

Bird collisions at an offshore platform in the North Sea

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Capsule Collisions with offshore structures in the North Sea could account for the mortality of hundreds of thousands of nocturnally migrating birds.

Aims To assess, for the first time, the circumstances of mass fatalities at an offshore structure, including the species involved, their numbers, ages, body conditions and injuries.

Methods At an unmanned tall offshore research platform in the southeastern North Sea, bird corpses were collected on 160 visiting days from October 2003 to December 2007. Corpses were identified to species and kinds of injury, ages, and fat and muscle scores were determined. Nocturnal bird calls were recorded, identified to species and quantified. Local and large-scale weather parameters were also considered.

Results A total of 767 birds of 34 species, mainly thrushes, European Starlings and other passerines, were found at 45 visits. Most carcasses were in good body condition and young birds were not more affected than adults. Three quarters of 563 examined individuals had collision induced injuries. Birds in poor body condition were less likely to be collision victims than those in good condition. Mass collision events at the illuminated offshore structure coincided with increasingly adverse weather conditions and an increasing call intensity of nocturnal birds.

Conclusions Assuming an average of 150 dead birds per year at this single offshore structure and additionally assuming that a considerable proportion of the corpses were not found, we estimate that mortality at the 1000 + human structures in the North Sea could reach hundreds of thousands of birds. Since offshore industrialization will progress and collision numbers at offshore turbines will consequently increase considerably, we recommend reinforced measures to reduce bird strikes at offshore structures, especially in the light of substantial declines in some migrant species.

For more than a century it has been well known that illuminated artificial offshore structures can attract nocturnally migrating birds and collisions with such structures are reported frequently (Gätke 1895, Clarke 1912, Hansen 1954, Cochran & Graber 1958, Gauthreaux & Belser 2006, Drewitt & Langston 2008, Kerlinger *et al.* 2010, Longcore *et al.* 2012). In relation to the huge numbers of migrant birds overflying the seas, collisions with man-made structures seem to be rare, but sometimes several thousand birds are affected in a single event. Collisions with man-made structures are thought to rank among the top threats to birds, in terms of numbers of individuals killed (Loss *et al.* 2012). Consequently, potentially harmful effects on populations have been debated (Garthe & Hüppop 2004, Fox *et al.* 2006, Stewart *et al.* 2007, Arnold &

Zink 2011, Loss *et al.* 2012) and fatality mitigation measures considered (Drewitt & Langston 2008, Gehring *et al.* 2009, Longcore *et al.* 2012).

Offshore, bird collisions are mainly reported from lighthouses and light-vessels (Blasius 1894, Clarke 1912, Hansen 1954, Vaughan 2009) but they also occur at oil, gas and research platforms (Bourne 1979, Sage 1979, Hope Jones 1980, Müller 1981, Wiese *et al.* 2001, Hüppop *et al.* 2006) and brightly illuminated ships (Bourne 1979, Bocetti 2011). Despite the fact that mass fatalities at sea have been reported repeatedly, the collision risk at offshore structures is still poorly studied. Systematically collected data on bird numbers and species killed are restricted to lighthouses and light-vessels and most of these studies are at least 60 years old (see above). Modern structures, with illuminations considerably different from those of older lighthouses and light-vessels, might

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be very different in how they attract and impact on nocturnally migrating birds. In the North Sea alone there are some 1000 oil and gas platforms (www.ecomare.nl) and more than 1000 wind turbines, and many more are expected to be built in the near future (de Oliveira & Fernandes 2012).

