

# Migration phenology and behaviour of bats at a research platform in the south-eastern North Sea

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**Abstract:** More than ten years of autonomous acoustic recording of bats' echolocation calls at an unmanned offshore research platform 45 km north of the island of Borkum (North Sea) were analysed in relation to season, time of day and weather. To our knowledge this is the longest systematic dataset on offshore bat migration worldwide. Three-hundred and seventeen call sequences were recorded during typical migration times in spring and autumn and assigned to at least 23 Nathusius' pipistrelles (*Pipistrellus nathusius*), 3 northern bats (*Eptesicus nilssonii*) and 2 Leisler's bats (*Nyctalus leisleri*). Compared to the prevailing wind conditions, more bats than expected were recorded at lower wind speeds and southerly winds. Bats occurred under supporting tailwinds, but also under strong headwinds. In both seasons most bats occurred under winds from the south (i.e. crosswinds), which indicates offshore wind drift. We neither found effects of air pressure, nor of change in air pressure. Most registrations coincided with a dense cover of clouds, fog/low stratus and/or rain. From the structure of echolocation calls it can be concluded that most bats explored the platform rather than just passed it on transfer flights, some even foraged there. We conclude that most of the bats were on migration and attracted by the brightly lit platform and/or sought refuge there. This involves the risk of collisions with offshore wind turbines (which need to be brighter lit at sea than onshore). We assume that a great part of offshore bat migration takes place beyond the range of currently available techniques at greater altitudes than known so far.

**Keywords:** bats, acoustic monitoring, migration, North Sea, offshore, light, weather, wind, behaviour, conservation.

## Introduction

Not too long ago, bats observed far offshore in the open North Sea were regarded as vagrants, regular offshore migration was virtually unknown (Vauk 1974, Vauk & Clemens 1982). Older notes on regular passage of bats at the remote island of Helgoland (Gätke in von Dalla Torre 1889) were even put into question (Vauk 1974, Skiba 2007). There are numerous records of several bat species from platforms, ships and islands far offshore, mainly from Europe but also from North America (e.g. Cryan & Brown 2007, Skiba 2007, Walter

et al. 2007, Boshamer & Bekker 2008, Ahlén et al. 2009, Hüppop 2009, Hatch et al. 2013, Lagerveld et al. 2014, Petersen et al. 2014, Sjol-lema et al. 2014, Smith & McWilliams 2016) indicating that regular but cryptic migration over sea, which is long known for terrestrial birds (e.g. Gätke 1895, Clark 1912), is also more common than formerly expected in bats. The seasonal appearance of bats in Bermuda emphasises their ability to travel even distances of more than 1000 km over open ocean (Hatch et al. 2013).

Studies on the offshore migration phenology of bats are nevertheless still almost exclu-

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sively restricted to coastal areas (recent overview in Rydell et al. 2014, Ciechanowski et al. 2016). Several studies compiled accidental observations or data from standardised studies covering shorter periods: Boshamer & Bekker (2008) reported 34 records of five species of bats (26 *Nathusius' pipistrelles* (*Pipistrellus nathusii*), 2 noctules (*Nyctalus noctula*), 2 northern bats (*Eptesicus nilssonii*), 1 serotine (*Eptesicus serotinus*) and 3 parti-coloured bats (*Vespertilio murinus*)) from platforms in the the Dutch sector of the North Sea from 1988 to 2007. Skiba (2007) observed on Helgoland, 50 km off the next coastal islands (figure 1), 105 bats in 36 nights from 2000 to 2006, mainly *Nathusius' pipistrelles* ( $n=84$ ), but also 8 common pipistrelles (*Pipistrellus pipistrellus*), 12 noctules and 1 Leisler's bat (*Nyctalus leisleri*). Walther et al. (2007) and Petersen et al. (2014) compiled further observations of bats on ships and platforms in the North Sea and Baltic Sea, and on islands and installations in the North East Atlantic, respectively. In a pilot study at two offshore wind farms located 15 and 23 km off the Dutch coast in autumn 2012, virtually all of the 216 recordings of bat echolocation calls concerned *Nathusius' pipistrelle*, while noctule was noted only a few times (Lagerveld et al. 2014). Surprisingly, besides the data presented here, there is only one standardised study at an offshore site that covers several years: during 1200 nights of year-round autonomous recording on the island of Helgoland in 2004 and 2006 to 2008 (Hüppop 2009, Hüppop, unpublished data) the main species were *Nathusius' pipistrelle* ( $n=ca. 160$ ), common pipistrelle ( $n= ca. 80$ ) and *Eptesicus/Nyctalus* species ( $n=ca. 30$ ).

Due to technical limitations associated with tracking the movements of small, cryptic and highly mobile animals over long distances, very little is known of the migratory pathways of bats (Cryan & Diehl 2009, Holland & Wikelski 2009, Weller et al. 2016). Systematic studies on the spatial and temporal occurrence of migrating bats (e.g. Rydell et al. 2014) are indispensable both for a better under-



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

standing of bat migration systems in general and for assessing anthropogenic threats to migrating bats, namely by wind turbines (Voigt et al. 2015, Arnett et al. 2016, O'Shea et al. 2016). It seems likely that offshore wind facilities will also kill bats, but it is difficult or impossible to find bat fatalities at sea and no attempts to assess such fatalities have been made so far (Arnett et al. 2016). Under adverse weather conditions lit offshore structures such as platforms, lighthouses and lightvessels may attract and kill large numbers of nocturnally migrating birds (Ballasus et al. 2009, Hüppop et al. 2016). Collisions of bats with lighthouses, lit buildings and communication towers have also been reported (Saunders 1930, Terres 1956, Crawford & Baker 1981, O'Shea et al. 2016). Hence, it can be predicted that those bat species that are attracted by lights (Rydell 1991, 1992, Blake et al. 1994, Stone et al. 2015) will also collide with lit offshore wind turbines and other manmade structures. Whereas onshore turbines in Germany have, depending on their height, either no red lights, flashing red lights, or flashing and



Figure 2. The research platform FINO 1. *Photo: Reinhold Hill.*

steady red lights for aviation safety, offshore turbines and working platforms in addition to the red lights must have bright steady lights for shipping and/or working safety. Ahlén et al. (2009) observed bats hunting insects at wind power turbines near the blades and on the vertical tower sides.

