Biodivers Conserv (2007) 16:3345–3359
DOI 10.1007/s10531-006-9082-1

ORIGINAL PAPER

Impact of wind turbines on birds in Zeebrugge (Belgium)

Significant effect on breeding tern colony due to collisions

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Received: 18 April 2006 / Accepted: 12 June 2006 / Published online: 11 November 2006

Abstract We studied the impact of a wind farm (line of 25 small to medium sized turbines) on birds at the eastern port breakwater in Zeebrugge, Belgium, with special attention to the nearby breeding colony of Common Tern *Sterna hirundo*, Sandwich Tern *Sterna sandvicensis* and Little Tern *Sterna albifrons*. With the data of found collision fatalities under the wind turbines, and the correction factors for available search area, search efficiency and scavenging, we calculated that during the breeding seasons in 2004 and 2005, about 168 resp. 161 terns collided with the wind turbines located on the eastern port breakwater close to the breeding colony, mainly Common Terns and Sandwich Terns. The mean number of terns killed in 2004 and 2005 was 6.7 per turbine per year for the whole wind farm, and 11.2 resp. 10.8 per turbine per year for the line of 14 turbines on the sea-directed breakwater close to the breeding colony. The mean number of collision fatalities when including other species (mainly gulls) in 2004 and 2005 was 20.9 resp. 19.1 per turbine per year for the whole wind farm and 34.3 resp. 27.6 per turbine per year for 14 turbines on the sea-directed breakwater. The collision probability for Common Terns crossing the line of wind turbines amounted 0.110–0.118% for flights at rotor height and 0.007–0.030% for all flights. For Sandwich Tern this probability was 0.046–0.088% for flights at rotor height and 0.005–0.006% for all flights. The breeding terns were almost not disturbed by the wind turbines, but the relative large number of tern fatalities was determined as a significant negative impact on the breeding colony at the eastern port breakwater (additional mortality of 3.0–4.4% for Common Tern, 1.8–6.7% for Little Tern and 0.6–0.7% for Sandwich Tern). We recommend that there should be precautionary avoidance of constructing wind turbines close to any important breeding colony of terns or gulls, nor should artificial breeding sites be constructed near wind turbines, especially not within the frequent foraging flight paths.

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Keywords Birds · Collision · Disturbance · Gulls · Impact · Mortality · Terns · Wind turbine

Introduction

Wind turbines can have a negative impact on birds. Several European field studies have shown that birds can collide with the turbines during local and seasonal migration, or they can become disturbed in their breeding, resting and foraging areas or during migration (Langston and Pullan 2003; Kingsley and Whittam 2005).

In commission by the Flemish government, in May 2000 the Research Institute for Nature and Forest started monitoring the impact of wind turbines on birds. Preliminary study results (until 2001) were presented in Everaert et al. (2002) and Everaert (2003).

One monitoring location is situated in the outer port of Zeebrugge, Belgium (51°22′ N, 3°13′ W), at the North Sea coast. There are 25 small to medium sized turbines in two lines placed alongside the water on the eastern port breakwater; 10 turbines of 200 kW (13–22 in Fig. 1), 12 turbines of 400 kW (1–12 in Fig. 1) and 3 turbines of 600 kW (23–25 in Fig. 1). In 2000, the construction of a peninsula was started next to 4 of the most northern 400 kW wind turbines. In the first phase, the peninsula was about 2 ha, in 2001 an additional 3 ha was constructed, in 2004 there was an extension to about 6.5 ha, and during the breeding season in 2005, the peninsula measured about 8.5 ha. The peninsula was created as an alternative breeding site for terns and plovers to compensate for the loss of other nearby areas