Illuminated offshore structures are considered to contribute substantially to night time light pollution in the open North Sea (Gaston *et al.* 2013). Consequently, there is an increasing collision risk for the many nocturnal migrants which are known to be attracted by artificial illuminations, especially during adverse weather conditions (Graber & Cochran 1960, Larkin & Frase 1988, Jones & Francis 2003, Gauthreaux & Belser 2006, Evans *et al.* 2007, Drewitt & Langston 2008, Ballasus *et al.* 2009). Offshore, disoriented terrestrial birds have no alternatives for landing (Drost 1960, Hüppop *et al.* 2006, Farnsworth & Russell 2007, Hüppop & Hilgerloh 2012). Consequently, the comparatively low numbers of collided nocturnal migrants and the relative absence of large-scale fatality events at onshore wind farms (Krijgsveld *et al.* 2009, Kerlinger *et al.* 2010) does not necessarily reflect the situation offshore. Similarly, the low collision rates at sea, as reported from studies during daylight or for large species (Desholm & Kahlert 2005, Newton & Little 2009), are unlikely to represent the general pattern of collisions for nocturnal migrants or smaller birds. Actually, Fijn *et al.* (2015) estimated that during the night more than 750 000 'bird-echoes' per year cross a windfarm off the Dutch coast at collision risk height.

Research platforms are likely to provide a more useful insight into the offshore collision risk for migrating birds than wind turbines, since a proportion of the carcasses is likely to remain on platforms whereas corpses at wind turbines are lost immediately in the surrounding water. The collision risk might be higher at wind turbines because of the rotating blades (Band *et al.* 2007), but guy wires and continuous lighting might increase the overall hazard of other structures (Longcore *et al.* 2008).

A project at a research platform in the German Bight gave us the unique opportunity to collect data on offshore bird fatalities and on bird call intensity for more than four years and to address the following questions: (1) How often do mass fatalities occur at offshore structures? (2) What is the seasonal distribution of fatalities? (3) Which bird species are affected, and are some age groups or birds in poor condition more likely to be involved? (4) What causes of death and kinds of injuries occur in colliding birds? (5) Do fatality events coincide with high levels of

nocturnal flight activity? (6) Are mass fatalities associated with particular types of weather? And (7) Are there mitigation measures which can be suggested?

MATERIAL AND METHODS

Study site

The unmanned tall offshore research platform FINO 1 (54°01'N 06°35'E) is located in the southeastern North Sea, 45 km north of the island of Borkum (Fig. 1). It is founded on 4 pilings with a 256 m² working deck 20 m above sea level (a.s.l.), and has an 81 m lattice tower in its southern corner and a 164 m² helicopter deck at 25 m a.s.l. (Fischer 2006).

The flight safety lighting consists of pairs of continuous red lights (10 cd) at 101.5 m, 75 m and 55 m a.s.l. Four continuous white halogen flood lights (400 W), installed at 19.5 m a.s.l., illuminate the foundation underneath the platform deck. There are 4 white lights (50 W) at 21.6 m a.s.l., blinking with Morse code 'U' (dot-dot-dash) for shipping safety. The name inscription at all four sides of the platform is each continuously illuminated by two 200 W halogen lamps (G. Fischer, pers. comm.).

Sampling and investigation of corpses

Since service flights by helicopters were only possible during daylight under good visibility and moderate



Figure 1. Locations of the research platform FINO 1 and the island of Helgoland in the North Sea.

wind speeds, they happened without regular schedule. From October 2003 to December 2007, there was a total of 160 flights with, on average, 3 flights per month. The bird corpses found on the platform were collected and deep frozen for later investigation if possible.

The corpses were identified to species and kinds of injury, and fat scores (grades 0–8) and muscle scores (0–3) were determined (following methods in Bairlein 1995). All birds with visible injuries were classified as collision victims. Fat and muscle scores of carcasses were compared to those of migrants trapped during stopover at the offshore island of Helgoland (54°11'N 07°53'E, 85 km ENE of FINO 1, Fig. 1; Hüppop & Hüppop 2011). Twelve carcasses with obvious fractures were X-rayed as examples.

Bird calls

The systematic and continuous recording of bird calls at FINO 1 started on 12 March 2004 and ceased on 1 June 2007, interrupted only by a few short equipment malfunctions. The bird calls were recorded by a shotgun condenser microphone (Sennheiser ME67) at the working deck. Calls of single birds or groups of birds were automatically stored in subsequent files on a computer. We used the hourly totals of all minute maxima to get an index of bird flight activity near the platform (for full details of methods see Hüppop & Hilgerloh 2012 and online supplementary appendix).

