Flight altitudes of Arctic and Nordic geese in their wintering area – a radar study

Gudrun Hilgerloh

gudrun.hilgerloh@t-online.de

Abstract

In East Friesland, a favoured wintering area of Arctic and Nordic geese, feeding areas are protected and exempted from the installation of wind energy plants (WEPs). In their flights between their different staging areas, however, they remain vulnerable. Above a plain designated for a wind farm, we studied the behaviour of geese by radar (Furuno FR-2125) and field observations in winter 2014/15. We studied the distribution of the overflying geese visually and measured the flight altitudes by a radar rotating vertically. We identified the species visually or by their calls.

The most frequent geese were Greylag Goose *Anser anser*, Greater White-fronted Goose *Anser albifrons* and Barnacle Goose *Branta leucopsis*. Egyptian Geese *Alopochen egyptiaca* and Canada Geese *Branta canadensis* also regularly crossed the area.

Overflying Greylag Geese, Egyptian Geese and Canada Geese were concentrated mostly in the western half of the study area, which can be explained by the position of the water bodies frequented by the local resident geese. Greater White-fronted Geese flew mostly along a W-E axis. In the E their heading was to the SW and in the W between SW and SE. Barnacle Geese most frequently were recorded flying along the NE-SW axis.

According to the radar measurements median altitudes varied between 18 m and 163 m (18 m Canada Goose, 20 m Egyptian Goose, 56 m Greylag Goose, 85 m Greater White-fronted Goose, 163 m Barnacle Goose). Of the three most frequent species the Greylag Geese flew lowest and the Barnacle Geese highest. Seventy five percent of Greylag Geese flew below101 m, of Greater White-fronted Geese below 144 m and of Barnacle below 231 m above ground level. Canada Geese and Egyptian Geese flew very low. The middle 50% of Greylag Geese, Greater White-fronted Geese and Barnacle Geese flew between 31 m and 231 m.

The rotor sweep zone of modern WEPs, the risk zone for birds, has changed in recent years. With the greater hub heights and rotor lengths nowadays, it is much wider and at a greater height. Correspondingly, the percentage of birds at risk has also changed. In this study, Barnacle Geese and Greater White-fronted Geese were at highest risk, while Greylag Geese suffered the lowest risk from modern turbines. Barnacle Geese were more at risk by turbines whose rotor reached the greatest height (67%).

The Greylag Geese and Greater White-fronted Geese showed no preference for particular altitudes at specific sites. Barnacle Geese flew higher in the NE and SW sector than in the NW and SE sector. Most high flying geese (mainly Greater White-fronted Geese and Barnacle Geese) were in the NE sector.

This present research gives insight into the spatial and altitudinal use made by geese wintering in the study area with particular reference to the high-risk zone above a potential WEP. This gives policy-makers an instrument that allows them to assess possible barrier effects of planned turbines and to make decisions accordingly.

Key words: flight altitudes, radar, Arctic geese, Nordic geese, wind farm, sweep zone, East Friesland, *Branta leucopsis, Anser albifrons, Anser anser*

Introduction

Arctic and Nordic geese winter in the North German Lowlands bordering the North Sea (KRUCKENBERG et al. 2022). Whereas in earlier times the wintering area of the geese consisted of vast areas with wet meadows, today it is segmented by human structures and activities (streets, wind mills, power lines) and transformed by drainage. Conflicts between humans and geese are inevitable. As we are responsible for the conservation of these geese, we have to take care that they do not collide with human structures (KRUCKENBERG 2018).

There is extensive knowledge on avian mortality through collision with wind turbines (DREWITT & LANGSTON 2008, HÖTKER et al. 2004, GARTHE & HÜPPOP 2004, TELLERIA 2009, FIJN et al. 2012). According to an inland radar study close to the Ramsar site "Ismaning reservoir and (former) fish ponds" during moult migration (June/July), 45% of all birds and 40% of water birds flew below 200 m (the risk zone) within the potential WEP as well as outside (KÖHLER et al. 2014).
As birds are most at risk of collision in the sweep zone of a rotor, a three year radar study focused on flight intensities and flight heights at an offshore wind farm (FIJN et al. 2015). Fifty percent of birds (by day and by night) flew below the height of the WEP (115m) and 30% flew in the sweep zone between 25 m and 115 m. Today these zones are much higher–consonant with modern hub heights and blade lengths–so that the percentage of geese flying at risk height, has changed.

According to the mortality list of species in collision with wind turbines, the danger of being killed in this way is small in geese (LANGEMACH & DÜRR 2020). DESHOLM & KAHLERT (2005) found out that the number of geese and ducks (mainly Eider Ducks *Somateria mollissima*) entering the site of an offshore wind park on migration decreased by a factor of 4 to 5 from the pre-construction to the initial operation of a wind farm. In fact, less than 1% of the geese and ducks flew close enough to be at any risk. In migrating Pink-footed Geese *Anser brachyrhynchus* more than 90% avoided offshore wind farms (PLONCZKER & SIMMS 2012). Apparently, wind farms act as a barrier for migrating Pink-footed and other geese species and Eider Ducks.

The phasing out of fossil fuel use is increasing pressure to construct more wind farms. These wind farms, if placed in areas with high densities of flying geese, will force the geese to undertake flight detours, thus dramatically increasing their energy costs (LANGSTON & PULLAN 2003, HOETKER et al. 2004). Therefore areas, where wintering geese have over many years been observed to concentrate for feeding, roosting or comfort behaviour (GERDES 1994, KRUCKENBERG 2013), have been put under protection, and no wind turbines are permitted in these protected areas. However, geese regularly fly outside of these areas to reach and return from their roosts, to visit an external comfort zone, or to continue their migration route.

This study was promted by large numbers of geese flying from a roost in the north of the study area towards their feeding areas in the south, thereby regularly crossing an area designated as a WEP, were what prompted this study. The aim was to find out which parts of the study area were crossed by geese and by what species and whether they were flying in the sweep zone of modern WEPs that might act as a barrier for them (HÖTKER 2017). We used a vertical radar to measure flight altitudes of visually identified geese.

Material and Methods

The study area

The study area was situated south-east of Marienhafe (fig. 1). It was a grassless plain devoted mainly to the cultivation of maize. In winter, post-harvest, it was a stubble-field. Some freshwater lakes close to the study area were visited by the geese: 600m north (53°31'04.93''N 7°18'28.06''E), 700m west (53°30'32.40''N 7°16'38.61''E) and at the southwest border of the study area (53°29'41.22''N 7°18'08.14''E).

Observation site

Fig.1. The study area is marked as a light area. The black point represents the observation site and radar site.

The observation site and position (53°30’16’’N 007°18’51’’E) of the radar (details given below) was chosen such that no spurious echoes from trees or man-made constructions would interfere with the measurements. For security reasons we chose a remote site at the end of a cul-de-sac dirt road, which we were allowed to shut temporarily. Additionally we installed a camera trap and made an arrangement with a local person to ensure the safety of the recording instruments. The recording site was 1 km from the western border and 2.4 km from the eastern border of the study area. The view to the east and west was open for several kilometres, but to the north and south, the study area was bordered by trees.

Observation period

During the first wave of arrivals of Arctic and Nordic geese in October, geese settled at the most attractive sites known from previous years (Großes Meer, Engerhafe). This, however, did not lead to recurrent overflights of the study area. Later, in the course of a cold snap in January, which was associated with further immigration of Arctic geese to East Friesland, flights of geese over the study area became frequent. The study started on 14 January 2015 and ended on 02 May 2015.

Field observations

The field work was done by a radar observer and a field observer, equipped with a binocular (10x40), a telescope (zoom 20-60x), a compass, a radio clock, a disc with the degrees of a circle, a forehead flashlight and a form sheet. The two observers had to work in close contact, in order to be sure that they were referring to the same flock of birds and radar echo. The field observations started one hour before sunrise and ended 2 hours after sunrise. In the evening, the observations started one hour before sunset and ended 2 hours after sunset. While in the morning most observations were made in daylight, in the evening most were made in darkness and numbers of geese could therefore be counted only at the beginning of the session. After dark, mostly neither the position nor the flight direction and the number of birds in each flock could be determined. In dark or foggy conditions the species were identified by their calls. We recorded observations on 50 days during the morning sessions and on 30 days during the evening sessions.

The field observer searched for geese in the entire study area, noting for each flock the species, the number of geese, the estimated distance and direction from the observer as well as the flight heading (bearing) and altitude of the geese. If a flock seemed likely to cross the radar beam, the observer informed the radar operator of its estimated distance to the W or E of the radar, its approximate height and the time. The radar operator verified the echo of the geese and noted the name of the file (date and time as file name), the position of the echo in the radar beam, the species and number of birds (determined by the field observer).

