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Flight call rates of migrating thrushes: effects of wind conditions, humidity and time of day at an illuminated offshore platform

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Many bird species call during migration, but call rates not necessarily reflect migration intensity. They rather seem to increase under deteriorating flight conditions. Often, nocturnal mass collisions at illuminated structures coincide with such conditions and are accompanied with high call rates of migrants. Thus, call rates could act as an indicator for situations with high collision risk for birds namely at offshore sites with hardly any alternatives for landing. In the face of increasing numbers of offshore wind farms knowledge about the environmental conditions in which maximum call rates occur, is needed for mitigation measures.

In this first long-term study at an offshore site in the southern North Sea we investigated the effect of weather on the frequency of flight calls of three thrush-species at an illuminated platform. Flight calls were registered automatically during three autumn migration seasons. Besides generally higher call rates from 5 to 2 h before until 6 h after midnight, call rates increased with tailwinds, a change of the tailwind component during the first part of the night, offshore crosswinds and very high humidity.

A monitoring programme is suggested that could help to reduce mass mortalities at illuminated structures.

Many bird species utter calls during migration (Dierschke 1989, Evans 2005, Farnsworth 2005). These apparently serve to maintain flocks, to communicate information within and perhaps among flocks and to stimulate migratory activity (Hamilton 1962, Farnsworth et al. 2004, Farnsworth 2007). They may also help to minimize collisions with obstacles (Graber 1968) and, in the context of orientation, to reduce the dispersion of headings of the birds or to detect changing wind directions (Farnsworth 2005). Call rates not necessarily reflect migration intensity as revealed by simultaneous radar counts. Accordingly also other factors are responsible for the variation of call rates of migrating birds (Farnsworth et al. 2004, Farnsworth 2005).

Call rates of nocturnal migrating species increase e.g. in connection with increasing cloud cover, decreasing cloud ceiling, fog or drizzle (Drost 1960, Graber and Cochran 1960, Dierschke 1989, Evans 2005, Farnsworth 2005). Artificial illuminations attract nocturnal migrants in these conditions and may lead to mass collisions with obstacles (Graber and Cochran 1960, Larkin and Frase 1988, Jones and Francis 2003, Evans et al. 2007, Drewitt and Langston 2008, Ballasus et al. 2009). This applies particularly to offshore sites where disoriented birds have no alternatives for landing (Drost 1960, Hüppop et al. 2006, Farnsworth and Russell 2007). There is still much debate about the weather conditions linked with high call rates and mass fatalities at illuminated structures (Farnsworth 2005, Gauthreaux and Belser 2006, Drewitt and Langston 2008, Ballasus et al. 2009).

With the construction of huge windfarms in the North Sea (Hüppop et al. 2006) large numbers of illuminated obstacles (wind turbines, transformer platforms, service vessels) have to be expected. As nocturnal migrants cross the North Sea in extensive broad front migration (Drost 1960, Buurma 1987, Hüppop et al. 2006) it is extremely important to find out under what circumstances they concentrate at illuminated offshore wind turbines and other structures or run into the risk to collide with them.

From March 2004 to May 2007, flight calls of migrants were collected at an unmanned platform in the southern North Sea. Thrushes formed the bulk of all species (62% of all calls). We analysed data of blackbird *Turdus merula*, song thrush *T. philomelos* and redwing *T. iliacus* in relation to weather parameters during autumn migration. All three species regularly cross the southern North Sea in large numbers on migration from their Scandinavian breeding grounds to their wintering areas in western or southern Europe (Bakken et al. 2006, Dierschke et al. 2011). We did not analyse calls of fieldfares *Turdus pilaris* because of the lack of information on their preferred autumn migration direction in the southern North Sea (see below).

To the best of our knowledge this is the first long-term study at an offshore site, where the effect of weather factors on the call rate of nocturnal migrants is investigated.

In accordance with general knowledge we assume that birds preferably cross the North Sea with favourable (tail) winds and a cloudless sky (Hilgerloh 1977, Alerstam 1990, Liechti and Bruderer 1998, Erni et al. 2002). However, we expect high call rates when high numbers of migrants approach the platform under bad or deteriorating flying conditions, e.g. in hours with very high humidity, after tailwinds turned into headwinds or when birds are blown offshore.