Here, we present the results of more than ten years of autonomous acoustic recording of bats' echolocation calls at an unmanned offshore research platform in the south-eastern North Sea in relation to season, time of day and weather. To our knowledge this is the longest systematically collected dataset on offshore bat migration worldwide. Signals used by echolocating bats are not only highly variable among species, there are also intraspecific variations. Bats vary signal structure and repetition rate of calls to suit their information acquisition tasks (Simmons et al 1979, Kalko & Schitzler 1993, Schnitzler & Kalko 2001, Parsons & Szewczak 2009, Fenton 2013). We hence also tried to deduce the bats' behaviour at the platform

from the recordings (e.g. transit vs. exploring or foraging) to get an idea of why bats occur at anthropogenic offshore structures.

## Material & methods

### Study site

The unmanned offshore research platform FINO 1 (54° 01' N, 06° 35' E) is located in the south-eastern North Sea, 45 km north of the island of Borkum (figures 1 and 2). It is founded on four pilings with a 256 m<sup>2</sup> working deck 20 m above sea level (a.s.l.) and has an 81 m lattice tower in its southern corner and a 164 m<sup>2</sup> helicopter deck at 25 m a.s.l. (Fischer 2006, for further details see [www.fino1.de](http://www.fino1.de)).

The flight safety lighting consists of two continuous red lights (10 cd) each at 101.5 m, 75 m and 55 m a.s.l., respectively. These lights were replaced in November 2007 and again in late autumn 2014 and spring 2015 by red

LED-lights of the same intensity. Further, four continuous white halogen flood lights (400 W) installed at 19.5 m a.s.l. illuminate the foundation underneath the platform deck. In summer 2012 the floodlights were equipped with energy-saving lamps (100 W) instead of the halogen bulbs. Four white lights (50 W) at 21.6 m a.s.l., blinking with Morse code “U”, serve for shipping safety. A replacement to LED-lanterns of the same light intensity was made at the end of 2014. The name inscription at all four sides of the platform is continuously illuminated by two 200 W halogen lamps each, which were replaced by single energy-saving lamps (80 W) at each side in summer 2012 (G. Fischer and S. Howorek, personal communication).

### Acoustic monitoring

Because access to the platform was only possible by irregular helicopter flights (see Fischer 2006, Hüppop et al. 2016) a recording system with the possibility of vast remote control was essential. Hence, we decided to setup a computer based system remotely accessible via the platforms computer network (Fischer 2006) rather than one of the autonomous bat recorders (e.g. Adams et al. 2013, Britzke et al. 2013) that were commercially available in 2004.

We installed a Pettersson D-230 bat detector at the platform’s working deck and replaced the battery by a 9 V power supply. This detector combines a divide-by-ten and a heterodyne detector (fixed at 45 kHz; for technical background of the different detector types see e.g. Skiba 2003, Parsons & Szewczak 2009 or Barataud 2015). In contrast to time expansion systems, which keep most details of the ultrasound calls, both heterodyning and frequency division can operate in real time. The latter is broadband and thus not limited to a narrow frequency range. It retains much of the signal’s time and frequency information (e.g. Miller & Degn 1981, Parsons & Szewczak 2009, Britzke et al. 2013). The bat detector was

sheltered from wind, water and gull excrements by a basket windshield with long-haired polyester fleece cover, and a stainless steel roof. Both output channels of the bat detector (frequency divider and heterodyne) were continuously sampled by the on board soundcard of a computer with “RecAll 2.4” ([www.sagebrush.com](http://www.sagebrush.com)). When the level of the incoming signals of the frequency divider exceeded a predefined threshold they were stored on the computer for later analysis as two channel WAVE-files (44 kHz, 16 bit).

From 12 August 2004 to 21 December 2015 the system was operational throughout the year in ca. 3530 out of 4148 nights from sunset to sunrise. Due to computer problems several major gaps were unavoidable (figure 3). Additionally we cannot exclude occasional failures of the system that may have occurred for a few hours. The bat recorder itself and the sound card were checked for effects of humidity, corrosion or possible other technical issues but have been functioning properly during the whole period.

All acoustical analyses were made with “Praat” versions 4.6.12 to 5.3.69 ([www.praat.org](http://www.praat.org)). Because of the harsh and noisy “technical” environment several millions of files were recorded making an automatic search for ultrasonic bat calls afterwards necessary. These were detected by pitch analysis with “Praat” (Hill & Hüppop 2008). Bat species were identified by frequencies of highest amplitude, signal structure, length of intervals between single calls and rhythm (mainly after Skiba 2009 and Barataud 2015, but also after Rydell 1993, Waters et al. 1995, Jensen & Miller 1999 and others). We checked all files with echolocation calls for feeding buzzes or other indicators of the bats’ behaviour (Parsons & Szewczak 2009, Ratcliffe et al. 2013, Rydell & Wickman 2015).

### Weather data

At the platform, wind speed and direction at 90 m above sea level were measured every

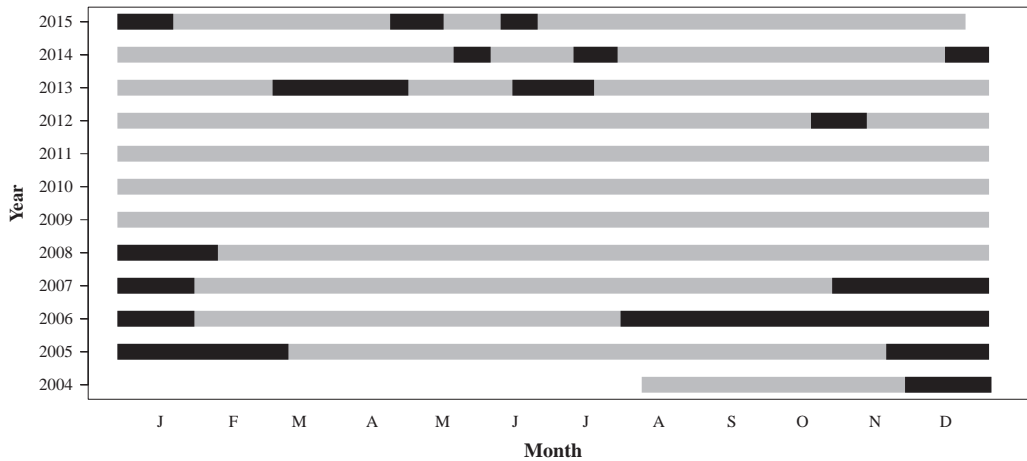


Figure 3. Functioning (grey) and not-functioning (black) of the recording system versus time.