If the field observer missed geese flying through the beam, the radar operator described the position of the echo in the beam for further identification by the field observer. Flocks, which could not be assigned to a species, were recorded and will in this paper be referred to as "unspecified Anser/Branta geese". If a mixed flock with unknown proportions of different species passed, we classified it similarly. If time was too limited to document all overflights of geese, priority was given to those flocks that were likely to cross the radar beam, as of these we were able also to establish the altitude.

Radar observations

We used a ship radar of the type Furuno (Fr-2125) (fig. 2). The antenna was 2 m long and rotated at 24 r.p.m.. An image was made of every rotation and after every 10 revolutions of the beam an integrated image was made in order to show the track. The radar worked with a pulse length of 0.08 (HILGERLOH et al. 2010). We normally worked with a range of 750 m because of the better resolution and as most geese could be detected within this range. Very high flying geese might be underrepresented, as the border of the range corresponded to a semisphere. Geese passing directly over the radar site were detected up to a height of 750 m, but further east or west the ceiling became lower. When we heard calls of geese flying outside of the normal range, we switched to a range of 1500 m. During the change-over, it is possible that a flock may have been missed. Additionally, geese flying close to the ground will also have escaped detection.

The radar was mounted on a metal stand, which was fixed to the ground by pegs. A tilt mechanism allowed a manual change of the rotation plane. From field observations from the previous year we deduced that the main flight directions would lie between N and S. As the detection of birds by radar is best from a position perpendicular to the line of flight, we scanned the sky along a W-E axis. The radar beam rotated vertically from west to east to measure heights. As it turned out, the main flight direction of the previous year was not confirmed. This, however, caused no problem, as birds the size of geese can be detected head-on or tail-on even if we double the working range (FIJN et al.2015, appendices).In order to minimize ground clutter (=unwanted echoes), we suppressed the beam for the first 2 degrees from the ground. Of all the geese crossing the study area along a W-E-axis, only the height of those flying in the radar beam could be measured. For measurement of flight directions the beam rotated horizontally from 270° over North to 90°. The beam was suppressed when it was directed towards the ground during the vertical rotation and towards the south during the horizontal rotation. A 30 m cable connected the antenna rig with the monitor assembly, which was situated in our field office (a van). The radar was powered by a generator, positioned at a distance of 30 m to reduce noise. We rarely used the horizontal radar, as there was too much ground clutter and as the width of the operational beam allowed only detection of low flying geese (below 300 m) (HILGERLOH et al. 2010).

Fig.2. The radar, in the position to rotate vertically, with view over the study area to the north.

The timing of the radar signal was calibrated according to the Furuno Installation and Operations Manual by a Furuno technician and further with the aid of a car at a known distance. This calibration ensured that the distance and height measurements of the radar were as accurate as possible. During the initial configuration of this radar a Sensitive Time Control (STC) was activated and remained in operation throughout the study. The purpose of this was to brighten the faint signals generated by objects (i.e. birds) detected at extreme range and to reduce glare from contiguous echoes (GÖBEL 2001). The computer program "Swarm" saved the images taken from the rotations of the radar beam. The integrated images containing ten revolutions of the beam showed the track of the flocks or of an individual goose.

Analyses

Height measurements of flying geese by radar: the files with the geese detected by the radar and identified by the field observer were checked after the field work. The position of the echoes of the geese was imported into a program that digitalized the echoes. Flight height and distance from the radar in metres was calculated by the program "radar calculations". These data were the basis for all further calculations. All graphs on the heights of the different species were created by the program R 3.1.0 (R DEVELOPMENT CORE TEAM 2014). Regional dispersion of overflying geese: The data on dispersion of overflying geese had been collected by the field observer. Some overflights at greater distances away from the observer might have been missed. Maps with trajectories of flocks of birds were created with the help of the program R 3.1.0 (R DEVELOPMENT CORE TEAM 2014). As they were based on estimations of distance and direction from the observer und flight direction of the birds, the values were rounded. Accordingly, several flight paths were exactly the same. In order to visualize all trajectories, we added a random spreading of ±4° (direction), and ±4% (distance).

Results

We registered 19,224 geese flying over the study area (tab. 1). The most frequent were the Greater White-fronted Goose *Anser albifrons*, followed by Barnacle Goose *Branta leucopsis*, Greylag Goose *Anser anser* and Tundra Bean Goose *Anser fabalis rossicus*. Egyptian Geese *Alopochon egyptiaca* and Canada Geese *Branta canadensis* were not migrants and were present throughout the year. A certain proportion of the Greylag Geese bred nearby and stayed through the winter.

Tab. 1. Number of overflying geese in the morning and in the evening. In darkness and in foggy weather the geese could not be counted.

species	number of individuals in counted flocks	flocks counted	flocks not counted	all flocks
Bean Goose	512	10	0	10
Greater White-fronted Goose	7335	217	52	269
Greylag Goose	959	123	17	140
Canada Goose	165	34	56	90
Barnacle Goose	5128	59	22	81
Egyptian Goose	97	41	2	43
Anser/Branta sp	4980	140	14	154

The highest number of flocks was observed in Greater White-fronted Goose, the second highest in Greylag Goose, followed by Barnacle Goose (tab. 1. and 2.).

Tab. 2. Flock sizes of the species (median, lower quartile, upper quartile), calculated on the basis of the morning flights

species	number of individuals in flocks counted	flocks counted	median indiv per flock	lower quartile	upper quartile
Bean Goose	222	7	2	1	61
Greater White-fronted Goose	6401	207	12	4	40
Greylag Goose	804	114	4	2	9
Canada Goose	156	28	3	1	6
Barnacle Goose	4659	49	35	10	110
Egyptian Goose	77	32	2	1	2
Anser/Branta sp	4904	131	7	3	19

The smallest numbers of geese were registered in the flocks of Greylag Geese and largest in those of the Barnacle Geese (tab. 3a).

Tab. 3a. Number of geese during the morning observations and % of all flocks in the morning and % of observation mornings with overflights of each species

species	number of individuals in morning	flocks counted in morning	flocks not counted in morning	flocks in total in morning	% of all flocks in morning	% of mornings present
Bean Goose	222	7	0	7	70	8
Greater White-fronted Goose	6401	207	8	215	80	54
Greylag Goose	804	114	13	127	91	7
Canada Goose	156	28	36	64	71	58
Barnacle Goose	4659	49	6	55	68	46
Egyptian Goose	77	32	1	33	77	48
Anser/Branta sp	4904	131	1	132	86	66

What was the temporal span of the overflights? While the local breeders such as some of the Greylag Geese, Canada Geese and Egyptian Geese stayed in the area all year, the Arctic geese were only present from mid-January to the end of March.
In their daily rhythm the geese started by flying from the nocturnal roost to their feeding area. During the day they moved between various feeding areas. At sunset they flew back to their roost. In the morning hours, more geese flew over the study area than at sunset. All in all, only 9 to 32% of flocks in each species flew over the study area in the evening hours (tab. 3b).

Tab. 3b. Number of geese during the evening observations and % of all flocks in the evening and percent of observation evenings with overflights of each species

species	number of individuals in evening	flocks counted in evening	flocks not counted in evening	flocks in total in evening	% of all flocks in evening	% of evenings present
Bean Goose	290	3	0	3	30	10
Greater White-fronted Goose	934	10	44	54	20	30
Greylag Goose	155	9	4	13	9	33
Canada Goose	10	6	20	26	29	50
Barnacle Goose	469	10	16	26	32	30
Egyptian Goose	20	9	1	10	23	33
Anser/Branta sp	76	9	13	22	14	30

Greater White-fronted Geese were present on 54% of the mornings, Barnacle Geese on 48% and Greylag Geese on 70% (tab. 3a). Some Greylag pairs bred nearby; these crossed the study area frequently. The same applies to Canada Goose and Egyptian Goose (tab. 3a).

We appraised whether certain parts of the study area were frequented more than others by the different species in the morning hours. Overflying Greylag Geese were concentrated mostly in the western half of the study area, which can be attributed to the position of the water bodies frequented by the local birds (fig. 3).

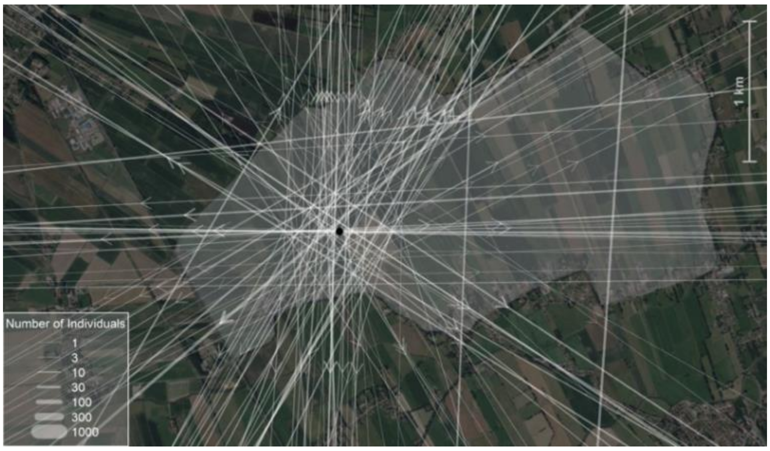

Fig.3. Dispersion of overflying flocks of Greylag Geese in the morning (n=105). The flight direction of the flocks was estimated visually.