Material and methods

Study site

The research platform FINO 1 (54°01′N, 6°35′E) is situated in the south-eastern North Sea, 45 km north of the island of Borkum (Fig. 1). The platform has a working deck at 20 m above chart zero and a 81.5 m lattice-tower (for details <www.fino-offshore.com>). The flight safety illumination consisted of 6 continuous red lights (10 cd), 2 at 101.5 m, two at 75 m and 2 at 55 m above chart zero). Further, four continuous white halogen flood lights (400 W) were installed at 19.5 m height to illuminate the foundation underneath the platform. Shipping safety lights were four white lights (50 W) at 21.6 m height, blinking with morse code 'U'. The name inscription at all four sites of the platform was continuously illuminated by two bright halogen lamps (200 W) at each side.

Audio system and data

Bird calls were recorded by a Sennheiser ME67 long shotgun condensor microphone capsule (40–20 000 Hz) with K6-P powering module at the working deck. The microphone was sheltered from wind, water and gull excrements by a basket windshield with long-haired polyester fleece cover, and a stainless steel roof. Special software (AROMA, automatic recording of migrating aves) had to be developed for the detection and registration of migrants' calls on a personal computer. It is based on the audio-processing-toolkit 'Snack' for Tcl/Tk (<www.speech.kth.se/snack>) and recognizes bird calls by their characteristic narrow sound spectrum and filters out wind, rain and wave noises to a large extent. Bird calls are stored as audio files (WAV, 16 bit, 22 kHz, mono; Hill and Hüppop 2008).

Qualified staff allocated stored records to species. Calls of single birds or groups of birds were stored on subsequent files if gaps between calls were longer than 1.5 s or the maximum file length of 5 s was reached. For each audio file the minimum number of birds calling was estimated. Since even a small passerine flying at 20 km h^{-1} will pass through the area of the microphone within one minute (Evans and Mellinger 1999), the audio file with the highest number of individual calls was chosen for the analysis of the corresponding minute. All calculations and figures are based on these maxima per minute. The capture range of the microphone is unknown and detectability of the calls presumably varies between species. Consistent with other studies (Evans and Mellinger 1999, Farnsworth et al. 2004) we assume that songbirds will have been detected up to a few hundred meters. It cannot be excluded that individuals circulating around the platform in poor visibility (Larkin and Frase 1988) were recorded more than once. Hence, our call rate data should be regarded as a relative measure