Weather data

Humidity, visibility, cloud cover, rainfall, wind speed and wind direction in the North Sea area, and the large-scale weather situation in the presumed take-off areas of the migrants in southern Scandinavia and western Central Europe were recorded (for details see electronic appendix). Since it was not possible to relate corpses to an exact time of collision they were associated with the weather conditions for a seven-day period ending with the collection date.

Statistics

The proportions of adult to first year birds were tested against expected numbers by χ^2 tests. The relations between number of corpses and bird calls and between body condition and age, respectively, and the proportion of birds with externally visible injuries

(collision victims) were analysed with generalized linear mixed models (GLMMs), with species as a random variable. All statistics were calculated with R version 3.1.0 (R Core Team 2014) with the additional packages *lme4*, *multcomp* and *MuMIn*.

RESULTS AND DISCUSSION

Numbers and age

In total, 767 birds of 34 species were found on 45 (28.1%) of 160 visits (Fig. 2, Table A1 in online supplementary material). Generally, fewer than 10 birds per visit were found and on 115 visits no carcasses were found at all (Fig. 3). More than half of all carcasses (415) were collected on 3 visits during autumn migration: 89 on 1 October 2003, 199 on 29 October 2004 and 127 on 29 November 2006.

Presumably, only a fraction of all birds that actually collided with the platform was found. Corpses may be displaced by wind after collision and fall into the water instead of dropping on the platform. Modelling carcass dispersal after collision with the tall lattice tower of FINO 1 showed that up to 90% of carcasses are likely to be missed, depending on wind direction and speed (own data). Here, only those events that coincided with, or were followed by, moderate winds could be categorized as 'mass collisions events'. Other events, when many corpses might have been blown into the sea, may have been missed.

Many more dead birds were found from July to December (78% or 6.6 birds per collection day) than from January to June (22% or 2.4 birds per collection day). At first, this seems unsurprising, since autumn migration includes the juveniles produced following a breeding season. However, in the two most frequently recorded collision victims, Song Thrush *Turdus philomelos* and Redwing *Turdus iliacus*, the absolute number of adult birds that collided in autumn (i.e. the presumed breeding birds of the year) is four to five times higher than the totals in spring (i.e. all returning potential breeding birds) although the number of helicopter flights to the platform was lower (see Table A1). Under the assumption that migration routes are the same in both seasons (Bairlein *et al.* 2014) this indicates a considerably higher collision risk in autumn than in spring.

There is no indication that the less experienced first-year birds had a higher collision risk than adults. We calculated the age ratios in autumn for Song Thrush and Redwing. Payevsky & Vysotsky (2003) estimated

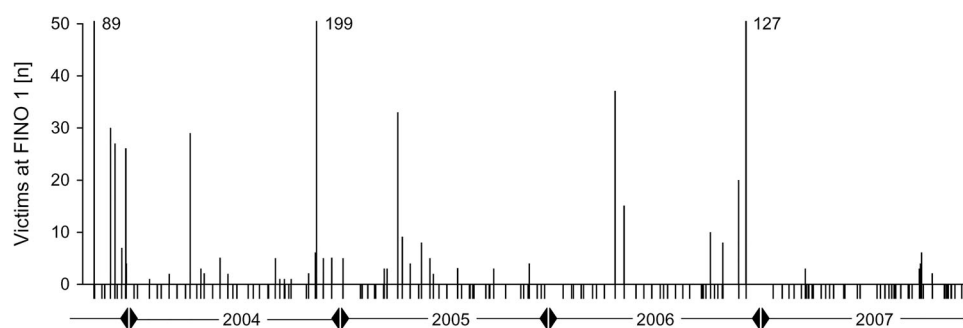


Figure 2. Number of birds found on FINO 1 and days with helicopter flights to the platform (tick marks) from October 2003 to December 2007. Figures in the graph indicate the numbers of collected birds on three mass fatality events.

an annual productivity of 3 young per pair in the Song Thrush, and for the Redwing, an average of 3.4 young per pair is reported (Glutz von Blotzheim & Bauer 1988). Our observed age ratios, for birds killed on the platform, were not significantly different from these (adult: first-year ratio: Song Thrush 35:65, Redwing 39:61, χ^2 tests, both $P > 0.5$).