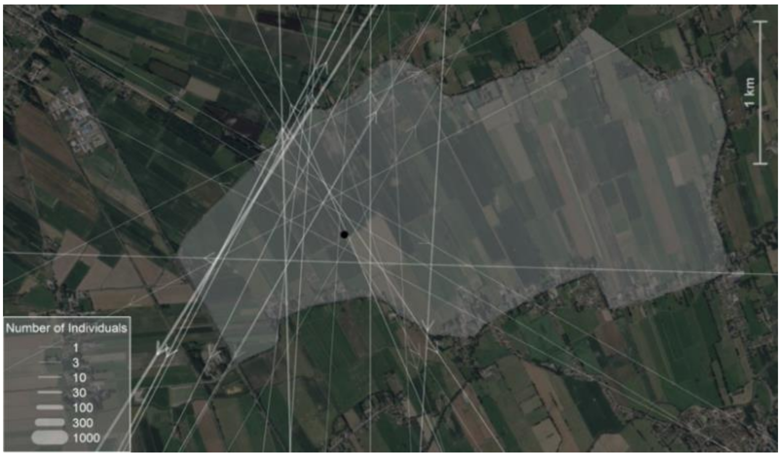

Fig.4. Dispersion of overflying flocks of Canada Geese in the morning (n=24). The flight direction of the flocks was estimated visually.

Canada Goose and Egyptian Goose, which visited the same water bodies, showed a similar distribution (fig.4, fig. 5). The Greater White-fronted Geese frequented the entire study area and were concentrated on a W-E axis along the radar beam (fig. 6). Barnacle Geese flew more frequently over the NE and SW sector than other parts of the study area (fig.7).

The few flocks of Bean Geese were seen crossing the entire study area mostly along the E-W axis (fig. 8). Unspecified Anser/Branta geese and flocks with unspecified proportions of different goose species were recorded in all parts of the study area, but most flocks were registered in the western part (fig. 9).

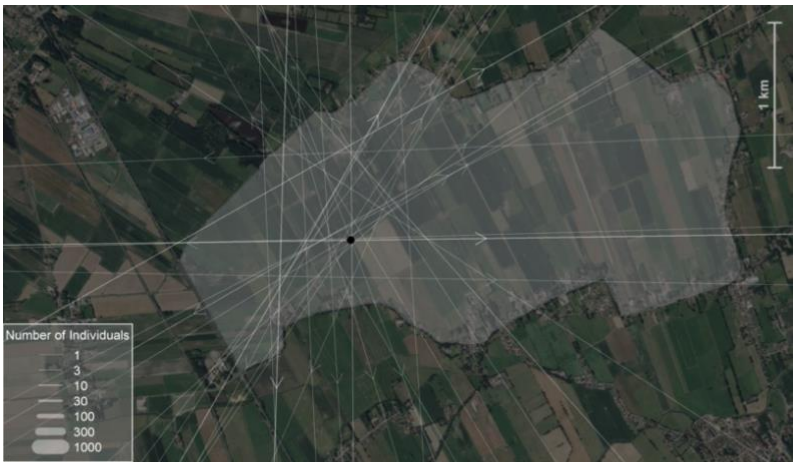

Fig. 5. Dispersion of overflying flocks of Egyptian Geese in the morning (n=29). The flight direction of the flocks was estimated visually.

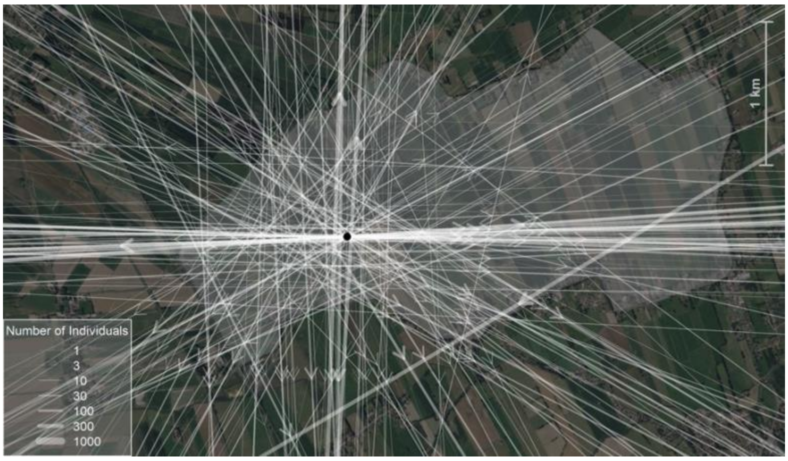

Fig. 6. Dispersion of overflying flocks of greater White-fronted Geese in the morning (n=193). The flight direction of the flocks was estimated visually.

Of the three most frequent species, Greylag Geese flew lowest, Barnacle Geese highest and Greater White-fronted Geese intermediate between them (fig. 10). In this graph the Greater White-fronted Goose is called simply White-fronted Goose. The five flocks of Bean Goose, measured by radar, flew on average lower than Greylag Geese (fig 11, tab. 4).

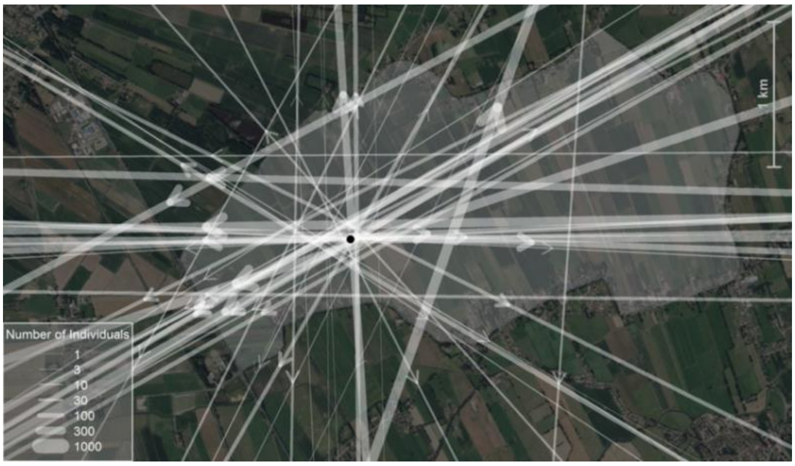

Fig.7. Dispersion of overflying flocks of Barnacle Geese in the morning (n=47). The flight direction of the flocks was estimated visually.

On average the unspecified Anser/Branta geese flew higher than Greater White-fronted Geese and lower than Barnacle Geese (fig. 10). The local Canada Geese (9 flocks measured) and Egyptian Geese (17 flocks measured) flew extremely low (fig. 11, tab. 4). The altitudinal layer of the middle 50% of the geese of the three most numerous species was between 31 m and 231 m (tab. 4). The flight height up to which 75% of the geese were recorded, was 101 m for Greylag Geese, 144 m for Greater White-fronted Geese and 231 m for Barnacle Geese (tab. 4).

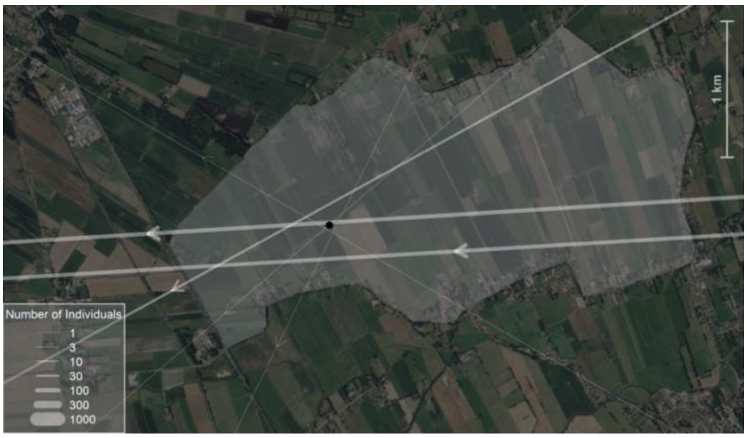

Fig 8. Dispersion of overflying flocks of bean geese in the morning (n=6).

We calculated the percentage of geese flying in the risk zone of a WEP having the dimensions of two modern types of turbine (E-160 EP5 and E-138 EP3, Enercon) with hub heights of 166m and 160 m and rotor lengths of 80 m and 69 m respectively. The rotor sweep zone extends from 86 m to 246 m height (160 m) and from 91 m to 229 m (138 m) (tab. 5).