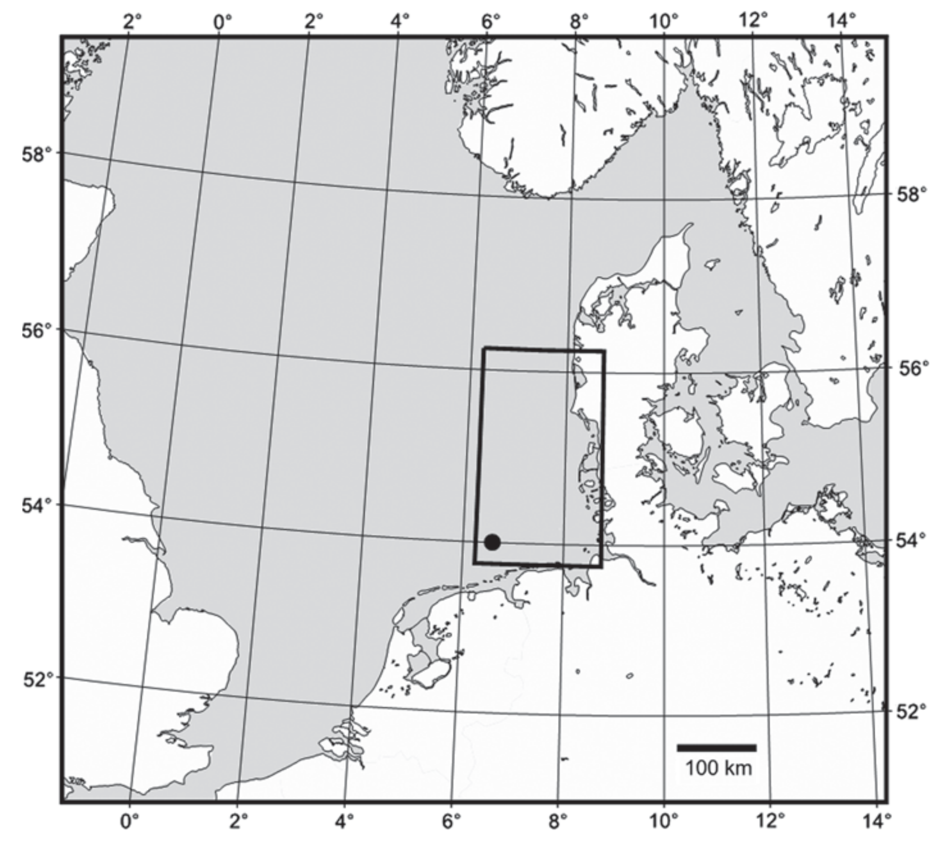

Figure 1. Locations of the research platform FINO 1 in the North Sea (black dot) and of the NCEP/NCAR reanalysis grid cell for wind data.

(which is sufficient in this context) rather than an absolute number of calling birds.

Though the audio system worked, apart from short interruptions due to technical problems, continuously all year and all day long from 12 March 2004 to 1 July 2007, we restricted our analyses to the main autumn migration periods of the three thrush species (i.e. the periods with the inner 90% of all calls of the respective species): 14 Oct to 13 Dec in blackbird (4006 h; 16 357 calls), 25 Sep to 12 Nov in song thrush (3344 h; 3447 calls), and 17 Oct to 13 Dec in redwing (3790 h; 20 364 calls).

Weather data

As the platform was unmanned no observations of fog, precipitation, visibility and cloud cover were available. Therefore we used the relative humidity measured at 90 m above chart zero (provided by the Federal Maritime and Hydrographic Agency) as a proxy for visibility. Observations at the island Helgoland (85 km ENE) confirm that high humidity coincides with poor visibility: during the autumn (October to December) of the study years a relative humidity $\geq 95\%$ was measured in 345 of 6602 h. In 94% of these there was fog, drizzle or rain (own compilation of data from the German Weather Service).

Data on the wind over the south-eastern North Sea at 18:00 and 24:00 GMT (= 19:00 and 01:00 Central European Time, CET, respectively) were extracted from the NCEP/NPAR reanalysis data archives provided at <www.cdc.noaa.gov/cdc/data.ncep.reanalysis.html> as $2.5° \times 2.5°$ grid data (based on measured and modelled data; Kalnay et al. 1996). Wind data at the pressure level of 925 hPa (corresponding to an altitude of 750 m a.s.l.) were extracted from the grid with the centre at 55°N and 7.5°E (Fig. 1).

Factors such as precipitation, cloud cover and cloud altitude were omitted since they are less reliably predicted by the reanalysis models (Kistler et al. 2001) and vary considerably in space. Wind conditions are spatially less variable and auto-correlated beyond grid cells (Shamoun-Baranes et al. 2006).

Mean autumn migration directions were derived from recoveries of birds ringed on Helgoland from September to December and found within one month after ringing (unpubl.; all directions were significant – $p < 0.05$ – according to the Rayleigh test). The calculation of the tailwind component (TWC) and crosswind component (CWC) was based on autumn migration directions of 235° in blackbird ($n = 81$), 207° in songthrush ($n = 123$) and 202° in redwing ($n = 33$): TWC = cos (observed wind direction − tailwind direction) × wind speed. CWC = sin (observed wind direction − tailwind direction) × wind speed. If e.g. the mean autumn migration is directed towards 235° associated tailwinds have a mean direction of 55°. Positive TWC values mean tailwind components, negative values headwind components. Crosswinds from the left of the migrating bird are expressed by positive CWC values, winds from the right by negative ones. We included the difference between the TWC values at 18:00 and 24:00 GMT (ΔTWC) as a variable indicating an increasing or decreasing tailwind component corresponding to improving or deteriorating migration conditions.