Species and conservation status

Mainly nocturnally migrating small birds collided at FINO 1 (Fig. 4, Table A1). Thrushes were affected most (76% of corpses), followed by European Starlings *Sturnus vulgaris* (9%) and other passerines (10%). Only 2% of carcasses were non-passerines and 3% could not be identified to species.

Compared to earlier investigations (Blasius 1894, Hansen 1954, Müller 1981), many abundant Scandinavian breeding passerines (BirdLife International 2004) are largely under-represented in numbers at FINO 1 (Table A1). For example, other than thrushes and European Starlings, species such as

Skylark *Alauda arvensis*, Goldcrest/Firecrest *Regulus regulus/ignicapillus*, European Robin *Erithacus rubecula*, Common Redstart *Phoenicurus phoenicurus*, Northern Wheatear *Oenanthe oenanthe* and Meadow Pipit *Anthus pratensis* were all found in low numbers. It is possible that the corpses of such small and lightweight species were displaced more frequently than heavier ones after collision with the tall lattice tower. The lower proportions of Skylark, European Starling and Common Redstart, as compared to the investigations mentioned above, might also reflect the declines in the populations of these species (BirdLife International 2004, Hüppop et al. 2013) or changes in migration behaviour, as seen in the European Starling (Dierschke et al. 2011).

With the thrushes, most corpses at FINO 1 belong to species classified as 'secure' (BirdLife International 2004), and as 'not endangered' as migratory birds in

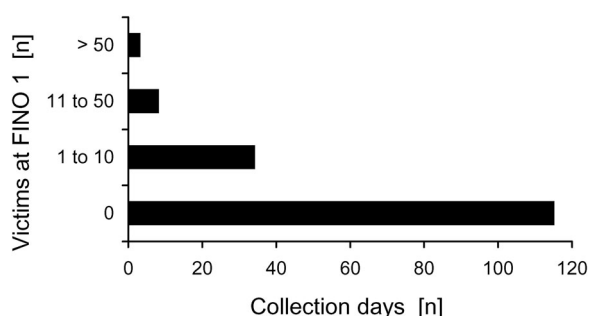


Figure 3. Frequency distribution of the number of corpses collected at FINO 1 from October 2003 to December 2007 ($n = 160$ days with visits).

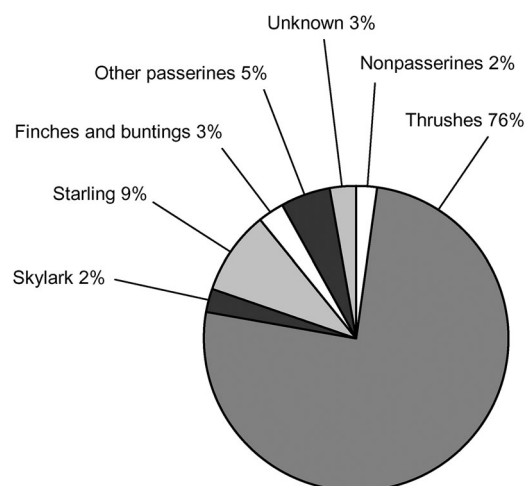


Figure 4. Proportion of the different species/species groups of all 767 birds found on FINO 1 from October 2003 to December 2007.

Table 1. State and injuries of corpses found at FINO 1 from October 2003 to December 2007. Since some birds had more than one injury, the total of injuries is greater than the number of examined corpses, and the sum of the percentage of corpses with externally visible injuries is greater than 100.