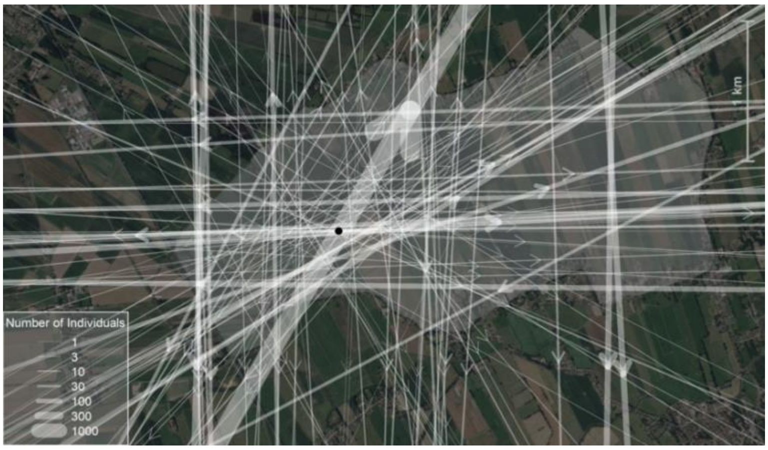

Fig. 9. Dispersion of overflying flocks of unspecified Anser/Branta geese in the morning (n=120).

The sweep zone of turbine 1 was 22 m wider than of turbine 2 and the maximal height of turbine 1 was 17 m higher than that of turbine 2. The calculations demonstrated that the highest percentage of individuals counted in the sweep zone of turbine 1 occurred in Barnacle Geese (67%). Of the three most numerous species, the one with the smallest percentage flying in sweep zone 1 was the Greylag Goose (33%) and White-fronted Geese were present in the risk zone with an intermediate percentage of 54%. A comparable analysis of goose flocks resulted in the same placement. The percentage of individuals in the sweep zone of turbine 2 was lower in all three species, in this case with the highest percentage in White-fronted Geese (45%), followed by Barnacle Geese (38%) and Greylag Geese (27%). Also the percentage of flocks in sweep zone 2 was smaller in all three species, the percentage of Barnacle Geese being the highest.

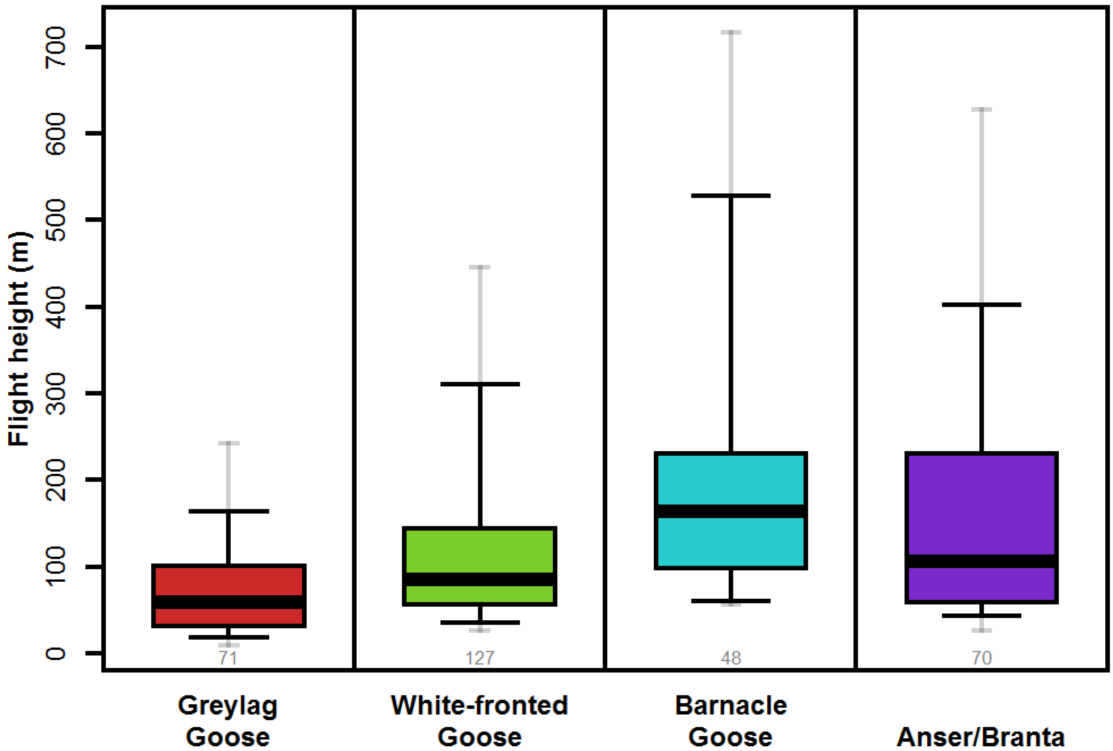

Fig. 10. Boxplot on flight altitude including median (thick black line), quartiles (box), 5% and 95%-quantile (black bars) and extreme values (grey bars). Number of flights in grey underneath each box-plot.

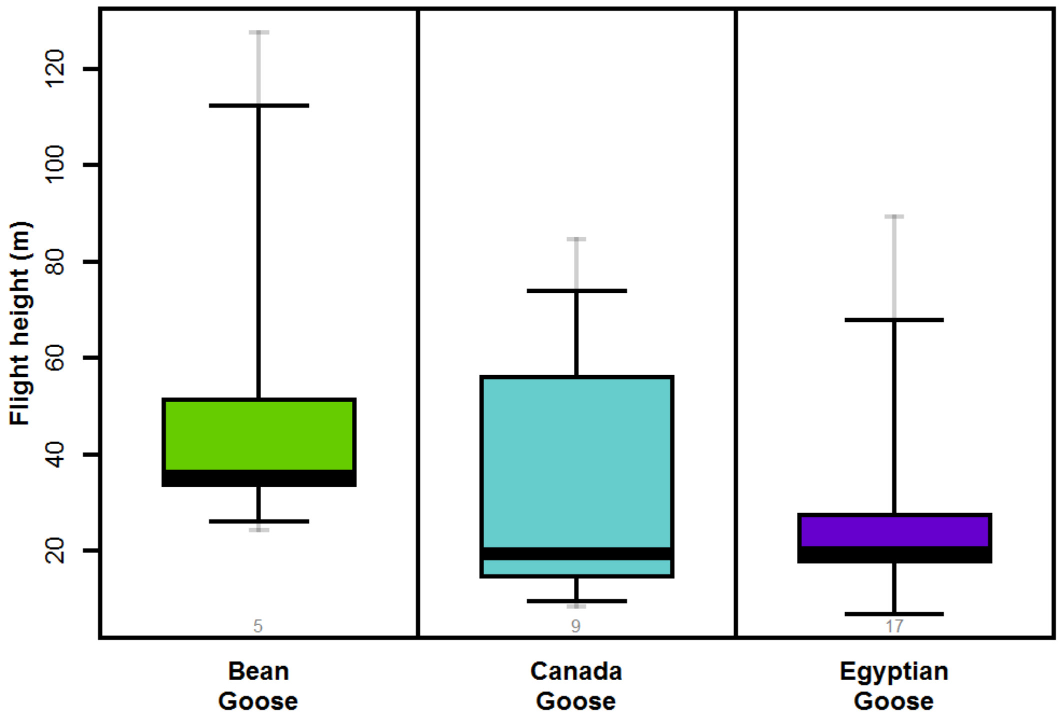

Fig. 11. Boxplot on flight altitude including median (thick black line), quartiles (box), 5% and 95%-quantile (black bars) and extreme values (grey bars). Number of flights in grey underneath each box-plot.

Tab. 4. Flight altitude of the flocks of the different geese species, measured by radar.

species	number of flocks	median (m)	middle 50% (m)	75% below (m)
Bean Goose	5	35	34 - 51	51
Greylag Goose	71	59	31 - 101	101
Greater White-fronted Goose	127	85	56 - 144	144
Barnacle Goose	48	163	99 - 231	231
Canada Goose	9	19	15 - 56	56
Egyptian Goose	17	20	18 - 27	27
Anser/Branta sp	70	106	60 - 227	227

In order to test whether regional patterns in respect to flight height could be detected, we considered only altitudes measured by radar, excluding evaluations made by the field observer, if the flight direction was estimated by the field observer.

Tab. 5. Percentage of geese in the sweep zone of two modern turbines:
Turbine 1 (E - 160 EP5) with a hub height of 166m and a rotor length of 80m. The sweep zone extends from 86 to 246m height (160m).
Turbine 2 (E - 138 EP3) with a hub height of 160m and a rotor length of 60m. The sweep zone extends from 91m to 229m height (138m).

species	sweep zone (1) % of individuals in counted flocks	% of all flock	sweep zone (2) % of individu in counted flocks	% of all flocks	individuals of counted flocks (n)	counted flocks (n)	total of flocks (n)
White-fronted Goose	54	42	45	36	3694	109	127
Barnacle Goose	67	67	38	52	3235	40	48
Greylag Goose	33	31	27	25	597	71	71
Anser/Branta sp	12	37	7	30	3117	65	70

In fig. 12 to fig. 15 flight height is shown together with flight direction and number of geese per flock in the corresponding position of the overflight for the most frequent species and unspecified Anser/Branta geese. Greylag Geese, Greater White-fronted Geese and unspecified Anser/Branta geese displayed no preference for particular altitudes in particular parts of the study area. Barnacle Geese flew higher in the NE and the SW sectors.