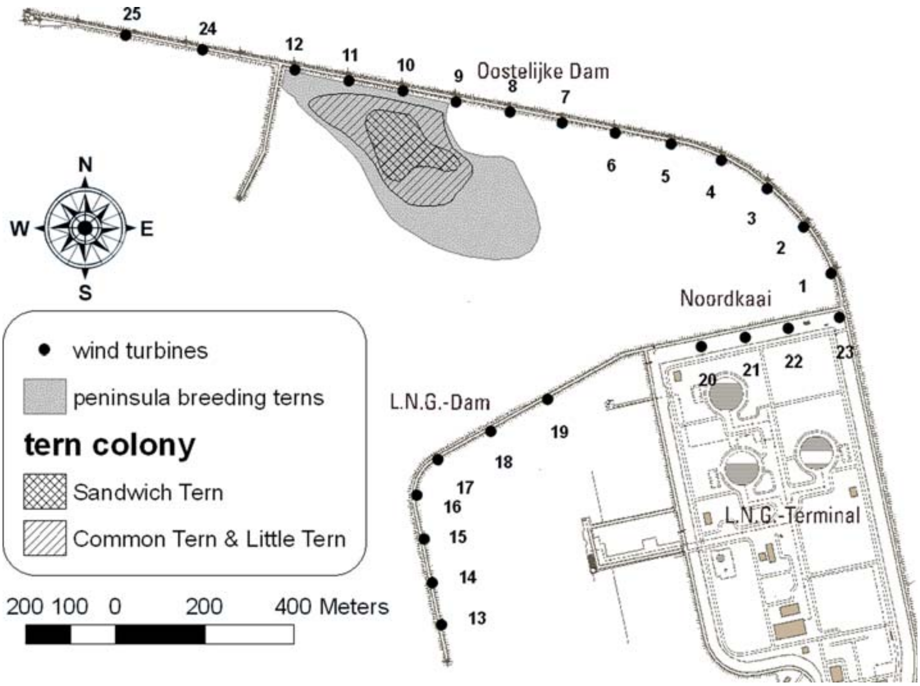

Fig. 1 Wind farm and tern colony on the eastern port breakwater in Zeebrugge. 'Oostelijke Dam' with 14 sea directed turbines. 'Noordkaai' and 'LNG-Dam' with 11 land directed turbines

at the western port breakwater (1500–3000 m west of the peninsula) where during the breeding season also a gull colony is present. The extension of the peninsula was assumed to be the only possible alternative in the short term (Courtens and Stienen 2004). As a result of the expansion of the peninsula at the eastern port breakwater and loss of habitat near the western port breakwater, in 2004 the numbers of terns at the peninsula strongly increased (Table 1).

Methods

Mortality

During 2004 and 2005, weekly or twice weekly searches for collision fatalities were performed under the wind turbines. Only the obvious or highly probable collision fatalities were used to determine the mortality (birds with lacerations, wing injuries, head injuries, back injuries and signs of internal injuries which were certainly or most probably caused by a collision). The range of the search circle was for all the turbines at the eastern port breakwater the same as the tip height of the 400 kW turbines (50 m), but not this whole area could be searched (see further). During the breeding season of the terns, more frequent searches were performed, sometimes daily (at least 3–4 times a week) and the search area was extended (Fig. 2). All useful information (date, collision victim, possible date of collision, species, age, sex, place/distance in relation to the nearest wind turbine, situation of the birds (wounds), etc.) was collected in a standardised database and spatially presented in a geographical information system (ArcMap in ArcGIS 9). In some cases, the distance between the nearest wind turbine and the location of the found collision victim was measured with a Leica Geovid 7 × 42 BDA, but often the distance was estimated by counting the number of steps to the nearest turbine.

Not all collision fatalities are found; some end up in the water next to the port breakwater and some are removed by predators. The estimated number of collision fatalities (Table 2) was therefore calculated using correction factors for available search area, search efficiency and scavenging (predation), deduced from Winkelman (1992a).

The correction factor for available search area for each wind turbine was calculated in ArcGIS with the most recent aerial photograph of the area, and was applied

Table 1 Number of breeding pairs of terns on the peninsula along the eastern port breakwater (=‘N_a’) and the total number in Zeebrugge including nearby areas in the western port and Heist (=‘N’). ‘% N_1’ is the percentage of the biogeographical population of the species that breeds in Zeebrugge, and ‘% N_2’ is the percentage of the Belgian population that breeds in Zeebrugge (Stienen 2005; Wetlands International 2002)

Year	Little Tern				Common Tern				Sandwich Tern			
	N_a	N	% N_1	% N_2	N_a	N	% N_1	% N_2	N_a	N	% N_1	% N_2
2001	126	184	1.62	100	–	2260	3.57	91	–	920	1.62	100
2002	70	145	1.28	100	12	2446	3.86	99	–	46	0.08	100
2003	150	152	1.34	88	257	2535	4.00	95	–	823	1.45	100
2004	138	172	1.52	98	1832	3052	4.82	90	4067	4067	7.18	100
2005	11	69	0.61	100	1475	1747	2.76	72	2538	2538	4.48	100

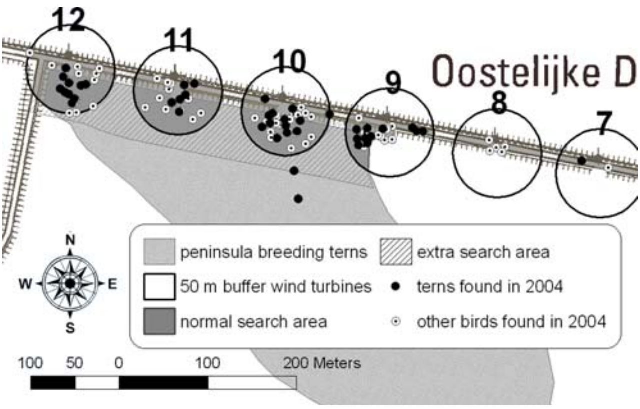

Fig. 2 Found collision fatalities on some of the 400 kW wind turbines (sea-directed breakwater near the peninsula) of the wind farm at the eastern port breakwater in Zeebrugge in 2004