	Numbers (n)	Injuries (%)	Corpses (%)
Examined corpses	563		
Without externally visible injuries	136		
With externally visible injuries	427		
Thereof:			
Blood in the mouth cavity	190	32.1	46.0
Haematoma on the head	109	18.4	26.4
Fracture of the leg	96	16.2	23.2
Fracture of the skull/bill	84	14.2	20.3
Fractures of the torso	38	6.4	9.2
Fracture of the wing	29	4.9	7.0
Blood on the torso	28	4.7	6.8
Fracture of the neck	18	3.0	4.4
Total	592		

Germany (Hüppop *et al.* 2013). However, the European Starling and Skylark (frequently recorded dead), as well as Snipe *Gallinago gallinago*, Dunlin *Calidris alpina*, Swallow *Hirundo rustica*, Wood Warbler *Phylloscopus trochilus*, Northern Wheatear and Linnet *Carduelis cannabina* (recorded in small numbers) are classified as 'declining' to 'depleted'. As migratory birds, Water Rail *Rallus aquaticus*, Snipe, Pied Flycatcher *Ficedula hypoleuca*, Northern Wheatear and Linnet are categorized as 'near threatened', and the Twite *Carduelis flavirostris* as 'vulnerable'. None of the species recorded as corpses on the platform were at worldwide risk (IUCN 2013).

Injuries

Of all 767 birds collected at the platform, 563 individuals were examined. Three quarters had externally visible injuries, and almost half of them had blood in the mouth cavity (Table 1). The most frequent other injuries were haematoma to the head and fractures of the leg, the skull or the bill (Fig. A1 in the online appendix).

Veltri & Klem (2005) reported similar injuries in collision victims at a land-based power plant cooling tower. Also, Müller (1981) found a high proportion of broken extremities in Song Thrushes that had collided in large numbers at another offshore research platform. We did not check for intracranial haemorrhaging, but it can be assumed that the percentage was very high (99% of the tower kills in Veltri & Klem 2005) and a

major cause of death in the birds without externally visible injuries.

The collision victims from FINO 1 were most likely the result of a mixture of 'active' and 'passive' collision, i.e. birds flew either against the structure by themselves or were dashed against it by strong winds. We agree with Orłowski & Siembieda (2005) that the nature and type of skeletal injuries suggests that they were not often the direct cause of mortality but lead to death following injury. Actually, a few birds with fractures were still alive when the platform was visited.

The proportion of collision victims with visible injuries was not higher in the probably less experienced first-year birds than in adults (GLMM with binomial error distribution on the 5 most abundant species, $n = 462$ individuals, $z = 0.191$, $P = 0.849$).

Body condition

Almost all carcasses showed signs of being in good body condition and therefore could not have died of starvation. Their body condition was often even significantly better than that of migrants trapped during their stopover at Helgoland (Table 2). Birds forced to land due to bad weather and subsequently trapped on the Greifswalder Oie on the German Baltic coast (Mähler *et al.* 2013) or due to illumination at the Col de Bretolet in the Swiss Alps (Bruderer & Jenni 1990) also had better body condition than birds that landed more voluntarily.

Only 24 birds at FINO 1 had a fat score of 0, but 13 of them also showed injuries indicating that their death was due to collision. This means that very few birds died due to exhaustion, possibly after continuous disoriented flight around the platform (cf. Hope Jones 1980, Larkin & Frase 1988, Gauthreaux & Belser 2006). The proportion of birds with externally visible injuries was significantly lower in corpses without visible fat reserves than in those with visible fat (37.5% with fat score = 0 vs. 75.7% with fat score > 0; GLMM with binomial errors on the 5 most abundant species: $z = 2.8$, $n = 464$ individuals, $P < 0.01$). This suggests that birds in good condition may have been less likely to rest on the platform, but the figures do not reflect true percentages of collisions (corpses with 'invisible injuries' had to be added).

Bird calls

In total, 95 318 individual calls (excluding those of large gulls which often roost on the platform) were registered

Table 2. Fat and muscle scores (after Bairlein 1995) of birds found dead at FINO 1 compared to those of migrants trapped on the island of Helgoland.