10 minutes (kindly provided by the Federal Maritime and Hydrographic Agency, <http://fino.bsh.de>). For statistical analyses we averaged these values over the last 60 min before the first registration of a bat. To assess the influence of winds on migrating bats flying over the sea we calculated tailwind components (TWC) and crosswind components (CWC) from the wind data (see also Hüppop & Hilgerloh 2012):

TWC =  $\cos(\text{observed wind direction} - \text{presumed direction of migration}) \times \text{wind speed}$   
 CWC =  $\sin(\text{observed wind direction} - \text{presumed direction of migration}) \times \text{wind speed}$

Positive TWC values mean tailwind assistance, negative ones mean headwinds. Crosswinds from the left of the bat migrating into the presumably preferred direction are expressed by positive CWC values, winds from the right by negative ones. Presumed directions of migration (WSW in autumn and ENE in spring) were estimated from recoveries of marked *Nathusius' pipistrelles* in the larger region of the southern North Sea (Petersons 2004, Vierhaus 2004, <http://fledermauszug-deutschland.de>).

For air pressure and change in air pressure over the last three hours before a registration we used data for the nearest full hour from a weather station on the island of Norder-

ney (50 km south-east; 53° 43' N; 07° 09' E; Deutscher Wetterdienst).

Information on cloud types and precipitation were derived from scan data of the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) on board METEOSAT Second Generation (MSG), the European geostationary satellite operated by EUMETSAT (Schmetz et al. 2002, Lensky & Rosenfeld 2008). The multi-channel MSG data were purchased from [www.eumetsat.int](http://www.eumetsat.int). They were analysed with the "MSG Native image reader" and interpreted according to the features in the EUMETSAT MSG interpretation guide (<http://eumetrain.org/IntGuide/>) and with the software "CAPSAT" (Lensky & Rosenfeld 2008, latest version kindly provided by I. Lensky).

To address fog/low stratus and precipitation detection at night we made use of the particular emissive properties of droplets at different infrared wavelengths: the small droplets found in fog or low stratus are less emissive at 3.9  $\mu\text{m}$  than at 10.8  $\mu\text{m}$  and 12.0  $\mu\text{m}$ , whereas the emissivities are roughly the same for larger droplets (Lensky & Rosenfeld 2003, 2008, Cermak & Bendix 2008). In this technique, the Brightness Temperature Difference (BTD) of 12.0  $\mu\text{m}$  - 10.8  $\mu\text{m}$  is a measure for the clouds' opaqueness (higher values mean more opaque clouds), whereas the

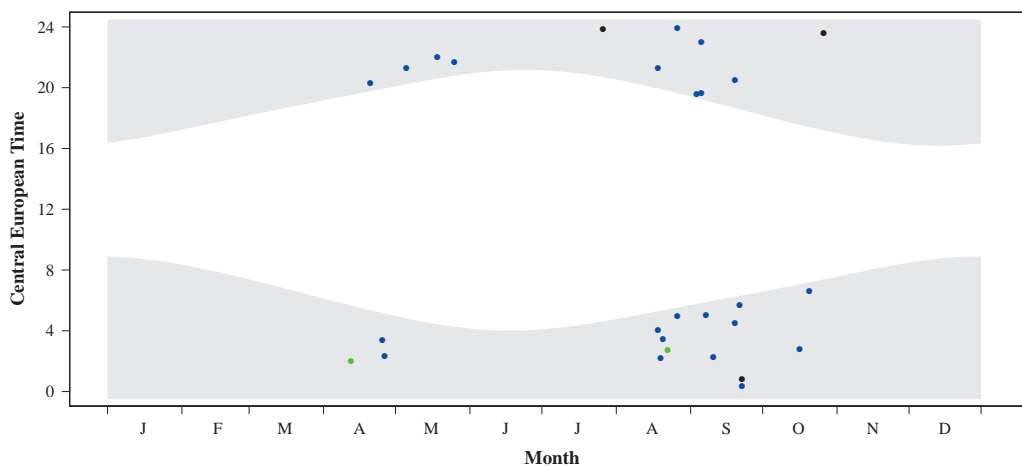


Figure 4. Acoustic recordings of *Nathusius' pipistrelle* (blue,  $n=23$ ), northern bat (black,  $n=3$ ) and Leisler's bat (green,  $n=2$ ) at FINO 1. Grey areas: times between sunset and sunrise at FINO 1.

BTD of  $10.8 - 3.9 \mu\text{m}$  is sensitive to particle size (higher values mean smaller droplets). Cloud top height was categorised according to the brightness temperature at  $10.8 \mu\text{m}$  (Lenskyy & Rosenfeld 2008, <http://eumetrain.org/IntGuide/>). Weather radar data (since 2006) are available at <http://meteox.com>. They were used to validate precipitation as predicted from satellite images.

### Statistical analyses

All statistics were carried out in R 3.2.4 (R Core Team 2016). We checked for the preference or avoidance of certain weather situations by comparing observed with expected frequencies for all weather parameters based on all available measurements at midnight over the years 2004 to 2015 (spring: April to May,  $n_{\text{wind}}=635$ ,  $n_{\text{pressure}}=732$ ; autumn: August to October,  $n_{\text{wind}}=1022$ ,  $n_{\text{pressure}}=1103$ ). We tested whether observed frequency distributions of bat observations fitted frequencies as expected from the distribution of several weather parameters by exact multinomial tests with log-likelihood-ratios as a measure for goodness-of-fit (see <https://cran.r-project.org/web/packages/XNomial/>

[vignettes/XNomial.html](https://cran.r-project.org/web/packages/XNomial/)). The null hypothesis for this test is that the observed frequency is equal to an expected count in each category. The low number of bat detections at the platform excluded any multivariate statistical approaches.

### Results

In total, 317 call sequences were recorded and analysed. They were assigned to a minimum of 28 individual bats (table 1). The recordings covered two distinct periods: 13 April to 26 May and 26 July to 26 October (table 1, figure 4). Three times more bats were observed during autumn ( $n=21$ ) than during spring migration ( $n=7$ ). Bats were recorded from immediately after sunset to shortly before sunrise, 16 before and 12 after midnight (figure 4). With at least 23 recorded individuals *Nathusius' bat* was the most numerous species. It was detected from 20 April to 26 May (median: 2 May) and from 19 August to 20 October (median: 9 September). Three individuals were identified as northern bat and two as Leisler's bat.

Bats occurred at the platform at winds with mostly southern directions between  $98^\circ$  (E)



Table 1. Observations of bats at the offshore research platform FINO 1 in the southeastern North Sea from 2004 to 2015.  $\Delta$  air pressure = change in air pressure over the last three hours. Cloud, fog and presumed rain are derived from satellite and weather radar images (see Methods).