Table 2 Used formula to determine the total number of collision fatalities (N_a = found number of collision fatalities, C_z = correction factor for search area (=100/z, where z = the proportion searched surface (in%) of the total surface which should have to be searched), C_p = correction factor for scavenging (=100/p, where p = the proportion of birds (in%) that were removed by predators during a scavenging-test, C_e=correction factor for search efficiency (=100/e, where e = the proportion of birds (in%) that were found by the investigator)

N-estimated = $N_a^* C_z^* C_p^* C_e$

for all collision fatalities (all species). The correction for scavenging was only used for small birds (wingspan smaller than a pigeon) and terns. In previous years, it was found that no correction factor for scavenging was necessary for larger birds. For small birds a correction factor of 7.14 was used (result of scavenging test in 2001, see Everaert et al. 2002). But because of the large number of collided terns since 2004, an extra test was performed to determine the predation on terns. In Juli 2004, 13 relatively fresh bird carcasses about the size of a Common Tern, 4 recently collided Common Terns and 2 Sandwich Terns were placed at the peninsula or on the road (port breakwater) next to it, and checked if the carcasses were still there after 2 days and further. The correction for search efficiency was only used for collided small birds and terns which were found on the peninsula. During March (small birds) and August (small birds and terns) in 2004, 28 bird carcasses were placed on the peninsula by one person. Within the next 24 h, another person who normally searches the area (author of this article) checked the peninsula as usual. It was concluded that no correction for search efficiency was needed for birds found at the road and on other clear areas. Hereafter, the 'calculated number of collision fatalities' will be called 'number of collision fatalities'.

During two full days (including dawn and dusk) in June 2004 and 2005 (17 h each) with similar weather conditions (dry with wind W-ZW 2–4 Bft.), the number of terns flying from the colony towards the sea and back, thereby crossing the eastern port breakwater with the wind turbines, were determined in the zone of wind turbines 7–12, with a total baseline distance of 720 m (Fig. 2). The observer was located at the end of the baseline on the breakwater. The terns flying above the colony were not counted, only those who crossed the line of wind turbines or were flying very close

(< 30 m) to the wind turbines thereby quasi crossing the line. The data (mean number) of these diurnal movements were extrapolated for the whole month and combined with the calculated number of collision fatalities in June 2004 and 2005. With this, it was possible to determine the collision probability of the terns crossing the line of wind turbines on the eastern port breakwater. Additionally, in June 2004 and July 2005, 2 inspections were performed with a ‘generation 3’ night vision goggle ITT Night Enforcer 5000 (standard and additional 60–300 mm lens) to check if the terns were also performing nocturnal movements, but none were seen.

Disturbance

During the breeding seasons, the distance between the wind turbines and nesting terns was measured with a Leica Geovid 7 × 42 BDA. This data was also spatially presented in a geographical information system (ArcGIS). Additionaly, during the whole year (mainly in winter), the distance between the wind turbines and foraging or resting birds (mainly ducks and other waterfowl) was measured.

Results

Mortality

The correction factor for available search area varied from 1.33 to 9.09 depending on the location of the wind turbine (visual example, see Fig. 2). The correction factor for scavenging was calculated to be 7.14 for small birds and 1.10 for all terns. The correction factor for search efficiency on the peninsula was 1.50 for small birds and 1.16 for all terns.

In 2004 and 2005, 121 resp. 105 collision fatalities were found, mainly gulls and terns. The total number of collision fatalities (corrected with the necessary correction factors) was calculated to be 523 resp. 459 birds, or 20.9 resp. 19.1 birds per turbine per year (Tables 3–4).

Tern mortality

Because of the large number of breeding terns on the peninsula since 2004, the daily number of terns crosssing (or almost crossing) the eastern port breakwater was consequently high (Table 5).

Table 3 Number of collision fatalities from the wind farm at the eastern port breakwater in Zeebrugge in 2004, with the mean number per turbine per year. The ‘found’ numbers without correction factors are presented between brackets

	Gulls + other large birds	Terns	Small birds	Total	Number per turbine per year
Sea directed turbines, n = 14	195.2 + 9.1 (54 + 1 found)	156.8 (48 found)	118.5 (4 found)	479.6 (107 found)	34.3
Land directed turbines, n = 11	31.9 (12 found)	11.5 (2 found)	0.0	43.4 (14 found)	3.9
Total wind farm, n = 25	227.1 + 9.1 (66 + 1 found)	168.3 (50 found)	118.5 (4 found)	523.0 (121 found)	20.9

Table 4 Number of collision fatalities from the wind farm at the eastern port breakwater in Zeebrugge in 2005, with the mean number per turbine per year. The 'found' numbers without correction factors are presented between brackets

	Gulls + other large birds	Terns	Small birds	Total	Number per turbine per year
Sea directed turbines, n = 14	138.7 + 1.7 (37 + 1 found)	150.9 (51 found)	95.3 (3 found)	386.7 (92 found)	27.6
Land directed turbines, n = 10 [a]	62.5 (12 found)	10.0 (1 found)	0.0	72.5 (13 found)	7.3
Total wind farm, n = 24	201.3 + 1.7 (49 + 1 found)	160.9 (52 found)	95.3 (3 found)	459.2 (105 found)	19.1

[a] One wind turbine was not operational during the whole year due to an accident where all blades were lost.