Species	FINO 1		Helgoland		Wilcoxon rank sum test	
	Mean ± sd	n	Mean ± sd	n	W	p
<i>Fat score</i>						
Redwing	2.12 ± 0.74	194	1.47 ± 0.84	2858	395 437	<0.00001
Song Thrush	1.71 ± 0.77	133	1.76 ± 0.90	11 809	766 762	0.620
Blackbird	2.67 ± 0.89	36	2.26 ± 0.85	12 715	279 148	0.016
Fieldfare	1.86 ± 0.90	36	1.48 ± 0.88	82	1880	0.012
Starling	1.80 ± 1.04	60	1.73 ± 0.94	479	15 801	0.178
<i>Muscle score</i>						
Redwing	2.07 ± 0.50	194	1.76 ± 0.48	2858	347 793	<0.0001
Song Thrush	1.89 ± 0.56	133	1.94 ± 0.30	11 809	749 914	0.074
Blackbird	2.25 ± 0.44	36	2.02 ± 0.27	12 715	280 746	<0.0001
Fieldfare	1.92 ± 0.73	36	1.72 ± 0.57	82	1750	<0.05
Starling	1.70 ± 0.74	60	1.75 ± 0.50	479	14 247	0.894

Note: Bold values are significant at $p < 0.5$.

in the whole period of investigation. Since high bird call rates were restricted to the nocturnal hours (Hüppop & Hilgerloh 2012) we concentrated on the data between 18:00 and 06:00 hours CET. These 69 043 individual nocturnal calls were distributed non-uniformly throughout the year, reflecting the spring and autumn migration periods (Fig. 5). The first 6 months of the year, including spring migration, accounted for 29.5% of calls (39 calls/night, excluding the missing nights) and the last 6 months, including autumn migration, accounted for 70.5% (104 calls/night).

As with collisions (Fig. 3), most nights had no bird calls registered at all (Fig. 6). However, on 5 spring and 26 autumn nights there were more than 500 calls recorded and, of these, on 16 nights (2 in spring, 13 in autumn) more than 1000 calls were registered.

Although Graber & Cochran (1960) found at least an approximate correlation between numbers of thrushes calling and those killed, at an onshore television tower in North America, such a correlation cannot necessarily be expected. While nights with high bird call rates near the platform indicated mass migration, only few mass collision events were registered. Even on 31 October 2005, after the highest bird call rates recorded throughout the project in the preceding three nights, no corpses were found on the platform. Furthermore, an unknown number of collided birds will have fallen into the water rather than onto the platform, depending on wind conditions. Nevertheless, we also found a significant positive relationship between the numbers of carcasses found (n_{carcass}) and the numbers of calls (n_{calls}) in the preceding night (GLMM on the 5 species with more than 20 corpses: $t = 8.98$, $n = 540$ cases, $P < 0.0001$; $\lg(n_{\text{carcass}} + 1) = 0.042 + 0.169 \lg(n_{\text{calls}} + 1)$).

But the variance of n_{carcass} explained by n_{calls} is small (conditional $R^2 = 0.132$; Nakagawa & Schielzeth 2013) and suggests a strong influence of other factors, such as those mentioned above.

Collisions and weather

Calling by flyover migrants has been recorded most frequently during dense fog, drizzle or rain (Drost 1960, Graber & Cochran 1960, Dierschke 1989, Hüppop & Hilgerloh 2012). However, these weather conditions do not necessarily mean high numbers of calling birds. The relative rarity of collision events, along with the uncertainties over timing and the many combinations of possible weather factors, both in the departure and collision areas, mean that there are limitations to the