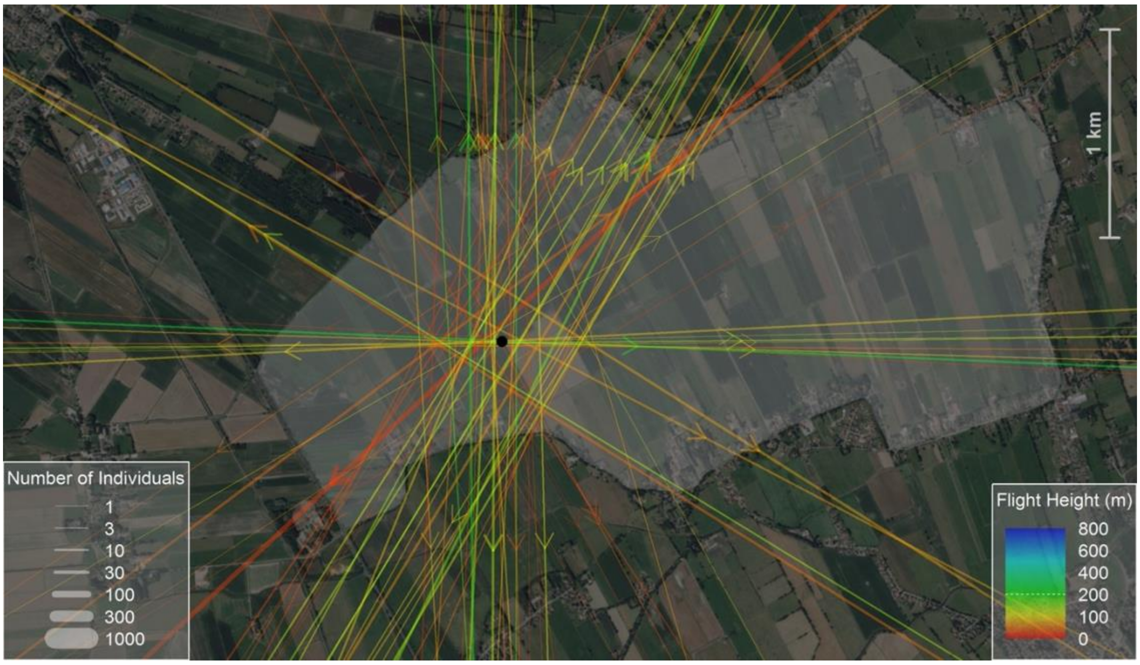

Fig. 12. Flight altitudes vs. area in Greylag Goose in the morning (n = 64). Flight directions were estimated visually, flight altitudes were measured by radar.

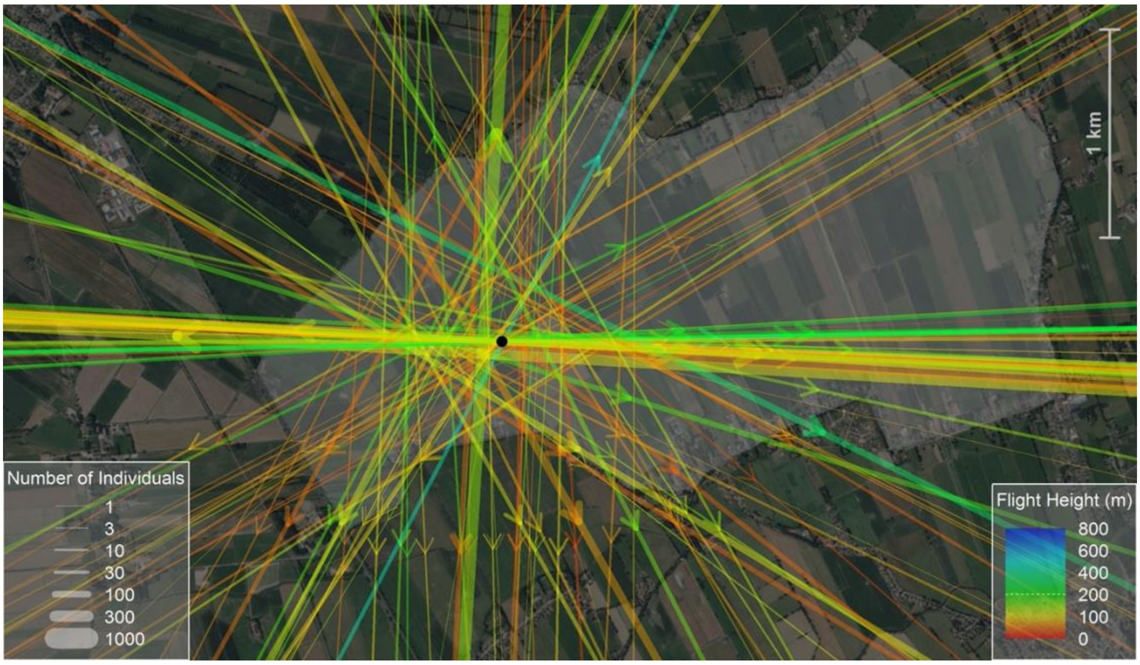

Fig.13. Flight altitudes vs. area in Greater White-fronted Goose in the morning n = 103). Flight directions were estimated visually, flight altitudes were measured by radar.

In order to examine any relationship between flight direction and flight altitude, the estimated flight headings of those flocks with altitudinal radar measurements were offset to our observation site and re-assessed. In Greylag Geese, no conspicuous correlation was demonstrable between flight height and direction (fig. 16).

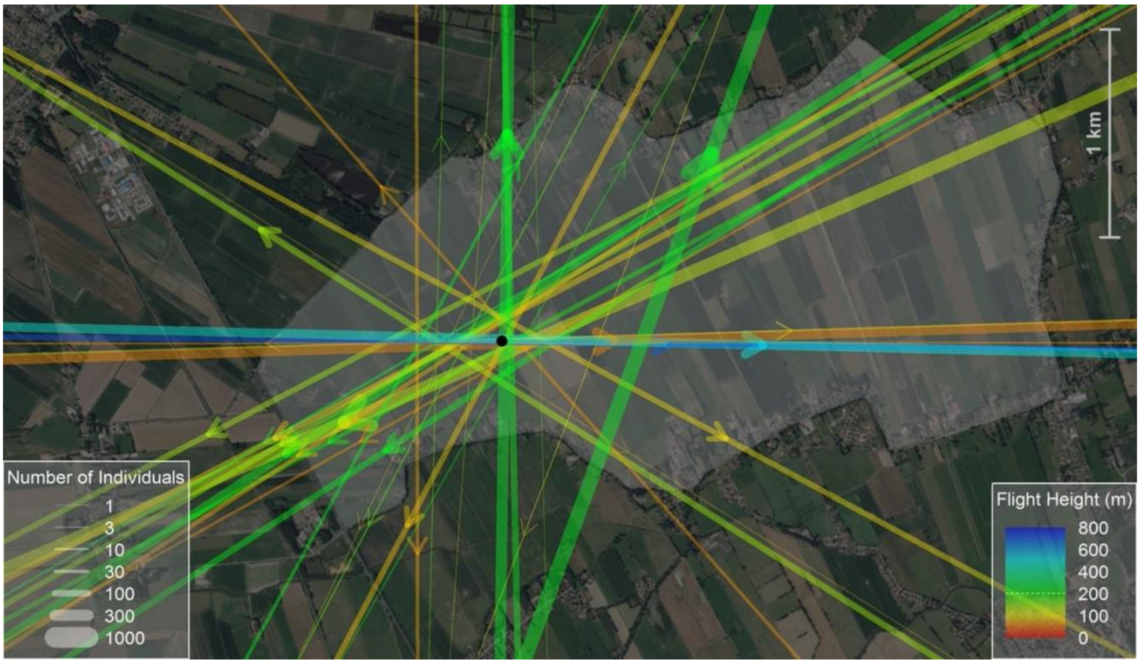

Fig.14. Flight altitudes vs. area in Barnacle Goose in the morning (n = 32). Flight directions were estimated visually, flight altitudes were measured by radar.