Table 5 Daily number of flights crossing or almost crossing the line of wind turbines in the zone of turbines 7–12 on the eastern port breakwater during the day in June 2004 and 2005. Mean number of 2 days of 17 h each

Height range	Little Tern		Common Tern		Sandwich Tern	
	June 2004	June 2005	June 2004	June 2005	June 2004	June 2005
0–15 m	1508 (86%)	130 (35%)	9548 (92%)	3062 (72%)	14090 (92%)	10724 (87%)
16–50 m	216 (12%)	240 (64%)	650 (7%)	1154 (27%)	942 (6%)	1596 (13%)
> 50 m	25 (2%)	5 (1%)	65 (1%)	12 (1%)	205 (2%)	14 (0%)
all heights	1749	375	10263	4228	15237	12334

[a]16–50 *m = rotor height of the wind turbines*

The increased number of foraging flights since 2004 resulted in a similar increase in the number of collision fatalities among the terns (Table 6). In the period from the beginning of May up to the middle of August 2004, in total 50 tern collision fatalities were found, the majority of it in May–July when the terns performed most movements between the breeding colony and the feeding grounds at sea. No collided

Table 6 Number of collision fatalities of terns at the wind turbines alongside the eastern port breakwater, Zeebrugge, during the breeding season. Corrected number = corrected for available search area, search efficiency, and scavenging

Year	Found number of collision fatalities				Corrected number of collision fatalities			
	Little Tern	Common Tern	Sandwich Tern	Total	Little Tern	Common Tern	Sandwich Tern	Total
2001[a]	2	3	0	5	8	20	0	28
2002[a]	2	4	0	6	9	15	0	24
2003[a]	3	6	0	9	10	32	0	42
2004	3	35	12	50	5	109	54	168
2005	1	41	10	52	2	129	30	161

[a]In 2001, 2002 and 2003, no correction for search efficiency and scavenging was used, but the correction for available seach area was larger than the one used in 2004 and 2005 because of the fact that during the breeding season of 2001, 2002 and 2003, not all necessary search-areas on the peninsula (breeding area) were searched completely (see Everaert et al. 2002)

terns were found during the rest of the year. All found fatalities were adults. With the necessary correction factors for the available search area, scavenging (removal by predators or other animals), and search efficiency, the total number of collision fatalities is calculated to be 168 terns, or 1.57 per day. In the period from the middle of April up to the end of July 2005, similar results were found, with a total number of 161 terns, or 1.51 per day.

In 2004, 90% of the tern fatalities that were effectively found (76% of corrected number) came in collision with the 4 wind turbines which are located alongside the peninsula (turbines 9–12, see Figs. 1–3). In 2005, this was 92% (75% of corrected number, see Fig. 4). These turbines stand approximately perpendicular on the flight route of the terns crossing the eastern port breakwater. Both in 2004 and 2005, a significant difference (Kolmogorov–Smirnov Test, $P < 0.005$) in tern collision fatalities was found between the group of wind turbines alongside the peninsula (turbines 9–12) and the other group (turbines 1–8 and 13–25).

During the 4 (2 + 2) observation days in June 2004 and 2005 (to determine the number of movements crossing the line of wind turbines near the peninsula) we 'witnessed' 5 collisions ourselves (2 Common Terns and 3 Sandwich Terns). This means that at least 1.25 terns collided during one day. Additionaly 3 Common Terns and 2 Sandwich Tern were seen colliding with one of the wind turbines during other shorter visits at the site in 2004 and 2005.

With the data of 48 fresh tern fatalities (died < 24 h before), found under the wind turbines alongside the peninsula (turbines 8–12) between May–August 2005, the mean diurnal wind direction (Dumon 2006) for the presumed collision-period was checked. It was calculated that 44 (91.67%) of these tern fatalities collided with NNW-ENE or SSE-WSW wind, and 4 (8.33%) with ENE-SSE or WSW-NNW wind. Between May–August 2005, there were 68.51% diurnal periods of 10 min with NNW-ENE or SSE-WSW wind and 31.49% diurnal periods with ENE-SSE or