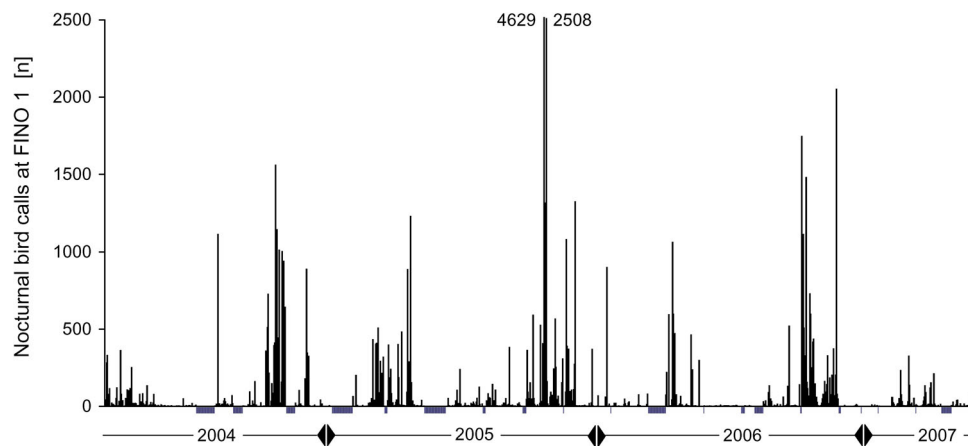


Figure 5. Sums of nocturnal bird calls registered at FINO 1 between 18:00 and 06:00 CET from March 2004 to June 2007, $n = 69\,043$, black bars indicate data gaps.

statistical approaches available for analysis (see also Hüppop & Hilgerloh 2012). Nevertheless, the weather conditions and the bird flight indices accompanying the 3 collision events with more than 50 carcasses, and 1 event with few carcasses but special weather conditions (as described in detail in the online appendix), give examples of the complexity of the weather conditions leading to collision. As Kerlinger *et al.* (2010) did for fatalities at onshore wind turbines (where corpses can be found on the ground), we can at least present a general scheme for those nights at sea which provide a high risk of mass collision events. During the migration seasons, intensive nocturnal bird migration over the sea can be expected after good conditions in the take-off areas. These are combinations of little cloud cover, good visibility and favourable tailwinds, or at least weak winds, in the

evening or night. Under this prerequisite, high numbers of birds can be expected to occur (and to be recorded acoustically) over the sea and near illuminated offshore structures. If there is rapid deterioration of the weather conditions during the flight, birds will be forced to look for stopover sites and to lower their flight height. Such changes could include a combination of: increasing cloud cover, decreasing cloud ceiling, arising fog or precipitation, increasing wind speed and wind changing towards an adverse direction. Birds may then be attracted to, and disorientated by, lit offshore structures and finally face a high risk of collision. High bird flight indices, estimated from call recordings, under such weather conditions confirm this attraction effect and the presence of birds within the collision risk area.

Migration intensive nights that combine the special conditions that lead to high collision events at illuminated offshore structures are not frequent. Bad or degrading migration conditions above the German Bight can be expected to be relatively frequent per se, but they generally occur with similarly bad conditions in the departure areas so birds do not set off, and of course outside the migration seasons very few nocturnal migrants will be flying over the sea.

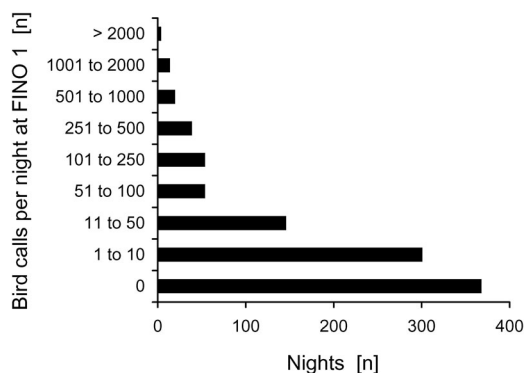


Figure 6. Frequency distribution of the sums of nocturnal bird calls registered at FINO 1 between 18:00 and 06:00 CET from March 2004 to June 2007 ($n = 991$ nights).