Statistical analysis

As call intensive nights are rare events and caused by different unfavourable weather situations conventional parametric statistics are unsuited for our analysis. Instead, data mining methods are more appropriate, namely tree models for recursively partitioning response variables into subsets based on their relationship to one or many categorical or continuous predictor variables (Cutler et al. 2007). Random forests categorization and regression is designed to produce accurate predictions that do not overfit the data. Bootstrap samples are drawn to construct multiple trees with a randomized subset of predictors. The trees are grown to maximum size without pruning and aggregation is done by averaging the trees. Out-of-bag samples are used to calculate an unbiased error rate and variable importance, so that no cross-validation is needed (Prasad et al. 2006, Cutler et al. 2007).

All analyses were performed with R 2.12.1 (R Development Core Team), circular statistics with the package 'CircStats', random forest regressions with the package 'randomForest'.

Results and discussion

Our data reflect extensive variation in the intensity of migration and/or the frequency of calling among nights and among hours. In all three thrush-species calls occurred in less than a fifth of all hours of the species specific 90% periods (blackbird 18.4%, redwing 19.8%, song thrush 12.1% of all hours). More than 50 calls h^{-1} of all three thrush species taken together were registered only in 5.2%, > 100 calls h^{-1} only in 2.3% of all studied hours (maximum 421 calls h^{-1}). However, high call rates always lasted for several hours. This emphasizes that, though high call rates are rare, they can include large numbers of birds and indicates a high risk of mass fatalities (Drost 1960, Graber and Cochran 1960, Farnsworth 2005, Hüppop et al. 2006, Drewitt and Langston 2008).

Depending on the species, 57.9–70.5% of the variance of the call rate could be explained by the same five variables with high partial influence in all three species (Table 1, Fig. 2): hour from midnight (as a completely nocturnal reference point between sunset and sunrise), relative humidity at the beginning of the respective hour, tailwind component (TWC) and crosswind component (CWC) at 18.00 GMT, and difference of the tailwind component between 18:00 GMT and midnight (ΔTWC).

Most flight calls were recorded from about five to three hours before midnight to about six hours after midnight (Fig. 2). In all three species call rates increased in the course of the night. This stands in contrast to the general pattern of nocturnal migration that peaks in most species, including thrushes, before midnight (Alerstam 1976, Zehnder et al. 2001, Farnsworth et al. 2004). Nocturnal increase of call rates was confirmed by other studies (Lowery and Newman 1955, Farnsworth et al. 2004) and might reflect decreasing flight altitudes over sea after midnight (Hüppop et al. 2004) but possibly also birds in search for a stopover site.

Table 1. Explained variance and variable importance (as percentage of the increase in the mean squared error if the respective variable is omitted) of the random forest regressions.

	Blackbird *Turdus merula*	Song thrush *T. philomelos*	Redwing *Turdus iliacus*
% explained variance	70.5	57.9	61.3
n_{hours}*)	4000	3343	3784
n_{calls}*)	16356	3447	20363
Hours from midnight	65.8	39.5	74.6
TWC	71.9	42.6	50.2
CWC	54.9	41.1	66.6
ΔTWC	41.1	27.4	45.9
Relative humidity	38.5	26.3	39.4

*Due to a few hours without humidity data sample sizes are slightly smaller than mentioned in the methods section.

The influences of the weather factors on call rates are, at a first glimpse, confusing because high call rates may be found under different weather conditions. However, some general rules became obvious.

Calls were mainly registered in tail- or moderate headwinds (positive or slightly negative TWC at 18:00) – indicating favourable wind conditions as a general prerequisite for bird migration – but hardly in strong headwinds (extremely negative TWCs, possibly also calls from birds involved that were forced to rest on the platform; Fig. 2). Migration without tailwind assistance might occur because of high cost of waiting for favourable winds, low frequencies of tailwind conditions and a need to use large proportions of nights for flying (Karlsson et al. 2011). According to our hypothesis a high call rate is expected if large numbers of migrants departed in favourable migration conditions (i.e. in tailwinds) in the evening (Hilgerloh 1977, Alerstam 1990, Liechti and Bruderer 1998, Erni et al. 2002) and if weather conditions deteriorated in the course of the night. Indeed, in blackbird and song thrush call rates correlated positively with the TWC. In redwing the relation is less clear, probably reflecting more flexible reactions to wind conditions (Alerstam 1975). In decreasing tailwinds or even a change of tailwinds to headwinds (i.e. a negative ΔTWC) the call rate increased (Fig. 2). Namely in redwing the call rate also increased with increasing TWC (i.e. a positive ΔTWC), probably reflecting an increase in migration intensity when wind conditions for SW/SSW-migration improved in the first part of the night.

