, with some surrounding winter cereal fields. Up to 6,000 pink-footed geese utilize the area in early spring (Larsen and Madsen 2000).
2) Vester Thorup, NW Jutland (57°03′N, 09°07′E). A line of five land-based, 225 kW turbines, established in 1996, with a hub height of 31.5 m, rotor diameter of 29 m, and a distance of 158 m between turbines. The turbines are positioned in a mixed farmland, primarily with cultivated grassland surrounding the turbines. The area is used by the same flock of geese visiting Klim (Larsen and Madsen 2000).
3) Velling Maersk, W Jutland (56°03′N, 08°19′E). A land-based cluster of 66, 75 kW turbines, established in 1986–1988, with a hub height of 21–31.5 m, rotor diameter of 17–27 m, arranged in four rows with a distance of 112 m between turbines and 171 m between rows. The wind farm area is primarily cultivated grassland, with some surrounding winter cereal fields. Up to 5,000 pink-footed geese utilize the area in early spring (J. Madsen pers. obs.).

Field methods

Field utilization by pink-footed geese was originally assessed by counts of dropping densities in pastures in early April 1998 (Klim and Thorup) and April 2000 (Velling). Geese produce droppings at short intervals during the feeding day, and droppings will be visible for at least 3–4 weeks, depending on the amount of precipitation. Hence, dropping densities provide a good indicator of integrated goose use of an area for a period of at least several weeks (Madsen 1985). In all three study areas, we laid out three transects perpendicular to the wind farms (at Velling in 2008, we used five transects), starting from an outer turbine and transect intervals of 150–200 m. Along each transect droppings were counted in plots of 1 m radius (3.14 m^2) at intervals of 25 m (Klim and Thorup) or 10 m (Velling). In addition, two transects were placed between turbines of the clusters to see whether the geese used the space between turbines. On 28 February 2008, we repeated the dropping counts in the three study areas, using similar transects and intervals as previously. At Velling, we repeated the measurements on 12 April 2008, to see if increasing densities of geese had an effect on site use.

We define 'avoidance distance' from wind turbines as the distance at which dropping density reached 50% of the maximum density along a transect. Because dropping densities varied between transects, sites and periods, we expressed goose utilization in terms of the percentage of the maximum dropping density recorded within a transect.

Results

In all three cases, both the median avoidance distance and the closest distance were reduced by 50–67% from 1998–2000 to 2008 (Fig. 1; Table 1). At both times, the geese kept the longest distance to the Klim wind farm and the shortest distance to the Velling wind farm, with the Thorup line of turbines in between. In 1998 and 2000, no goose droppings were found inside the two wind farms. In 2008, we still did not find any droppings within the Klim wind farm, whereas in Velling, geese had been foraging all over, except for a 20–30 m zone around the turbines (Fig. 1; Table 1).

On 28 February, the densities of droppings outside and inside the Velling wind farm were equal, viz. 1.71 droppings m^{-2} ($SD = 0.89$; $n = 51$) versus 1.80 droppings m^{-2} ($SD = 0.90$; $n = 32$)(Student's t-test, $t = 0.655$; $P > 0.05$). We only compared plots which were 40 m or further away from wind turbines. On 12 April, the density of droppings had increased, but densities outside and inside the wind farms were still equal, viz. 5.77 droppings m^{-2} ($SD = 3.47$; $n = 42$) versus 5.44 droppings m^{-2} ($SD = 2.91$; $n = 32$)($t = 0.659$; $P > 0.05$).

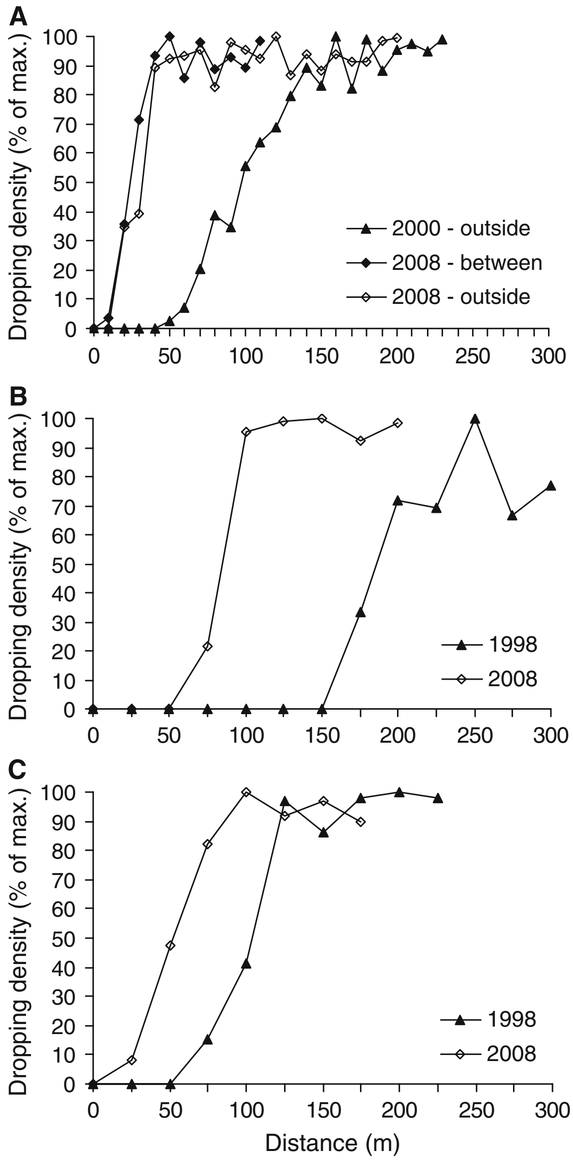

Fig. 1 Field utilization by pink-footed geese in relation to distance from wind farms, expressed by the relative goose dropping density (as a percentage of maximum) on transect lines perpendicular to the wind farms. (**a**) Velling, (**b**) Klim, (**c**) Thorup. For Velling, the field utilization between turbines inside the wind farm is also shown. Each line represents the median of three transects (for Velling 2008, outside, it is the median of five transects)