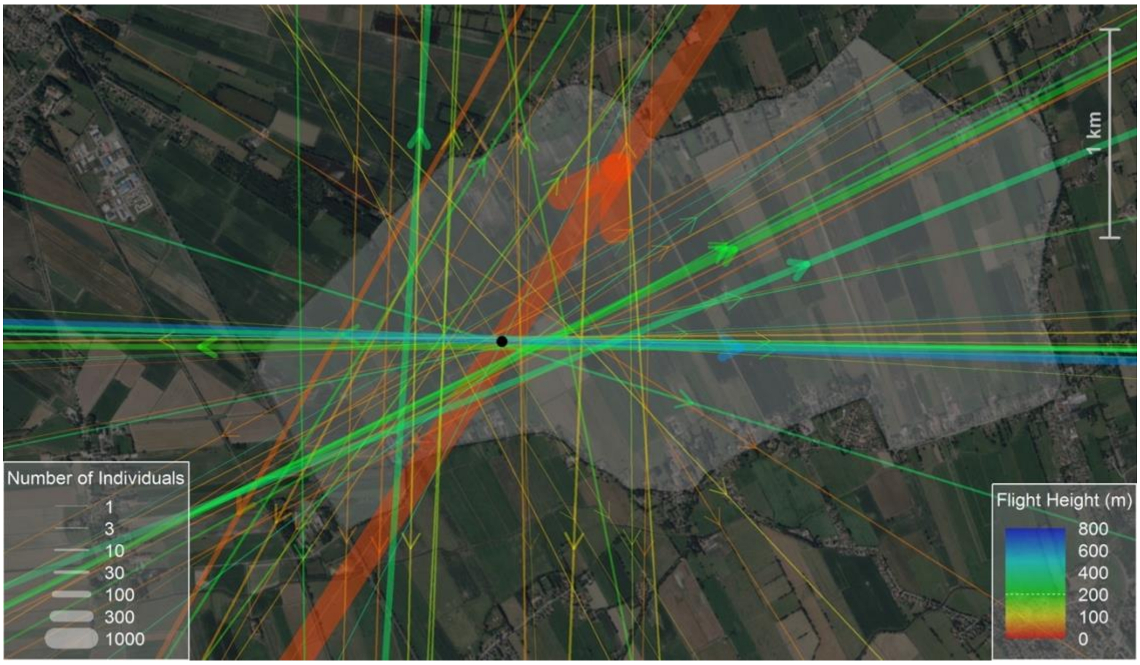

Fig.15. Flight altitudes vs. area in the group of unidentified geese in the morning (n = 57).

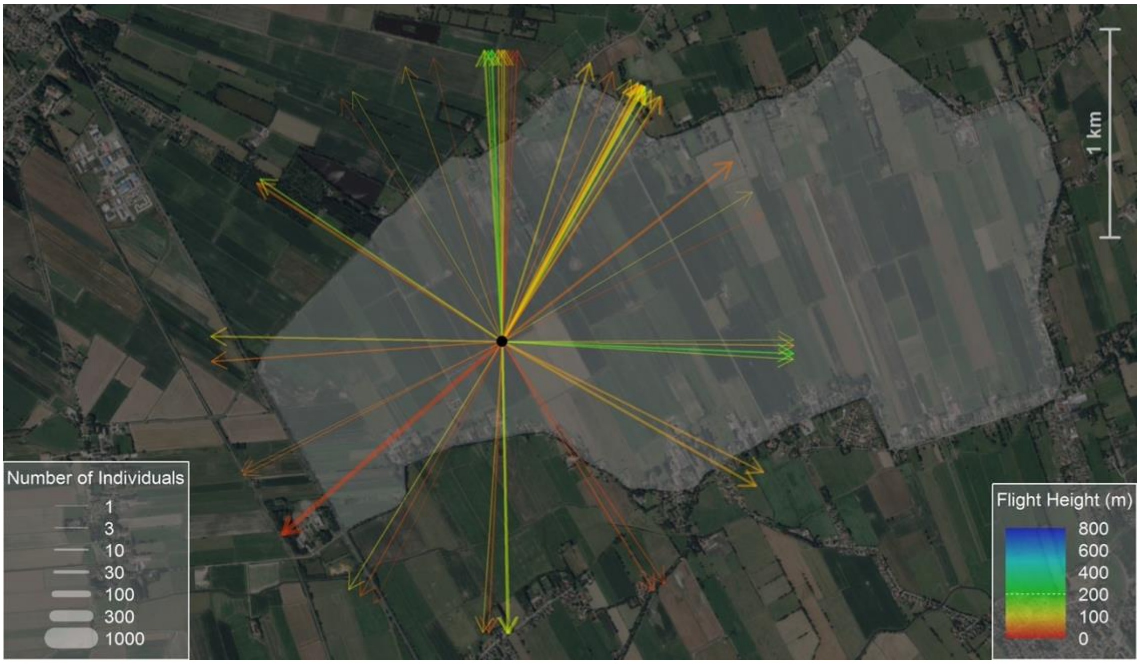

Fig.16. flight altitude vs flight direction in Greylag Goose in the morning (n= 64). Flight directions were estimated visually, flight altitudes were measured by radar.

Most low flying Greater White-fronted Geese were heading towards the sector extending from W to SE and the highest flying were heading towards the sector extending from N to ESE (fig. 17).

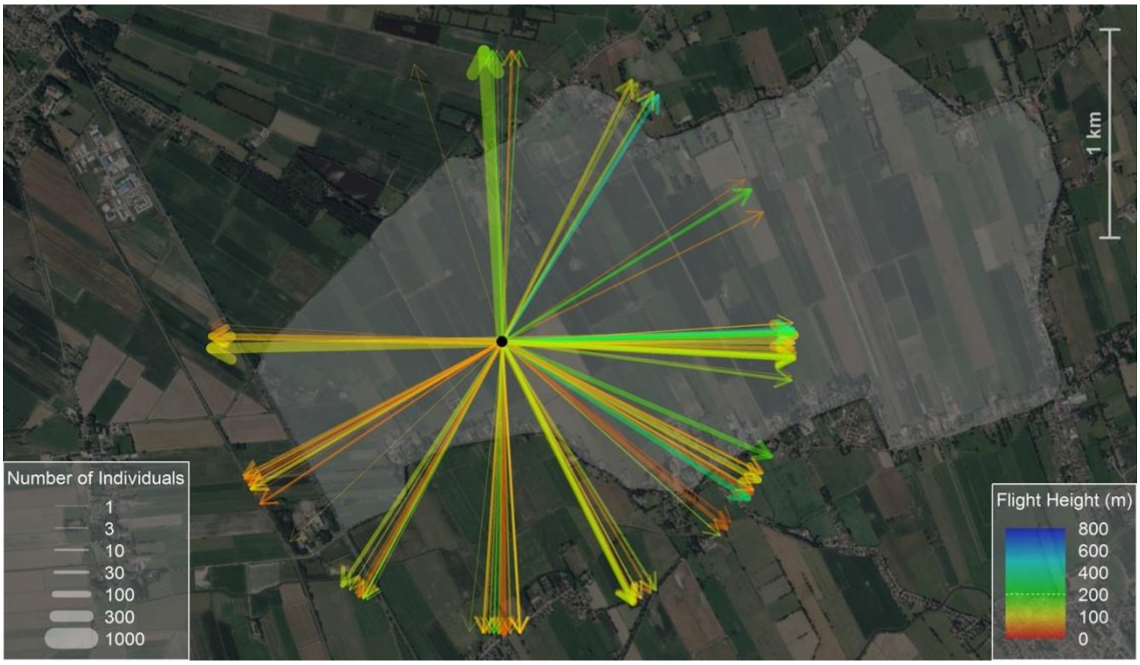

Fig.17. Flight altitude vs. flight direction in Greater White-fronted Goose in the morning (n = 103). Flight directions were estimated visually, flight altitudes were measured by radar.

The flight altitudes of Barnacle Geese heading in N to NE directions were all high, whereas in other directions lower altitudes were also registered (fig. 18).

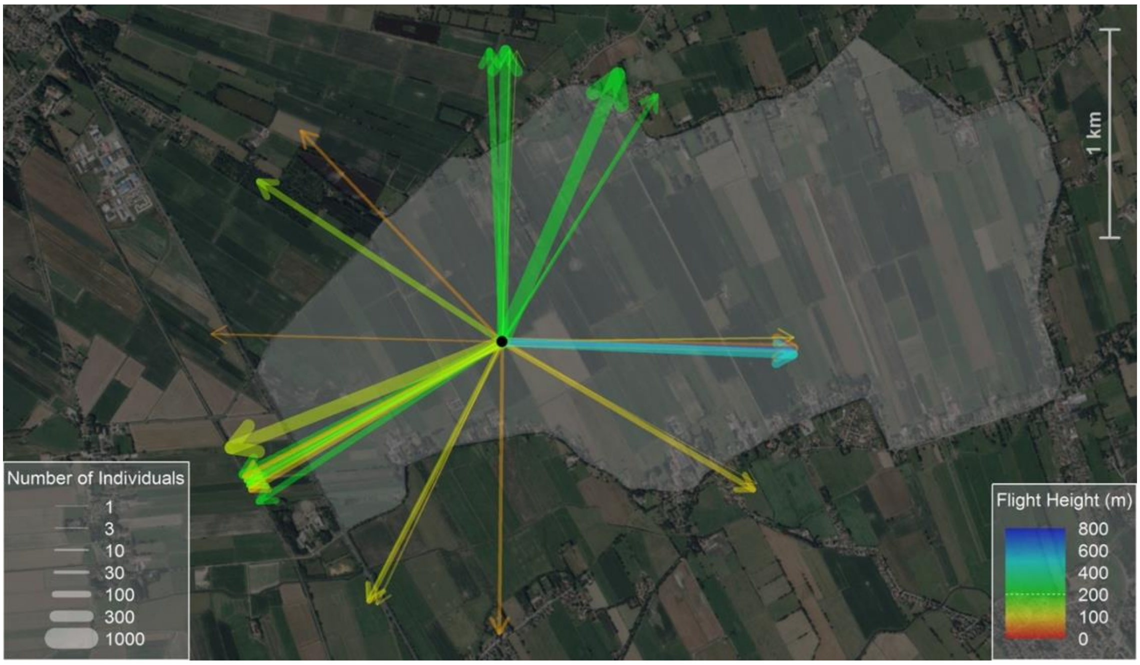

Fig. 18. Flight altitude vs. flight direction in Barnacle Goose in the morning (n = 32). Flight directions were estimated visually, flight altitudes were measured by radar.