Offshore crosswinds from the south-east (= positive CWC) positively affected the call rate of all three species as birds got drifted towards the sea from their preferred SW/SSW directed overland flight. These results correspond to the appearance of continental migrants at the east-coast of Britain in easterly winds (Archer et al. 2010). In blackbirds the call rate increased also considerably with crosswinds from northwest, explainable by the fact that huge numbers of blackbirds cross the sea between Norway or Denmark and Great Britain (Bakken et al. 2006, Bønløkke et al. 2006) that probably get drifted by north-westerly winds.

In all species the highest call rates were related to very high humidity. Given the excellent coincidence of poor visibility and relative humidity of ≥95% at Helgoland and a general steep increase of call rates at these humidity values, our result corroborates observations of most intensive

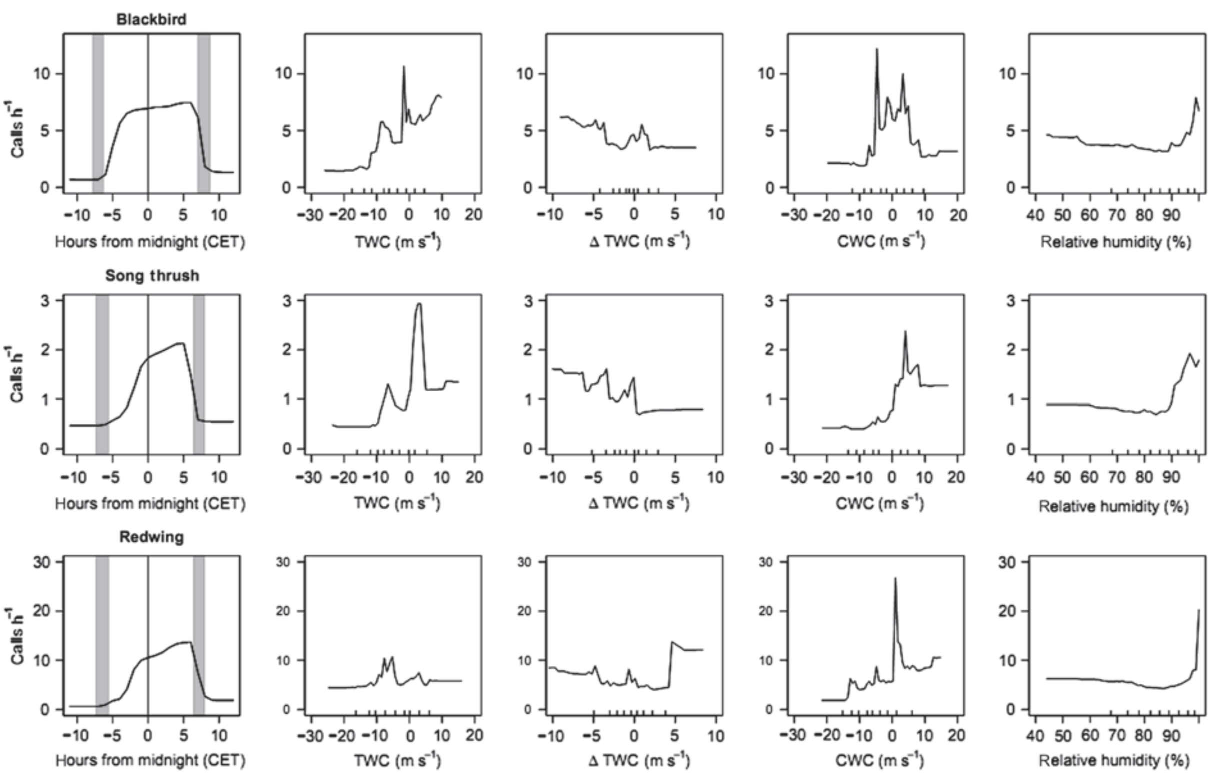

Figure 2. Partial dependence plots of random forest regressions of call rates of the three thrush species at the research platform FINO 1. Hash marks at the bottom of the plots indicate the 10%-percentiles of the explaining variables, grey bars the ranges of sunset and sunrise. Note different scaling of y-axes between species.

calling in dense fog, drizzle or rain (Drost 1960, Graber and Cochran 1960, Dierschke 1989).