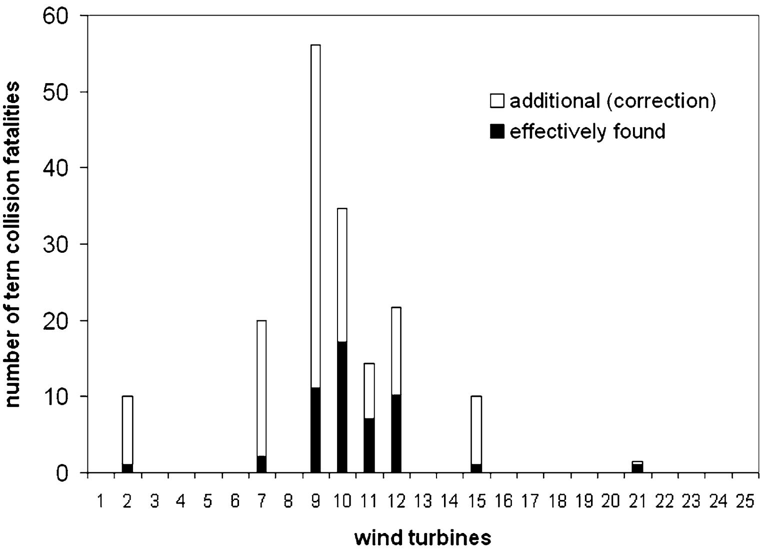

Fig. 3 Number of collision fatalities of terns per wind turbine on the eastern port breakwater, Zeebrugge, in 2004. The numbers of turbines correspond with those mentioned in Fig. 1

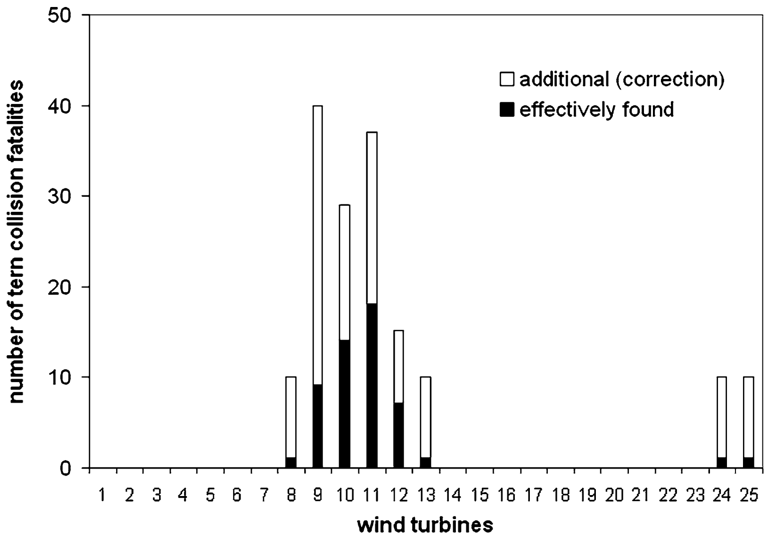

Fig. 4 Number of collision fatalities of terns per wind turbine on the eastern port breakwater, Zeebrugge, in 2005

WSW-NNW wind (Dumon 2006). The difference between the observed number of collision fatalities in the 2 subdivided wind directions (44 vs. 4) and the expected number (33 vs. 15) based on the total number (48) and the wind directions between May–August, was significant (Chi-Square = 11.73, $P < 0.001$). Concluding, the chance for a collision was higher during NNW-ENE or SSE-WSW wind with the turbine blades standing perpendicular on the flight route of the terns.

A significant correlation was found between the number of breeding pairs in the tern-colony and the number of collision fatalities ($P < 0.01$ for Common Tern, $P < 0.001$ for Sandwich Tern, see also Figs. 5, 6).

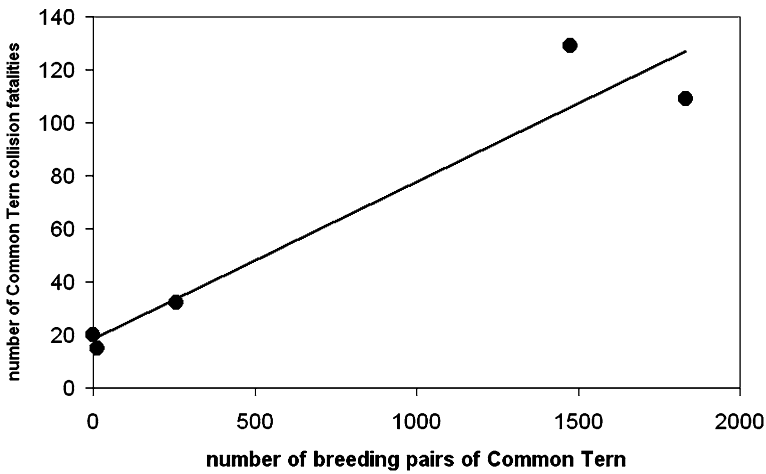

Fig. 5 Correlation between the number of Common Tern pairs in the breeding colony and the number of collision fatalities in the years 2001–2005 ($r = 0.96$; $P < 0.01$)