Date	Time (CET)	Species	Wind- direction	Windspeed (m/s)	Air pressure (hPa)	$\Delta$ air pressure (hPa)	Clouds, fog and rain	Remarks
16.10.2004	02:53 to 04:27	Nathusius' pipistrelle	104°	1.4	998.2	-1.1	low-level clouds, some rain	hunting
26.10.2004	23:37 to 23:53	Northern bat	231°	2.1	1012.4	-0.2	low- to high-level clouds, rain	
27.04.2005	02:23	Nathusius' pipistrelle	167°	5.5	1011.5	-1.4	mid-level clouds, rain	
26.05.2005	21:45 to 22:04	Nathusius' pipistrelle	308°	5.1	1017.1	1.3	mid-level clouds, rain	
19.08.2005	21:20 to 21:26	Nathusius' pipistrelle	261°	8.1	1013.1	1.1	mid- to high-level clouds, rain	hunting
20.08.2005	02:16 to 03:24	Nathusius' pipistrelle	181°	2.5	1013.9	0.7	mid-level clouds, rain	
06.05.2007	21:21	Nathusius' pipistrelle	271°	12.5	1012.5	-0.2	low- to mid-level clouds, rain	
23.09.2007	00:24 to 00:49	Nathusius' pipistrelle	168°	3.7	1022.2	-0.1	fog/low stratus	hunting
23.09.2007	00:52 to 00:54	Northern bat	174°	6.5	1022.4	0.2	fog/low stratus	
26.07.2008	23:54 to 00:21	Northern bat	161°	10.0	1017.6	1.6	high-level clouds, rain	hunting
07.09.2008	05:06 to 05:12	Nathusius' pipistrelle	164°	9.4	1005.1	-0.3	mid-level clouds, rain	
10.09.2008	02:20	Nathusius' pipistrelle	192°	10.9	1011.7	-0.6	mid- to high-level clouds, rain	
19.09.2008	04:36	Nathusius' pipistrelle	147°	4.2	1025.6	-0.5	low-level clouds	
19.09.2008	20:35 to 20:43	Nathusius' pipistrelle	268°	1.4	1030.5	1.2	fog/low stratus	
13.04.2009	02:05	Leisler's bat	98°	7.3	1010.3	-0.8	low-level clouds	
26.04.2009	03:26 to 04:05	Nathusius' pipistrelle	197°	5.4	1013.4	-0.2	high cumulonimbus, rain	
19.05.2009	22:06	Nathusius' pipistrelle	185°	3.5	1020.4	0.7	low-level clouds after passage of fog/low stratus	
22.09.2010	05:46	Nathusius' pipistrelle	151°	6.0	1021.7	-0.8	low-level clouds	
04.09.2011	19:37 to 19:48	Nathusius' pipistrelle	212°	4.3	1008.7	0.2	mid-level clouds, rain showers	
20.04.2012	20:20 to 20:21	Nathusius' pipistrelle	182°	2.4	997.1	1.4	extended fog/low stratus, rain	
20.10.2012	06:41	Nathusius' pipistrelle	194°	11.1	1012.4	0.6	mid-level clouds, cumulonimbus approaching	
27.08.2013	05:03 to 06:26	Nathusius' pipistrelle	111°	4.7	1018.7	-0.5	clear sky	
06.09.2014	19:42	Nathusius' pipistrelle	272°	3.9	1012.5	0.4	mid- to high-level cumulonimbus, rain	
06.09.2014	23:03	Nathusius' pipistrelle	234°	5.1	1012.9	0.4	after high-level cumulonimbus with rain	transfer
19.08.2015	04:07 to 04:15	Nathusius' pipistrelle	173°	5.8	1017.7	0.3	mid- to high-level clouds, rain	
21.08.2015	03:29 to 03:46	Nathusius' pipistrelle	144°	6.1	1024.0	-0.3	clear sky	hunting
23.08.2015	02:49	Leisler's bat?	98°	6.9	1016.6	-1.4	clear sky	
27.08.2015	23:59 to 00:29	Nathusius' pipistrelle	256°	7.3	1009.9	1.4	few low-level clouds, light showers	

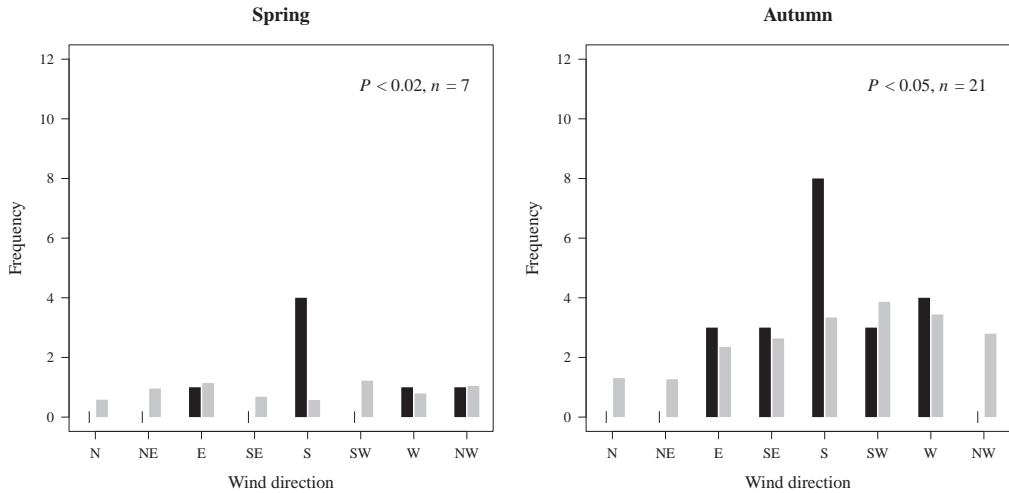


Figure 5. Observed (black) and expected (grey) frequencies of bat recordings at FINO 1 in relation to wind direction.