Discussion

The finding that spring-staging pink-footed geese have reduced their avoidance both in terms of coming closer to the wind farms and, in one of the cases feed

Table 1 Displacement effects of wind farms in 1998–2000 compared to 2008, expressed by the closest distance at which goose droppings were recorded and the avoidance distance (distance at which 50% of maximum use was recorded). For Velling, also the displacement distance between turbines inside the wind farm is given

	No. of transects	Closest distance (m) Median (range)	Avoidance distance (m) Median (range)
Velling wind farm cluster			
2000 (outside)	3	60 (50–70)	100 (80–120)
2008 (outside)	5	20 (20–40)	40 (20–120)
2008 (between)	5	20 (10–40)	30 (20–70)
Klim wind farm cluster			
1998	3	175 (175–175)	200 (200–200)
2008	3	75 (75–75)	100 (100–100)
Thorup line of wind turbines			
1998	3	75 (75–100)	125 (100–125)
2008	3	25 (25–50)	50 (50–75)

inside the wind farm area, suggests that they have habituated to the wind farms over the last 8–10 years, i.e., almost within the expected life span of the species, which is approximately 6 years (J. Madsen unpubl. data). Agricultural practices have remained the same in the three areas, with predominance of artificial pastures and some mixed in winter cereal fields. Therefore, it is unlikely that deterioration in habitat availability has contributed to an increased tolerance. During 1998–2008, the population of pink-footed geese (breeding in Svalbard) has increased from approximately 30,000 to 60,000 individuals (J. Madsen unpubl. data). This may have lead to increased food competition in the spring-staging areas; however, as the population has increased, geese have dispersed into many new areas, rather than building up higher densities in the known areas. Hence, in the study areas, there is no suggestion of increased spring-staging numbers during the last decade (J. Madsen, unpubl. data). The fact that densities of geese were equal outside and inside the Velling wind farm in March (when densities were relatively low) as well as in April suggests that the geese utilize the wind farm areas freely and not only as a secondary habitat which is only taken into use when the primary less disturbed habitat is depleted. Taken together, we interpret the responses by the geese as an experience-based learned adaptation to wind farms.

One reason why geese are less tolerant to the Klim wind farm compared to Velling, with Thorup as intermediate, may be that higher turbines create more disturbance, either due to the larger rotor-swept area and longer rotor blades, possible effects of blade-tip and blade wake turbulence, or the higher levels of noise produced by the larger turbines. In support, Hötker et al. (2004) showed a significant relationship between height of turbines and minimal distances to turbines in flocking lapwings (*Vanellus vanellus*); however, with inconclusive evidence in other species.

From a landscape perspective, the reduction in avoidance distance has important implications in terms of the area from which geese are displaced by wind farms. In a case with at wind farm like Klim and Velling, which almost cover an area of 1000 m × 1000 m, an avoidance distance of 200 m means that geese are displaced from an area of 1.96 km^2. If the avoidance distance is reduced to 100 m, the displacement area is 1.44 km^2. If geese start using the wind farm area (however, which they only do in Velling at present), the geese will only be excluded from an area of approximately 0.1 km^2, namely from the immediate radius around each of the turbines. If existing small wind turbines are replaced by larger turbines, which is the general tendency in order to produce more efficient energy, and the wind farm will still occupy the same area, the area of displacement is likely to increase, unless that geese habituate further in the longer term. However, with the "industry standard" turbine size now ranging from 2.5 to 3.0 MW, the tip of the rotor-swept area exceeding 130 m in height, the footprint of the turbines now expanding, and the need for greater turbine separation to avoid wake impacts on the blades, the results from this study do not reflect impacts to pink-footed geese based on current turbine size. Whether and how long habituation to these larger, more spaced turbines will take, remains yet to be studied. We recommend that this question be addressed since the impacts from fragmentation, site avoidance and disturbance are important issues regarding wind–wildlife interactions.

However, to evaluate the effect of wind farms in a wider landscape perspective, the functional landscape connectivity (as defined by Taylor et al. 1993; Bélisle 2005; Baguette and Van Dyck 2007), has to be taken into account. Hence it is important to evaluate the landscape configuration before and after construction against the behavioral trade-offs the birds have to make to utilize patches, such as foraging patch quality and perceived predation risks as well as travel costs (in terms of energetic costs and predation risk). The motivation by birds to utilize a given area may change with resource availability, predation risks, including hunting during autumn which has a strong effect on site use and behavior of geese (Madsen 1985), and with the learning ability of the birds. However, with our present poor knowledge of the behavioral plasticity of most species, the effect of these elements is generally difficult to predict.

In conclusion, we showed that pink-footed geese have habituated to small-scale wind farms; in one case the area of displacement was reduced dramatically because geese were also foraging within the wind farm. The degree of habituation seems to be dependent on the height of the wind turbines. This is the first example of long term habituation by a bird species to wind farms, pointing to the need for longer term impact assessment studies to properly evaluate the disturbance effects of wind farms. Compared to other species, pink-footed geese are considered to be extremely wary against human activity (Madsen et al. 1998). The fact that this species shows habituation makes it likely that other species will also do the same. However, until this hypothesis is tested and validated, most especially at the currently much-larger sized, "industry standard" turbines, a precautionary approach to wind farm development should be taken.

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