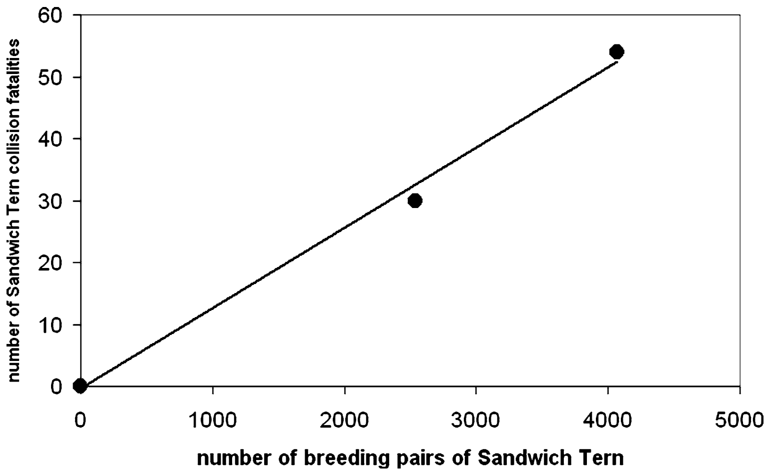

Fig. 6 Correlation between the number of Sandwich Tern pairs in the breeding colony and the number of collision fatalities in the years 2001–2005 (in 2001–2003 there were no breeding birds on the peninsula ($r = 0.998$; $P < 0.001$)

We observed that during the breeding season the line of wind turbines at the eastern port breakwater didn't act as a barrier for the foraging flights of the terns and gulls.

The collision probability for Common Terns crossing the line of wind turbines amounted 0.110–0.118% for flights at rotor height and 0.007–0.030% for all flights. A lower collision probability was found for Sandwich Tern, with 0.046–0.088% for flights at rotor height and 0.005–0.006% for all flights (Table 7).

In the breeding population at the eastern port breakwater, the wind turbines caused an additional mortality of 3.0–4.4% for Common Tern, 1.8–6.7% for Little Tern and 0.6–0.7% for Sandwich Tern (Table 8).

Disturbance of breeding, foraging or resting birds

In 2004, the nearest Common Terns were breeding at 30 m distance from the turbines, but the majority of the Common Terns, Little Terns and Sandwich Terns were breeding 100 m or further away from the turbines (Fig. 1). In 2005, most of the Sandwich Terns and many Common Terns were breeding at 50 m distance or further. Kentish Plover *Charadrius alexandrinus* and Common Ringed Plover

Table 7 Collision probability for Common Tern and Sandwich Tern in June 2004 and 2005. Calculated from the corrected number of collision fatalities on wind turbines 7–12 (near Tern peninsula) in June, and the number of diurnal flights across the eastern port breakwater in the zone of wind turbines 7–12 in June (extrapolated from the mean number of flights during 2 days in June, see also table 5)

	Collision probability with diurnal flights at rotor height		Collision probability with diurnal flights at all heights	
	2004	2005	2004	2005
Common Tern	1/848	1/911	1/13387	1/3338
Sandwich Tern	1/1130	1/2176	1/18283	1/16819

Table 8 Impact of the number of wind turbine fatalities (adult) on the breeding population of terns in 2004 and 2005 (eastern port breakwater and total of Zeebrugge)

	Little Tern		Common Tern		Sandwich Tern	
	adults 2004	adults 2005	adults 2004	adults 2005	adults 2004	adults 2005
Eastern port breakwater (peninsula)	276	22 + ca.8[a]	3664	2950	8134	5076
Total Zeebrugge (incl. Western port & Heist)	344	138	6104	3494	8134	5076
Number of fatalities	5	2	109	129	54	30
Number of fatalities in % of the total breeding population on the eastern port breakwater	1.8%	6.7%	3.0%	4.4%	0.7%	0.6%
Number of fatalities in % of the total breeding population in Zeebrugge	1.5%	1.5%	1.8%	3.7%	0.7%	0.6%

[a]Including non-breeding birds, present during the breeding season

Charadrius hiaticula were breeding at about 40 m or further from the turbines, but were sometimes foraging at closer distances.

Large groups of non-breeding foraging/resting waterfowl and shorebirds normally held a distance of about 100–300 m from the turbines. Individual birds and small groups were sometimes closer (Table 9).

Discussion

Mortality

Research results of individual wind farms can not be generalised. In general, the collision mortality is related to the number of (flying) birds present, whereas the size of the turbines seems less important. Large modern turbines of 1500 kW or more can have as much or even more collision fatalities than smaller turbines (Akershoek et al. 2005; Everaert 2003; 2006). However, more data on large wind turbines is urgently needed.