In the consort of unspecified Anser/Branta geese, a high proportion of flocks flew very high with headings in the northern half of the compass (fig. 19).

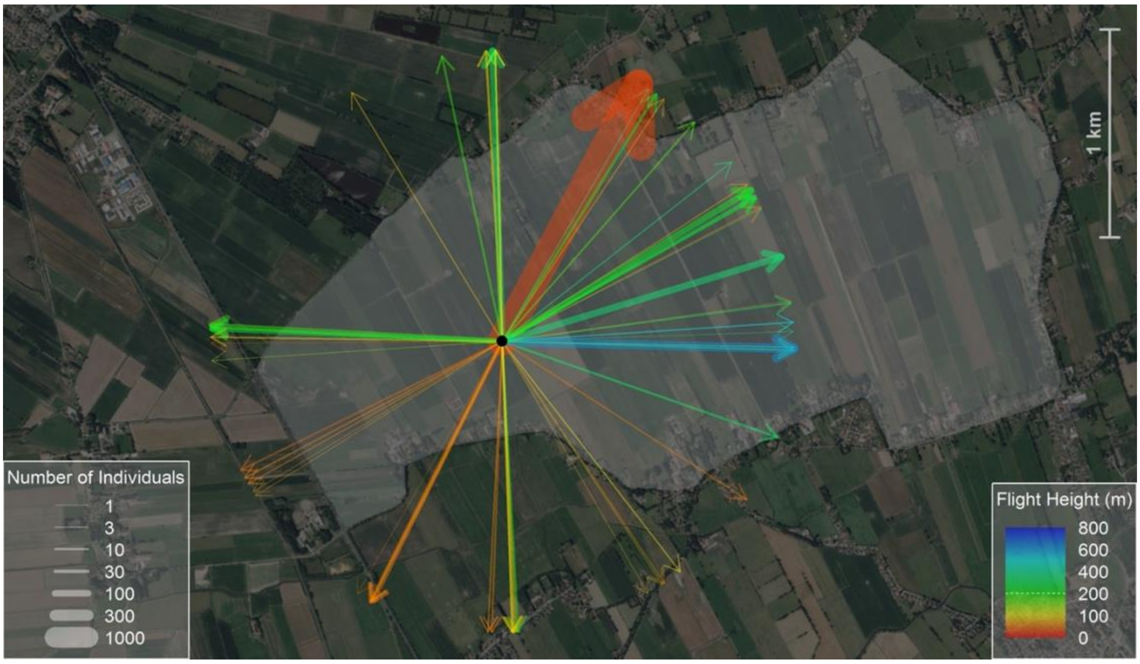

Fig 19. Flight altitude vs. flight direction in unspecified Anser/Branta geese in the morning (n = 57).

Discussion

Discussion of the methods

Radar is an accepted tool in bird studies (EASTWOOD 1967, BRUDERER 1971, HILGERLOH 1981, PLONSZKIER & SIMMS 2012). With radar, observations can also be made at night and in poor visibility. It is also possible to measure the altitude and follow the flight path both of flocks and of individual birds. Nonetheless, the identification of species or taxa presents much more of a problem. To overcome this, recent studies have developed a number of new methods. Using an X-band tracking radar the wing-beat pattern of the birds was used to distinguish several groups of species: 1. waterbirds (such as ducks, coots and grebes), 2. songbirds, 3. swifts and 4. larger, unspecifiable birds (comprising geese, cormorants, herons and gulls) (KÖHLER et al. 2014). Other researchers have used an x-band surveillance radar rotating vertically. Two distinct groups emerge: a diurnal group and a nocturnal (FIJN et al. 2015).

An overview of the different species involved in day movements was established by independent field observations and consisted of gulls, terns, Cormorant, Gannet, ducks, geese and raptors. Passerines migrating during the night were identified by their calls (FIJN et al. 2015). Thus by the wing-beat method geese cannot be distinguished from cormorants, herons and gulls and by the second method geese are not distinguishable from gulls, terns, cormorants, gannets, ducks and raptors. Clearly, these methods would not answer the needs of the present study. It was decided, therefore, to adopt the method of PLONCZKER & SIMMS (2012) in their radar study on migrating Pink-footed Geese, where the species was identified by field observers. We used an x-band surveillance radar rotating vertically and identified the species visually or by their calls if possible. All studied birds belonged to the goose taxon.

The phenology of Arctic and Nordic geese wintering in East Friesland

As in previous years, the geese appeared over the study area in noteworthy numbers from mid-January (H. KRUCKENBERG, pers. com.), while the main feeding area at the "Großes Meer" and Leda-Jümme lowland had already filled up as usual by the end of November/beginning of December (KRUCKENBERG 2013, 2015).

As Greylag, Egyptian and Canada Geese bred and wintered nearby, they were seen crossing the study area throughout the entire observation period. By the 13th week of the year overflights of Greater White-fronted and Barnacle Geese ceased (23 March 2015 and 26 March 2015, respectively)

The pattern of geese movements differed greatly from that of the preceding winter, when a regular early morning movement of geese from a roost was observable within the study area (E. GIESE, pers. com.). On only a very few mornings did we register geese departing from the nearby roost. The pattern of flights may easily change enormously from one year to the next if, for instance, Greater White-fronted Geese, which normally prefer small lakes as nocturnal roosting sites, are no longer tolerated by a lake-owner.

Spatial distribution of the geese

Every evening, we saw large numbers of geese at a distance of about 5 km to the SW of the study area, flying towards the bay of the River Ley in the west and on the following morning back to the feeding areas at the Großes Meer, situated in the south of the study area.

Inside our study area, most flight activities were registered in the western part but there was no part of it entirely without flight activity.

Flight altitude

Radar-measured flight altitudes of geese migrating over the North Sea have been found to lie between 1000 and 3000m, most being between 1500 and 2100m (JELLMANN 1979a, 1979b). Similar altitudes of Greater White-fronted Geese (up to 1800m) were measured by satellite telemetry during spring migration (A. KÖLZSCH, pers. comm.). Conversely, most of the geese in our study area were wintering and only a small fraction was on migration (over land). Geese were flying either to feeding areas, their roost, their comfort zone or onwards towards their next wintering area or to their breeding grounds. In our study area, unless they were very close to their starting or destination point, the geese's flight altitudes varied according to their destination.

Thus, the altitudinal differences between the species was occasioned by the intentions of the geese: the relatively high altitude figures of the Barnacle Geese, for example, were due to the fact that several flocks observed were on active migration, The lower altitude figures of Greater White-fronted Geese may indicate a different flight motivation: they were relocating from one feeding area to another or to a comfort zone or to their roost. Very few will have been migrating. The highest flying Greater White-fronted Geese never reached the altitudes of the highest Barnacle Geese. These are known to make fewer breaks during migration than Greater White-fronted Geese (VAN WIJK et al. 2012). Barnacle Geese may have set off on their migration journey a fair distance away, for example in the Netherlands, whereas Greater White-fronted Geese most likely departed from East Friesland. In the even lower flying Greylag Geese two populations were involved: 1) the local population with short flights of small groups of geese between their local haunts (roost, comfort zone and feeding area), and 2) the wintering Nordic population. Canada Geese and Egyptian Geese flew even lower than Greylag Geese, explainable by the fact that they belonged to a purely local resident population. If a route to the roost of the geese had crossed over the study area we would have been better able to study the effect of the environment on flight altitude.

According to fig. 17 and 18 the highest flying geese, which involved Barnacle and Greater White-fronted Geese, were heading towards the NE sector. This corresponds with the expected migration directions towards Schleswig-Holstein, where they pause before migrating to their breeding area (JELLMANN 1979a). The highest concentrations of Greater White-fronted Geese in Schleswig-Holstein are recorded in March (HILGERLOH & BIERWISCH 1991), which is in line with the departure time from the study area. The highest flights to the W and SW, potentially involving migration flights towards the Netherlands, stayed below 250m.