In summary, our results emphasize that high call rates are restricted to the nocturnal hours, namely after midnight, and occur under different adverse weather conditions. The corresponding variables could elevate call rates singularly (e.g. either favourable tailwinds turning into cross-/headwinds or humidity rising to values just below 100%) or in combination. If we restrict the analysis to the nocturnal hours and omit the factor 'hours from midnight', the relevance of the other factors increases slightly and the explained total variance decreases. The fact that single factors never cause call rates to drop to zero (Fig. 2) emphasizes that factors never should be regarded separately (e.g. despite favourable low humidity there may be many calling thrushes because winds became unfavourable). The pronounced peaks indicate that high call rates could be singular events which involve large numbers of birds. They also suggest that unfavourable weather will cause high call rates only if precedent favourable winds (= positive TWC) and clear skies (Alerstam 1990) have induced mass migration. Hence, high call rates were registered only in few nights. The virtually 'unlimited' possibilities of relations between call rates and environmental factors exclude classical approaches such as general linear models, general additive models or discriminant analysis.

Conclusions

Obstacles on the migration route across the sea, illuminated e.g. for air and shipping traffic safety, may cause high collision rates and mass kills of birds in certain weather conditions (Drewitt and Langston 2008). As in these situations the frequency of bird calls is high, bird calls are a good indicator of situations with collision risks for birds. Actually, large numbers of fatalities were recorded at the FINO 1 platform, too: on 159 visits from October 2003 to December 2007, 770 dead birds were found with thrushes comprising 76% of the victims (Hüppop 2010). Because the unmanned platform cannot be visited daily, it is only exceptionally possible to relate mass fatalities to certain weather conditions.

Several offshore wind farms are already working and more are waiting for construction (Desholm and Kahlert 2005, Hüppop et al. 2006). Only if we understand under which conditions birds appear in great numbers at offshore structures, we can suggest appropriate measures to mitigate collisions. High call rates were namely found in high humidity (i.e. in fog and drizzle that impair birds' orientation abilities, Drewitt and Langston 2008). Areas known for intensive bird migration and common fog and drizzle would probably not qualify for the construction of offshore wind farms.

We recommend a collision avoidance program by 1) continuously monitoring migration intensity and direction by radar and measuring fog, drizzle, precipitation, cloud cover, visibility and wind and 2) installing an audio system in order to have an instantaneous automatic collision risk indicator. As mass collisions and nights with high call rates are rare events, but can affect huge numbers of birds (Drewitt and Langston 2008) it is important to have long-term data for further analyses and to test mitigation measures such as optimization of the illumination of offshore structures or shutting down wind turbines (the collision rate of birds and bats increases with rotation speed; Tucker 1996, Baerwald et al. 2009) in the few nights with high collision risk.

Although we were able to show the environmental conditions for high call rates of thrushes at an illuminated offshore structure the physiological processes behind this behaviour mainly remain in the dark. Nocturnal migrants, once aloft, most likely rely on a magnetic or a star compass only. Guilford et al. (2011) suggested that stable man-made lighting at night may be sufficient to enable drift compensation. However, our data imply that at least under deteriorating weather conditions such lighting is rather confusing than helpful for nocturnal migrants. Since questions on compass orientation of birds have largely been tackled within the laboratory and with a restricted set of model species (Guilford et al. 2011) we can only guess why the magnetic compass alone is not sufficient to avoid disorientation when celestial cues are no longer accessible. Further, the function of flight calls is not yet clear. Under conditions of poor visibility it is likely that migrants utter flight calls to keep in touch with neighbours to benefit from group navigation (Simons 2004).

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