The average number of collision fatalities in different European wind farms on land varies between a few birds per turbine per year up to 64 birds per turbine per year (Langston and Pullan 2003; Everaert 2006). Also within a wind farm the impact can strongly differ between individual turbines, indicating that 'site selection' can play an important role in limiting the number of collision fatalities. During previous years, for some wind turbines at the eastern port breakwater in Zeebrugge, up to 111 and 125 fatalities were calculated as a result of the correction factors for some small birds that were occasionally found (Everaert et al. 2002; Everaert 2003). In Sylt and Helgoland, Germany (each with only one wind turbine), after a full year study, bird deaths per turbine per year were estimated to be respectively 2.8–103 and 8.47–309 (Benner et al. 1993). One example of multiple bird kills occurred at a wind turbine in Nasudden, Sweden, where 49 collided birds were found after one night with poor

Table 9 Nearest observed distance to the wind turbines of non-breeding foraging or resting waterfowl and shorebirds at the peninsula and direct surroundings on the eastern port breakwater in Zeebrugge

Species (-group)	Distance (m) of individual or small groups	Distance (m) of large groups (> 50 ex.)
Great Crested Grebe *Podiceps cristatus*	50	100
Cormorant *Phalacrocorax carbo*	25	?
Grey Heron *Ardea cinerea*	200	?
Little Egret *Egretta garzetta*	100	?
Eurasian Spoonbill *Platalea leucorodia*	200	?
Gulls *Larus spec.*	<10	?
Terns *Sterna spec.*	<10	50
Common Shelduck *Tadorna tadorna*	100	?
Mallard *Anas platyrhynchos*	100	250
Gadwall *Anas strepera*	150	300
Northern Shoveler *Anas clypeata*	100	250
Tufted Duck *Aythya fuligula*	150	?
Greater Scaup *Aythya marila*	150	?
Pochard *Aythya ferina*	150	?
Northern Pintail *Anas acuta*	100	250
Eurasian Wigeon *Anas penelope*	100	250
Common Eider *Somateria mollissima*	50	?
Red-breasted Merganser *Mergus serrator*	100	?
Oystercatcher *Haematopus ostralegus*	50	200
Dunlin *Calidris alpina*	150	250
Common Ringed Plover *Charadrius hiaticula*	<10	?
Kentish Plover *Charadrius alexandrinus*	<10	?
Eurasian Curlew *Numenius arquata*	100	?
Bar-tailed Godwit *Limosa lapponica*	200	?

? = not of application/not known

weather conditions; the turbine was not operational at the time, but was lit with a single lamp 10 m above the ground (Gill et al. 1996; Karlsson 1983). Overall, mortality events of this magnitude are seldom recorded, but with more and bigger wind turbines planned (certainly offshore), it is still unclear if this will only be a rare phenomenon. More intensive searches during the whole year and with many wind turbines at different types of locations are urgently needed.

Some researchers reported (almost) only common species (Winkelman 1992a; Van der Winden et al. 1999). However, the situation depends on the location. Even the presence of relatively low numbers of rare birds doesn't always guarantee a low collision probability. In Germany researchers already found 17 White-tailed Eagles *Haliaeetus albicilla* and 69 Red Kites *Milvus milvus* during occasional searches and the numbers are still increasing every year (Hötker et al. 2004; Dürr 2006). The find of 4 White-tailed Eagles between August and December 2005 in the new wind farm on the Island Smola, Norway (68 turbines) is also worrying and deserves attention (Follestad 2006). Wind turbine locations with relatively large numbers of protected birds of prey or song-birds, as in Tarifa and Navarra (Spain), Altamont Pass California are examples of poorly sited wind farms (SEO/Birdlife 1995; Lekuona 2001; Smallwood and Thelander 2004; Langston and Pullan 2003; Hötker et al. 2004). We must also take into account that the cumulative impact will increase with a growing number of wind turbines (Langston and Pullan 2003). More wind farms means an extra pressure superimposed to the already existing sources of disturbance.

Towards the situation for migrating birds, Kaatz (2002) recommended not to build large wind turbines on the coast, because of disturbance (barrier) but especially because of the possible large numbers of collision fatalities of which the biggest part of the small birds just get squashed totally during a collision with the rotors, whereby they can't be found on the ground. Even for large wind turbines the speed of the rotors goes to about 230 km/h at the tips. Therefore, the estimated collision of small birds using searches of dead birds on the ground (as with most studies) isn't totally reliable, even with corrections for scavenging and search efficiency. The only—known to us—comprehensive study whereby the collision chance for nocturnal migrating birds was calculated by means of the actual observed collisions (thermal image intensifiers) was performed in The Netherlands (Winkelman 1992b). The results there showed a remarkable high nocturnal collision probability of 1 on 40 (2.5%) passing birds at rotor height.

Daily searches for collision fatalities during the migration periods, together with systematic field observations of passing birds, could lead to a better picture of the behavior and collision chances of small birds. Observation methods by means of night vision devices and/or radar and thermal image intensifiers are a necessity. The recent developments of a full automatic sound- and image-detection system for collisions, with contact microphones on the turbine mast in combination with web cams (Verhoef 2003), and the thermal animal detection system (TADS) for estimating collision frequency of migrating birds at wind turbines (Desholm 2005) are also promising, but optimalisation of these techniques is still necessary. Certainly given the current worldwide offshore wind energy plans, a reliable technique for general use is urgently needed.