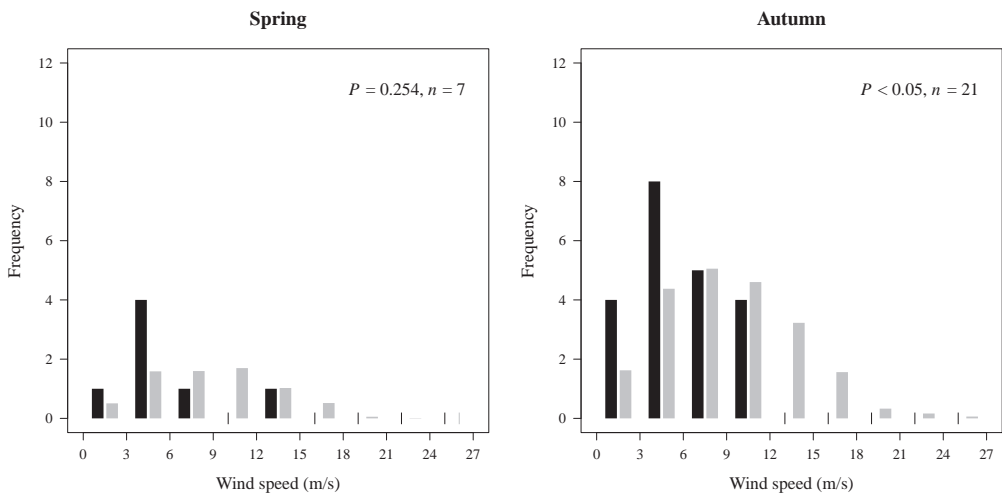


Figure 6. Observed (black) and expected (grey) frequencies of bat recordings at FINO 1 in relation to wind speed.

and 308° (NW) and with speeds up to 12.5 m/s (figures 5 and 6). Compared to the prevailing wind conditions, more bats than expected from the prevailing wind conditions were recorded at lower wind speeds (significantly in autumn) and southerly winds (significantly in spring and autumn). Bats occurred under supporting tailwinds (high positive TWC values in figure 7), but also under strong headwinds (high negative TWC values). In

accordance with the preference of lower wind speeds, more bats were observed under low TWC values than could have been expected from the prevailing TWC conditions (significantly in autumn). In both seasons most bats occurred under winds from the south and accordingly CWC values (again significantly in autumn) which indicate offshore wind drift (figure 8). We neither found effects of air pressure (figure 9), nor of change in air pressure



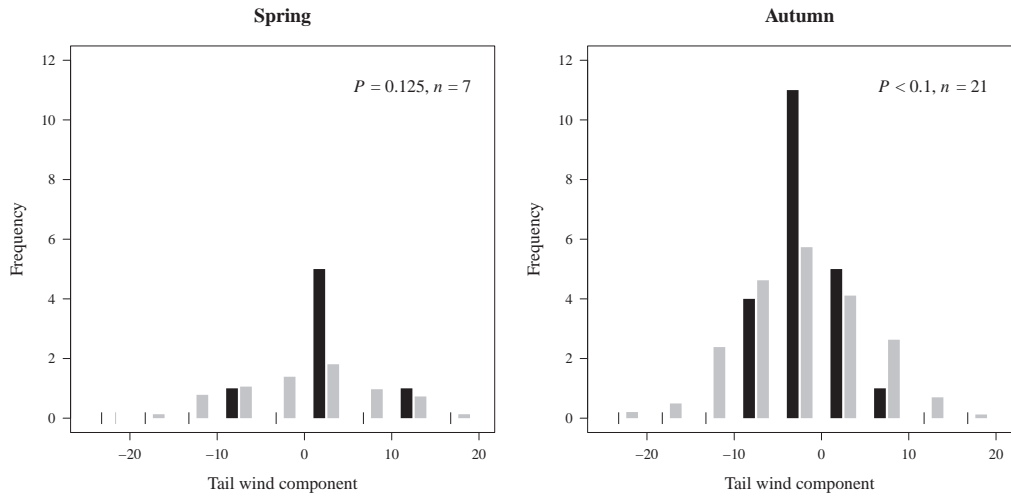


Figure 7. Observed (black) and expected (grey) frequencies of bat recordings at FINO 1 in relation to the tailwind component. Positive values mean tailwinds, negative ones headwinds.

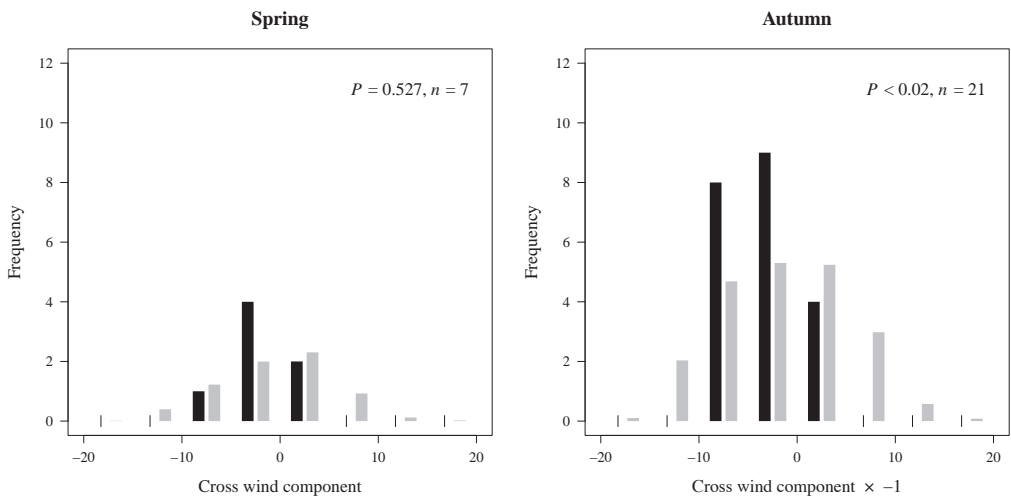


Figure 8. Observed (black) and expected (grey) frequencies of bat recordings at FINO 1 in relation to the cross-wind component. In both seasons, negative values mean offshore winds (from southerly directions)

(figure 10). Most registrations coincided with a dense cover of clouds, fog/low stratus and/or rain while only three bats were detected under clear sky conditions (table 1).

Individual bats were recorded over merely a few seconds up to more than one and a half hours (mean: 14 min; table 1), but there was only one *Nathusius' pipistrelle* that presumably just passed the platform (intervals between

calls regular and  $> 200$  ms, frequency of calls comparatively low and almost constant). Since all other bats had fairly irregular call intervals and a high proportion of calls with considerable frequency modulation it can be concluded that these bats were exploring the platform (see Kalko & Schnitzler 1993, Schnitzler & Kalko 2001, Fenton 2013). Feeding buzzes indicate that some also foraged there (table 1).