CONCLUSIONS

Based upon an approximate average of 150 dead birds per year at a single human made offshore structure and assuming that a considerable proportion of the corpses were not found because they fell into the sea, we would conservatively estimate that bird mortality at

the 1000 or so platforms in the North Sea could run into the hundreds of thousands per year. Regarding this highly conjectural projection from just one platform, it has to be noted that the study site is on a significant part of the flyway of birds passing over the North Sea and that numbers of collisions might be less at structures elsewhere.

Birds colliding with wind turbines are generally perceived as one of the major conflict issues for wind-energy development (May *et al.* 2015). Since many bird species are experiencing substantial population declines (BirdLife International 2004, Hüppop *et al.* 2013), determining whether mortality sources such as collisions with anthropogenic structures contribute to these declines is crucial for developing conservation and management objectives (Arnold & Zink 2011, Loss *et al.* 2012). Simply documenting deaths does not determine whether a particular threat constitutes an additive source of mortality (Arnold & Zink 2011). In the first instance, our results do not seem alarming since projections on a species level mean less than 1% of the populations are affected (mainly Scandinavian, numbers in BirdLife International 2004) and most collision mortality occurs during autumn migration when populations are at their annual maximum (Arnold & Zink 2011). However, offshore industrialization will progress further, possibly even faster than before. Numbers of offshore wind turbines will soon outnumber those of oil and gas platforms. Onshore, multi-bird fatality events with wind turbines are rare (Kerlinger *et al.* 2010) and nocturnal migrants might be underrepresented, because many landing sites other than the structures themselves exist, but presumably the different illumination circumstances also play a role. Whereas onshore turbines generally only have flashing red lights, for aviation safety, offshore turbines in addition must have bright steady lights for shipping safety. Since steady lights attract nocturnal migrants more than flashing ones (Gauthreaux & Belser 2006, Evans *et al.* 2007, Longcore *et al.* 2008, Gehring *et al.* 2009) and birds fly at lower altitudes over sea, especially under deteriorating weather conditions when birds are looking for 'rescue sites' (Farnsworth & Russell 2007, Hüppop & Hilgerloh 2012), we expect considerably higher collision rates at offshore turbines than at onshore ones.

Although we know a lot about the conditions which increase the risk of mass collisions at sea, the events are hard to forecast. We must take into account the season, but also numerous weather parameters, not only in the offshore collision-risk sites but also in the

departure areas. To mitigate offshore mass fatalities of nocturnal migrants, both at platforms and wind turbines, we explicitly support measures as mentioned previously (Hüppop *et al.* 2006). We recommend: (1) locating illuminated offshore structures outside areas with high bird flight activity and offside migration routes, outside areas known for frequent occurrence of fog and drizzle (Hüppop & Hilgerloh 2012) and, especially for wind turbine farms, along rather than across the prevailing migration direction; (2) to reduce lights in numbers and intensities as much as possible, to avoid steady-burning lights (Gehring *et al.* 2009), to promote further studies on the effects of light colour (Evans *et al.* 2007, Poot *et al.* 2008) and to put their results into action; (3) to develop a need based beaconing system which will automatically switch on obstruction lights only in case of an approaching watercraft or aircraft; (4) to minimize electromagnetic noise that can disrupt the magnetic compass orientation and lead to disorientation of birds (Engels *et al.* 2014) and finally (5) to alter turbine rotation speed or to power down wind turbines for a few hours in the few nights with a high bird collision risk (May *et al.* 2015). An actual and local detection system within larger offshore structure areas could help to minimize such off-times and the collision risk. With continuous online recording and automatic contemporary evaluation of the nearby bird call intensities (Hüppop & Hilgerloh 2012) or an autonomous thermal/infrared camera system (Hill *et al.* 2014) and with the knowledge of the current local weather conditions, risky circumstances could be recognized and collision mitigation rapidly initiated.

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SUPPLEMENTAL DATA

Supplemental online material about bird call intensity, the affected species (split by season and age), examples of X-ray images and the weather situation during four example collision events, can be accessed at: <http://dx.doi.org/10.1080/00063657.2015.1134440>.

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