Tern mortality

The European Birds Directive requires that Member States of the EU take appropriate measures for deterioration of the important bird areas, and to prevent disturbance in these areas, as far as these are of substantial (significant) influence. Terns are K-strategists, meaning that they are long-lived and raise a relatively small number of young annually (slow reproduction). For this reason these birds are sensitive for external factors causing an additional mortality for adults. Various authors have valued the annual mortality of adult Common Terns. Local mortality was 8 and 10%, and estimates based on mark-recapture analysis varied between 7 and 12% (Becker and Ludwigs 2004). For some long-lived species, more than 0.5% additive mortality could be a considerable impact (Dierschke et al. 2003). Population models revealed that significant decreases in size of bird and bat populations may be caused by relatively small (0.1%) additive increases in annual mortality rates, provided they are counteracted by density dependent increases in reproduction rates (Hötker et al. 2004). An environmental assessment for a proposed wind farm at the western port breakwater in Zeebrugge, concluded that the estimated additive mortality of 1% and higher in the local tern population of Zeebrugge, would be a significant impact on that population (see 10.3. & 10.4. in BMM 2004).

Given the biological importance of the breeding tern colony in Zeebrugge, it is prudent, and consistent with legal and regulatory policy, to consider the described biological impact of the wind farm at the eastern port breakwater in Zeebrugge to be significant, and to require substantial measures to avoid, minimize, or otherwise compensate to offset this impact. The best measures in the short term would be to temporary shut down some of the turbines close to the breeding colony where most foraging flights occur, or to allocate the terns to a safer site in the future. It is contradicting that at other locations in Belgium and elsewhere, huge efforts are made to preserve some small colonies of Common Terns while at the same time a similar number of collision fatalities is allowed in the large colony in Zeebrugge.

In 2004 and 2005, the diurnal collision probability for Common Terns, flying at rotor height (Table 7) was similar to the result that was found in 2001 (1 on 600, see Everaert et al. 2002). The 2004/2005 difference in collision chance for Common Terns flying at all heights is contradicting, but it should be noted that in 2001 a collision chance of 1 on 3000 was found similar to the results in 2005. The contradicting figures found in 2004 may be caused by differences in wind and other weather conditions. The lower collision probability for Sandwich Terns may be due to the fact that Sandwich Terns mainly flew in a straight line towards the feeding grounds and back, whereas Common Terns had more irregular flight paths and performed more circling movements around the colony.

Relatively long lines of wind turbines or large wind farms can become an important barrier on the local and seasonal migration routes of non-breeding birds (diving duck's: Van der Winden et al. 1996; Wigeon *Mareca penelope*: Poot et al. 2001; Common Crane *Grus grus*: Brauneis 2000; seasonal migrating birds in general: Albouy et al. 2001; Richarz 2002; Langston and Pullan 2003). For certain birds the disturbance on their local migration routes could remain limited. Van den Bergh et al. (2002) concluded that a line of wind turbines at the Maasvlakte in The Netherlands didn't act as a barrier for the daily migration routes (foraging) of local breeding gulls and terns. Results from the turbines at the eastern port breakwater in Zeebrugge confirm this finding. Most terns in this study performed no or very small changes of course, before crossing the line of wind turbines (see also Everaert 2003).

Disturbance of breeding, foraging or resting birds

The fact that in 2004 some peripherical nests of terns (30 m and further) were closer to the wind turbines than the centre of the colony (>100 m), was most likely the consequence of the type of habitat (vegetation) and not because of a possible disturbance effect of the wind turbines. During the breeding season in 2005, many nests of the Sandwich Tern were located closer at 50–100 m distance. This suggests that the disturbance factor is relatively low for breeding terns, although effects on reproductive output have not been studied.

The observed distances with some other foraging or resting birds (especially shorebirds) can partially be also the consequence of specific habitat use (water line) on the peninsula. The results show that large groups of non-breeding waterfowl and shorebirds held a larger distance than individual or small groups of birds. Some studies on non-breeding birds have found significant disturbance for several duck species up to 300 and 400 m from wind turbines, and for some other waterfowl and shorebirds like geese up to at least 600 m (Langston and Pullan 2003; Kingsley and Whittam 2005).

General recommendations

Our study results clearly show that reasonable amounts of gulls and terns can collide with wind turbines, which seems to be a consequence of their quasi undisturbed flight and breeding behavior. We recommend that there should be precautionary avoidance of constructing new wind turbines close to any important breeding colony of terns or gulls, nor should artificial breeding sites be constructed near wind turbines, especially not within the frequent foraging flight paths.

An exhaustive study before the selection of future wind farm locations is a key factor to avoid deleterious impacts of wind farms on birds. In general, current knowledge indicates that there should be precautionary avoidance of locating wind farms in all important bird areas and/or migration routes.

Acknowledgements In the first place, we want to thank the Flemish government for supporting the monitoring project in which the first author received his contract at the Research Institute for Nature and Forest. Many thanks to Wouter Courtens and Marc Van De Walle, for collecting some of the collided birds and witnessing some collisions during their research on the biology of the breeding terns. Also thanks to the Port Authority Zeebrugge (MBZ) for granting access to the site.

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