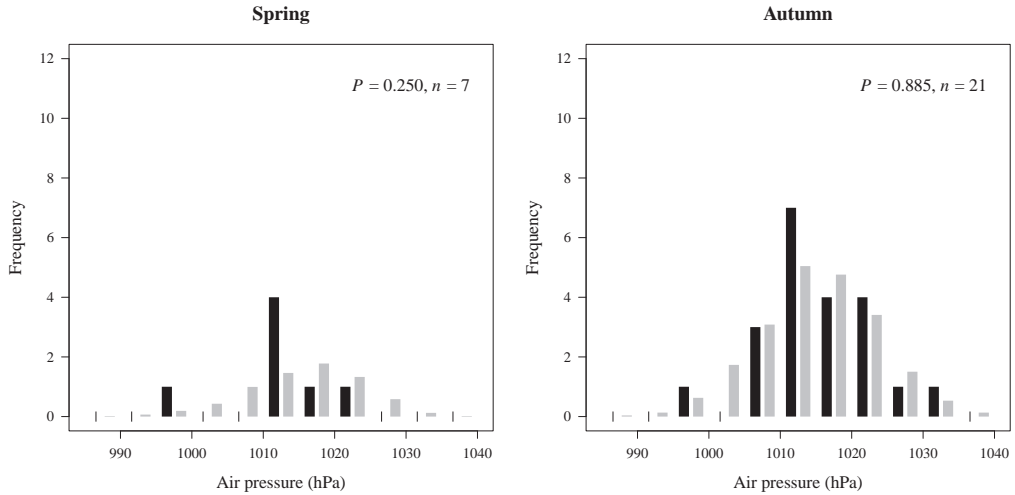


Figure 9. Observed (black) and expected (grey) frequencies of bat recordings at FINO 1 in relation to air pressure.

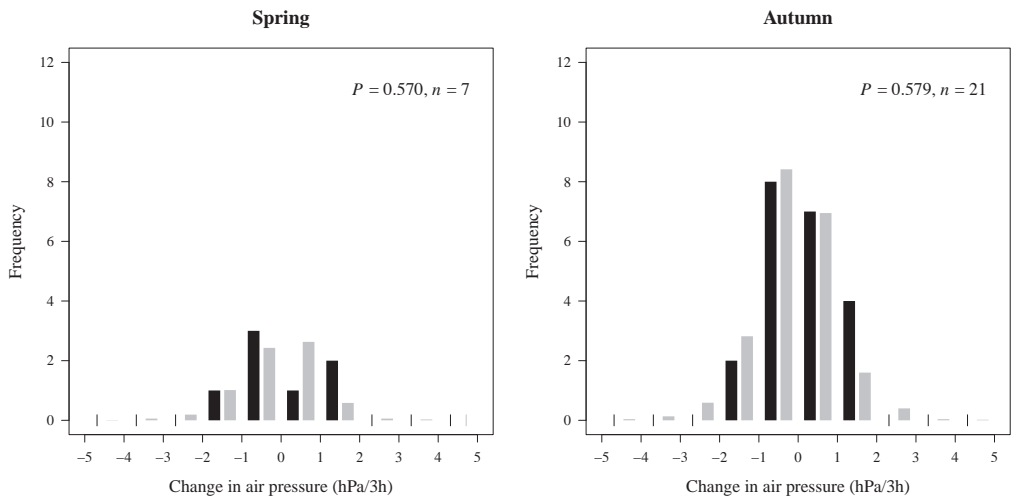


Figure 10. Observed (black) and expected (grey) frequencies of bat recordings at FINO 1 in relation to change in air pressure.

## Discussion

All but one of the bat observations were restricted to the typical migration periods of the observed species in central Europe (e.g. Pétersons 2004, Rydell et al. 2014 and Ciechanowski et al. 2016 for coastal areas of the North Sea and the southern Baltic Sea or Meineke 2012 for *Nathusius' pipistrelle* inland passage

in the Harz mountains, 249 km south-east), emphasising that the bats were on migration rather than on extended foraging flights from the mainland. Also, the distance from the platform to the coast is far beyond what has been reported for foraging distances or home ranges of the observed or closely related bat species (see e.g. Shiel et al. 1999 and Waters et al. 1999 for *Leisler's bat*, Nicholls & Racey

2006 for *Pipistrellus* species or Frafjord 2013 for northern bat). However, the only bat that was registered outside the migration periods (a *Nathusius*' bat on 26 June 2008) might have been blown offshore from its summer area by strong south-easterly wind.

While *Nathusius*' bat and Leisler's bat are well known as long distance migrants (Skiba 2003, Pētersons 2004, Vierhaus 2004), the northern bat is regarded as a resident species with only occasional migrations (Skiba 2003, Gerell & Rydell 2004, Ahlén et al. 2009). However, as already suggested by Tress (1994), our observations at FINO 1, and those made by others at oil rigs and on remote islands (Gerell & Rydell 2004, Boshamer & Bekker 2008, Petersen et al. 2014, Hüppop unpublished data) indicate that this species might be more migratory than the low number of recoveries of marked individuals and the few observations imply. Actually, numbers of marked northern bats are so far still small. In accordance with the compilation of findings of bats at offshore platforms in the Dutch sector of the North Sea by Boshamer & Bekker (2008) and the recordings of Lagerveld et al. (2014) at two wind farms off the Dutch coast in autumn 2012, we did not detect a single common pipistrelle. This is surprising since this species occurs as a regular migrant on the island of Helgoland (figure 1), 85 km ENE, at a comparable distance to the coast (Skiba 2007, Hüppop 2009).

The extensive exploratory behaviour of bats at the platform causes some uncertainty in the identification of northern bat and Leisler's bat. These two species, serotine (which can be expected at the platform, too; Boshamer & Bekker 2009, Hüppop 2009) and other bat species may considerably change and adapt the characteristics of their echolocation calls. Especially serotine and Leisler's bat, but also northern bat reduce the length and increase both the frequencies and the bandwidth of their calls when e.g. approaching obstacles or flying close to the ground or in dense vegetation (Rydell 1993, Waters et al. 1995, Jensen

& Miller 1999, Skiba 2003, Gerell & Rydell 2004, Ahlén et al. 2009). The result is an extensive overlap of echolocation call structure between all three species which necessitates the use of other features such as "left out" single calls in the sequences of serotine, the "waltz-like rhythm" in northern bat or the "plip-plops" in Leisler's bat (Skiba 2003, Barataud 2015). Regrettably, individuals may omit these species specific characteristics in their call sequences. In conclusion, our identification of bat species other than *Nathusius*' pipistrelle has to be regarded with some caution.