Avoidance behaviour and risk zone

More action is required in the wintering areas of Arctic and Nordic geese than simply to protect their feeding areas. They fly out of these areas every evening to reach their roosts and fly back to their feeding area the following morning. Wind farms installed on these daily routes may have an adverse effect on the birds not principally as a direct cause of mortality but as a barrier around which they are constrained to detour (DESHOLM & KAHLERT 2005, PLONCZKER & SIMMS 2012, LANGGEMACH & DÜRR 2020). The energy costs of such circumnavigations can be significant (LANGSTON & PULLAN 2003, HÖTKER 2017).

However, if the geese did not change their route, in traversing a WEP they would incur the higher risk of fatal collision in the sweep zone of the turbines. The dimensions and height of this risk zone have altered in recent years owing to increasing hub heights and rotor length of the installations. According to an offshore wind farm study published seven years ago, 30% of migrating birds were at risk from a sweep zone of turbines between 25 m and 115 m height (FIJN et al. 2015). However, in our inland study, up to 67% of Barnacle Geese were at risk from the sweep zones of modern turbines between 86 m and 246 m height. Risk redefinition of this nature may be necessitated by changes either in the flight behaviour of the birds (on migration or on the wintering grounds as in our study) or of the width, height and number of turbines risk zones. Further studies in the wintering area of Arctic and Nordic geese are needed in order to elucidate in what situations and what percentage of geese are exposed to WEP risk zones.

The present research gives a first insight into the spatial and altitudinal use made by a number of geese species of the air space over an inland study area with characteristics similar to those suitable for the construction of WEPs. The percentage of birds flying in the risk zone of modern wind turbines was calculated for each geese species. It is hoped that this paper will help policy-makers to make informed assessments of the risks involved in the construction of WEPs in an important overwintering area of Arctic and Nordic geese.

Acknowledgements

I am very grateful to R. Kima and J. Buddemeier for their assistance with the fieldwork and analyses. For their valuable assistance with the field work my thanks go to J. Hinrichs, C. Kaltofen, G. Pegram, A. Pemöller, T. Willers, D. Wilson and C. Blessing, in addition for her analyses and R. Kima for preparing the graphs and maps. I am grateful to the Landkreis Aurich, who provided the opportunity for this research. Special thanks are also due to E. Giese and F. Puchert, to H. Kruckenberg for advice and to T. Caprano for the development of the radar data processing software. K. Wilson cast a critical eye on the language of the manuscript.

References

BRUDERER, B. (1971): Radarbeobachtungen über den Frühlingszug im Schweizerischen Mittelland (Ein Beitrag zum Problem der Witterungsabhängigkeit des Vogelzuges. - Orn. Beob. 68: 89 – 158.

DESHOLM, M. & J. KAHLERT (2005): Collision at an Offshore Wind Farm. - Biology Letters 1: 296-298.

DREWITT, A. L. & LANGSTON, R. H. W. (2006): Assessing the impacts of wind farms on birds. - Ibis 148: 29–42.

DREWITT, A.L. & R.H.W. LANGSTON (2008): Collision Effects of Wind-power Generators and Other Obstacles on Birds. - Annals of the New York Academy of Sciences. 1134. (1): 233-266.

EASTWOOD, E. (1967): Radar ornithology, 1. Auflage. - Methuen-Verlag, London.

FIJN, R, K. KRIJGSVELD, M. POOT & S. DIRKSEN (2015): Bird movements at rotor heights measured continuously with vertical radar at a Dutch offshore wind farm. - Ibis 157: 558 – 566 (additional appendices).

FIJN, R.C., K.L. KRIJGSVELD, W. TIJSEN, H.A.M. PRINSEN & S. DIRKSEN (2012): Habitat use, disturbance and collision risks for Bewick's Swans *Cygnus columbianus bewickii* wintering near a wind farm in the Netherlands. - Wildfowl 62: 97 – 116.

GARTHE, S. & O. HÜPPOP (2004): Scaling possible adverse effects of marine wind farms on seabirds: Developing and applying a vulnerability index. - J. of Applied Ecology 41: 724 - 734.

GERDES, K. (1994): Lang- und kurzfristige Bestandänderungen der Gänse (*Anser fabalis, A. albifrons, A. anser* und *Branta leucopsis*) am Dollart und ihre ökologischen Wechselbeziehungen. - Die Vogelwarte 57: 157-178.

GÖBEL, J. (2001): Radartechnik. Grundlagen und Anwendungen. 242pp. - VDE Verlag, Berlin und Offenbach, Berlin.

HILGERLOH, G. (1981): Die Wetterabhängigkeit von Zugintensität, Zughöhe und Richtungsstreuung bei tagziehenden Vögeln im Schweizerischen Mittelland. - Orn. Beob. 78: 245-263.

HILGERLOH, G. & I. BIERWISCH (1991): Die Bleßgans. - In: BERNDT, R.K. & G. BUSCHE (Hrsgb.) (1991): Avifauna Schleswig-Holsteins. Bd. 3, Entenvögel I.

HILGERLOH, G., T. CAPRANO & E.M. GRIEBELER (2010): Calibrating the operational beam width and the maximum range of a ship radar used for bird observations. - The Journal of Navigation 63: 363- 371.

HOETKER, H., K.-M. THOMSEN & H. KOESTER (2004): Auswirkungen regenerativer Energiegewinnung auf die biologische Vielfalt am Beispiel der Vögel und der Fledermäuse – Fakten, Wissenslücken, Anforderungen an die Forschung, ornithologische Kriterien zum Ausbau von regenerativen Energiegewinnungs-formen. - NABU Deutschland, Berlin.

HÖTKER, H. (2017): Birds: displacement. - In: PERROW, M.R. (ed) (2017): Wildlife and wind Farms, Conflicts and Solutions. Onshore: Potential Effects. - Pelagic Publishing, Exeter, UK.

JELLMANN, J. (1979a.): Radarbeobachtungen zum Heimzug von Wildgänsen (*Anser, Branta*) im Raum der Deutschen Bucht. - Abhandlungen aus dem Gebiet der Vogelkunde 6: 269-288.

JELLMANN, J. (1979b): Flughöhen ziehender Vögel in Nordwestdeutschland nach Radarmessungen. - Die Vogelwarte 30: 118-134.

KÖHLER, U., H. STARK, K. HAAS, A. GEHROLD, E. KROSIGH, A. LINDEINER & P.KÖHLER (2014): Wind farms and water birds at inland wetlands – a radar ornithological pilot study at Ismaninger reservoir documents the need for buffer zones. - Ber. Vogelschutz 51: 43 – 60.

KRUCKENBERG, H., A. KÖLZSCH, J.H. MOOIJ & H.-H. BERGMANN (2022): Das große Buch der Gänse. 256S. - Aula Verlag, Wiebelsheim, ISBN 978-3-89104-841-2.

KRUCKENBERG, H. (2013): Vorkommen von Gastvögeln im Bereich der Ostfriesischen Binnenmeere. Ergebnisse der Geländeerfassungen Oktober 2012 bis Mai 2013. - Im Auftrag des Landkreis Aurich. 40pp.

KRUCKENBERG, H. (2015): Bestand und räumliche Verbreitung ausgewählter Gastvogelarten in der LedaJümme-Niederung (Landkreis Leer) im Winter 2013/14. - Vogelkdl. Ber. Niedersachs. 44: 1-22.

KRUCKENBERG, H. (2018): Familienbande. In: SÜDBECK, P., F. BAIRLEIN & R. LOTTMANN (hrsg.) (2018): Zugvögel im Wattenmeer. Faszination und Verantwortung. S. 82 – 101. - Rune-Mettcker Druck- und Verlags-GmbH, Wilhelmshaven.

LANGGEMACH, T. & T. DÜRR (2020): Informationen über Einflüsse der Windenergienutzung auf Vögel. - Landesamt für Umwelt Brandenburg. Staatliche Vogelschutzwarte, D-14715 Buckow.

LANGSTON, R. H. W. & J.D. PULLAN (2003): Windfarms and birds: An analysis of the effects of windfarms on birds, and guidance on environmental assessment criteria and site selection issues. - BirdLife International on behalf of the Bern Convention, Strasbourg.

PLONCZKIER, P. & C. SIMMS (2012): Radar monitoring of migrating pink-footed geese: behavioural responses to offshore wind farm development. - Journal of Avian Ecology 49: 1187 – 1194.

TELLERIA, J.-L. (2009): Potential impacts of wind farms on migratory birds crossing Spain. - Bird Conserv. Int. 19: 131–136.

R CORE TEAM (2014): R: A language and environment for statistical computing. - R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

VAN WIJK, R., A. KÖLZSCH, H. KRUCKENBERG, B.S. EBBINGE, G.J.D.M. MÜSKENS & B.A. NOLET. (2012): Individually tracked geese follow peaks of temperature acceleration during spring migration. - Oikos 121: 655-664.