At FINO 1, only 317 sequences of echolocation calls were recorded in a period of eleven years, while Lagerveld et al. (2014) recorded 189 and 25 bat call sequences at two Dutch offshore wind farms from 29 August until 20 October 2012 and from 4 to 23 September 2012, respectively. These wind farms, however, are only 15 and 23 km offshore, while the distance from the FINO 1 to the next coastal island is 45 km. This might suggest that bat migration is more coastal as proposed by Bach et al. (2009), Frey et al. (2012) and Rydell et al. (2014). But somehow it stands in contrast to the high number of bat recordings at the island of Helgoland (Skiba 2007, Hüppop 2009) where bats might stay for longer than on a platform without vegetation and presumably less insects. Also technical differences between the studies that influence the detectability of echolocation calls cannot be excluded, e.g. by the deviating sensitivity of the systems used (e.g. Adams et al. 2009, own observations) but also due to orientation and weatherproofing (Britzke et al. 2010). Our knowledge on the detection range of bat recording systems is very limited, but from handheld bat detectors it is known that e.g. *Pipistrellus* species can be detected up to only 25 m, northern bat up to 50 m and Leisler's bat up to 80 m (Barataud 2015). Hence, depending on the species, typically only altitudes up to considerably less than 50 to 100 m a.s.l. were covered and only bats flying close to the platform could be detected.

Bats likely use vision and their magnetic sense rather than echolocation to migrate (Holland 2007) and offshore wind turbines and other offshore structures attract bats (Ahlén et al. 2009). Many bat species, including those of the genera *Pipistrellus*, *Nyctalus* and *Eptesicus* seek lights because of the higher numbers of insects attracted to street lights, especially those emitting short wavelengths (see e.g. Rydell 1991, 1992, Blake et al. 1994, Stone et al. 2015, Shoeman 2016). Insects move over the North Sea (and other marine areas) in huge numbers (e.g. Chapman et al. 2004, Drake & Reynolds 2012) and sometimes masses also occur at the FINO 1 (own observations of flies, flying beetles and moths) or other offshore installations (Heydemann 1967). Bats presumably forage during their migration flight as do aerial feeding birds, such as swallows or swifts (Ahlén et al. 2009, Cryan & Diehl 2009, Šuba et al. 2012, Voigt et al. 2012). We hence assume that at least some of the observed bats were attracted by the (white) lamps of the FINO 1 platform signalling a possible chance for a “quick snack” or a suited daytime stopover to them.

Our results concerning bat registrations at FINO 1 in relation to weather are difficult to interpret and somehow contradict previous findings. In accordance with former offshore studies (Baltic Sea: Ahlén et al. 2009, North America: Cryan & Brown 2007, Sjollema et al. 2014, Dutch North Sea: Boshamer & Bekker 2008, Lagerveld et al. 2014) we found that bats were mainly recorded at low to moderate wind speeds. But in contrast to the findings at other offshore installations in the southern North Sea (Boshamer & Bekker 2008), we found a considerable effect of off land crosswinds. On the one hand, this might actually reflect drift (cf. Petersen et al. 2014) and suggest a preference of a more coastal migration as suggested by Bach et al. (2009), Frey et al. (2012), Lagerveld et al. (2014) and Rydell et al. (2014). On the other hand, it cannot be excluded that our registrations are only partly representative for the overall offshore bat

migration, missing possibly stronger migration at altitudes which were beyond the coverage by our equipment (see above). Nevertheless we tried to distinguish between bats migrating on their intended routes and those deviating from these routes by wind drift. For this purpose, we separately investigated the wind direction according to seasons and halves of the night. In the first half of the night, bat calls were registered in both seasons only at southerly to westerly winds (161° to 308°, table 1). In spring, this means tailwind support for animals that set off from the coast of Lower Saxony or the eastern Netherlands and destinations in southern Scandinavia or Schleswig-Holstein, while in autumn, it means headwinds for bats coming from there. Within just a few hours after sunset bats coming from Scandinavia under headwinds can hardly reach the platform within the first half of the night. Therefore bats recorded at this time and with offshore wind directions are more likely drifted from the coastal islands or the mainland in the south or may have been individuals that spent the day at the platform without being recorded on their arrival. In the second half of the night, on the other hand, bat calls were recorded in both seasons exclusively during winds from easterly and southerly directions (98° to 197°, table 1). In spring we would expect mainly drifted bats at FINO 1 after midnight, whereas in autumn animals arriving from southern Scandinavia under head- or crosswind conditions are to be expected.

Mainly due to technical reasons our knowledge on flight altitudes of migrating bats is very limited. According to Ahlén et al. (2009) bats migrating close to the coast over the Baltic Sea fly at relatively low altitudes (<10 m, a few >40 m, altitudes of more than 100 m not covered). Further offshore, bats probably use supporting winds (Hatch et al. 2013, Smith & McWilliams 2016) on a larger scale and correspondingly fly much higher as found in eastern red bats (*Lasiurus borealis*), a medium-sized Vespertilionid, off the North

American east coast (at least five out of eleven bats > 200 m a.s.l.; Hatch et al. 2013). Onshore, McCracken et al. (2008) observed feeding Brazilian free-tailed bats (*Tadarida brasiliensis*) in large numbers up to 1118 m above ground level with peak activity at 400-500 m. When recorded at the FINO 1 platform, many bats probably sought refuge during periods of adverse weather (offshore platforms or vessels are the only available options at sea), food or for daytime resting.

Birds predominantly occur at FINO 1 when previous, favourable migration conditions (low wind speeds or tailwinds, clear sky) turn into unfavourable winds, heavy clouds, rain or drizzle and they accordingly get disoriented or seek refuge (Hüppop & Hilgerloh 2012, Hüppop et al. 2016). This also seems to hold for migrating bats: Normally bats accumulate in coastal areas during poor weather (e.g. strong winds or rain; Ahlén et al. 2009). But when they take off in good conditions they might come into worse weather on prolonged overseas flights. Especially rain is a problem since it can roughly double a bat's flight costs when the fur gets wet (Voigt et al. 2011). For a small bat flying at 4 to 9 m/s (Holderied & Jones 2007) it will take one and a half to over three hours of direct flight to reach the mainland from FINO 1, under adverse headwinds even longer. Since offshore wind turbines, platforms and vessels are the only available structures at sea it is likely that bats seek refuge there when flight conditions suddenly deteriorate. This could explain why – quite in contrast to the Dutch sites much closer to the coast (Lagerveld et al. 2014) – so many bats occurred at FINO 1 under rainy or at least overcast conditions. In accordance with this, Cryan & Brown (2007) recorded bats at an island 48 km west of San Francisco mainly under cloudy conditions.

The assumption that bats seek refuge at offshore structures is further supported by the temporal distribution of records throughout the night (in contrast to Lagerveld et al. 2014 numbers were lowest around midnight) and

by the fact that the body masses of *Nathusius'* bat from platforms in the Dutch sector of the North Sea (many of them far away from the coast) were on average considerably lower than those from bat boxes in mainland North Holland (Boshamer & Bekker 2008).

## Conclusions

With our long-term acoustic recording at a research platform we confirmed that there are regular movements of bats over the open North Sea as suggested by earlier accidental offshore observations on islands, ships, platforms or other man-made structures and by systematic but much shorter monitoring closer to the coast. The temporal restriction to the known migration times and the distance to the next islands or coast make it likely that these bats were on migration. However, the relation to adverse weather conditions (unfavourable winds, rain or at least more or less thick cloud layers), the exploring behaviour and some accumulation of recordings shortly after sunset and before sunrise, suggest that the bats rather sought refuge at the brightly lit platform than just were on transfer flights.

There is good reason for us to assume that the majority of migration takes place under better conditions (clear sky, tailwinds, e.g. Ahlén et al. 2009) but was missed in this and other offshore studies because bats flew beyond the range covered by the recording systems, presumably even at altitudes above 100 m under tailwind conditions. Currently there is no technology at hand to investigate bat migration over the North Sea or the Baltic Sea at higher altitudes, mainly because discrimination of migrating bats from birds e.g. in radar is not yet possible (Drake & Reynolds 2012, Aschwanden et al. 2015). Of course, bat detectors could be installed at 100 m a.s.l. at FINO 1. But since bats are attracted by lit structures (see above) and change their altitude rapidly when they are near tall vertical obstacles such as ships, bridges, and wind

turbines (Ahlén et al. 2009) this would provide little information on migratory transfer flights. In the near future, miniature GPS tags and data loggers (Weller et al. 2016) might give a closer insight into the migration and flight behaviour of the larger European bat species. The coastal flight behaviour of smaller bats could be studied with the help of tiny radio tags and a system of automatic receiving stations (see <http://ifv-vogelwarte.de/das-institut/forschung/vogelzug/ag-hueppop/bird-move.html> for a project on small songbirds).

Onshore, collisions with wind turbines are nowadays the leading cause of reported mortality in bats (O'Shea et al. 2016). But despite this and earlier evidence of bats migrating or foraging offshore in the North and Baltic Seas, there have been no studies to date to document collision mortality of bats with offshore wind turbines (or other artificial structures) even though they have been operational in Europe since 1991 (Hatch et al. 2013). Compared to onshore ones, offshore wind turbines require more and steadier lights with, in total, a higher light intensity in accordance with shipping safety regulations. Therefore, we see an increased risk of wind turbines attracting not only birds under deteriorating weather conditions (Hüppop & Hilgerloh 2012, Hüppop et al. 2016) but also considerable numbers of bats, with an unknown collision risk. We recommend bat monitoring as being part of the standardised "Investigation of the Impacts of Offshore Wind Turbines on the Marine Environment (BSH 2013)", also in the German exclusive economic zone of the North Sea. Regarding the rapid development of offshore wind farms, not only in Europe, there is an urgent need for further studies including the development of adequate technologies for offshore use.

Based on their compilation of migratory bat activity across the Baltic Sea and the south-eastern North Sea coasts and islands, Rydell et al. (2014) concluded that the entire coastline and islands around the Baltic Sea are of potential importance to migrating bats in

spring (April-May) and autumn (August-September) and should achieve relevant protection according to EU legislation and its implementations. This recommendation possibly needs to be extended to parts of the North Sea area. However, because of their cryptic migration behaviour, we have only a rough clue on the quantitative spatial distribution of bat migration. Fortunately, a new research project called "BatMove" is on the way that will hopefully shed new light on bat migration issues with regard to offshore wind farms.

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## Samenvatting

### De fenologie van migrerende vleermuizen en hun gedrag bij een onderzoeksplatform in de zuidoostelijke Noordzee

Wij analyseerden de waarnemingen van echogeluiden van vleermuizen, die gedurende meer dan tien jaar werden opgenomen op een onbemand onderzoeksplatform in de Noordzee, 45 kilometer ten noorden van het waddeneiland Borkum. Daarbij keken we specifiek naar de relatie tussen deze waarnemingen en het seizoen, het moment van de dag en de weersomstandigheden, met name de windrichting en de windkracht.

Voor zover wij weten betreft het hier de langstlopende, systematisch verzamelde data-

set betreffende overzeese trek van vleermuizen. In totaal werden 317 echogeluiden geregistreerd, uitsluitend gedurende de typische migratieperiode van vleermuizen in voorjaar en najaar. Daarvan konden er tenminste 23 worden toegerekend aan de ruige dwergvleermuis (*Pipistrellus nathusius*), drie aan de noordse vleermuis (*Eptesicus nilssonii*) en twee aan de bosvleermuis (*Nyctalus leisleri*).

Bij lagere windsnelheden en bij wind uit zuidelijke richtingen worden er meer vleermuizen waargenomen dan op basis van toeval mag worden verwacht. Zowel bij wind mee als bij sterke tegenwind zijn er vleermuizen waargenomen. In beide trekseizoenen kwamen de meeste vleermuizen voor bij zuidelijke winden, dat wil zeggen steeds bij zijwind. Dit laatste wijst erop dat er sprake moet zijn van verdrifting vanaf de kust. We konden geen effect aantonen van de algemene luchtdruk en ook niet van veranderingen in deze luchtdruk. Het merendeel van de waarnemingen vond plaats onder zwaarbewolkte omstandigheden, bij mist of laaghangende bewolking en/of bij regen.

Uit de duur en de eigenschappen van de geregistreerde echogeluiden kan worden afgeleid dat de meeste vleermuizen rond het platform verkenningsvluchten uitvoerden en er dus gedurende de trek niet alleen langs het platform vlogen. Sommige dieren voerden zelfs foeraergevluchten uit.

Wij concluderen dat de meeste waargenomen vleermuizen op trek zijn en worden aangetrokken door het helder verlichte platform en/of daar een veilige plek zochten. Deze conclusie maakt duidelijk dat het risico van botsingen met offshore windturbines reëel is. Deze turbines zouden dan ook meer moeten worden aangelicht dan turbines op het vaste land. We nemen aan dat een groot deel van de overzeese trek van vleermuizen op grotere hoogten met de op dit moment beschikbare apparatuur niet kan worden waargenomen.

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