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Summary

Since a few years it is known that bats migrate over sea on a regular basis. As numerous land-based studies have shown that wind turbines can cause high fatality rates amongst bats Rijkswaterstaat started a bat monitoring programme for 2015 and 2016 in order to reduce uncertainties about possible impacts. At the same time Eneco commissioned a bat monitoring programme for 2015 and 2016 as part of the Monitoring and Evaluation Programme (MEP) for the offshore windfarm Luchterduinen. In 2016 Gemini conducted a bat monitoring campaign in windfarm Buitengaats and Wageningen Marine Research executed a bat monitoring programme at Wintershall platform P6-A and offshore research station FINO3 in the same year. The joint monitoring effort included 12 different offshore locations and 5 locations at the coast.

The specific aims of these monitoring programmes are an assessment of :
1. The species composition at sea and at the coast
2. The spatiotemporal pattern of occurrence, including the flight height
3. The relation between environmental conditions and the occurrence of bats
4. The function of the Dutch Territorial Sea for bats

The monitoring results at the coast showed that Nathusius' pipistrelle is very common during both spring and autumn migration, but is also regular throughout the summer. It is also the most frequently recorded species at sea, albeit much less frequently recorded in comparison to the coast. At sea it was recorded from late August until late October (and one observation in November), and –to a lesser extent- from early April until the end of June. There were no records in July until mid-August. The observed pattern of occurrence matches previous offshore monitoring studies in the German and Dutch North Sea.

Due to a limited amount of data in spring we analysed the presence/absence of Nathusius' pipistrelle per night from mid-August until late October. In this period bat activity was recorded during 11% of the nights at sea and during 66% of the nights at the coast. The higher number of nights at the coast may reflect the relative proportion of bats migrating at the coast and over sea, but the numbers at the coast are likely to be higher due to funnelling, whereas migration over sea is likely to follow a broad front due to the absence of guiding landscape features. However, locally densities at sea may be also inflated as bats are likely to be attracted to offshore structures. Consequently, based on bat detector-data alone, we cannot estimate the proportion of bats migrating along the coast and over sea.

Due to the differences in occurrences at sea and at the coast we developed one statistical model for the offshore stations and one for the coastal stations. We modelled the presence/absence per night as a function of various weather parameters, the moon illumination, the spatial coordinates and the night in year in the period mid-August until late October.

The most important predictor for the occurrence of Nathusius' pipistrelle in autumn at sea and at the coast are low to moderate *wind speeds*, followed by *night in year* (the date). At the coast their presence increases rapidly from mid-August and continues to be high subsequently. At sea the occurrence is strongly peaked. The first wave of migrating animals occurs late August/early September and the second late September. Next, high *temperatures* increase significantly the presence of bats, both at the coast and at sea. *Wind direction* is also important; at sea wind directions between NE and SE (with a peak at 94 degrees) result in highest presence, whereas this is the case with wind directions between E and SW (with a peak at 170 degrees) at coastal locations. The observed optimal wind direction at sea (94 degrees) implies that bats crossing over sea choose tailwind conditions, whereas the presence at the coast seems to be shaped by funnelling. Therefore, it seems unlikely that wind drift or storms cause its presence off our western coastline. However, it has been suggested that wind drift is the main cause for the occurrence of bats north of the Wadden Islands. We also found a *moon illumination* effect in both models. Increasing moon illumination raised the probability of

presence at sea and at the coast. *Rain* reduced probability of the presence of bats at the coast. In contrast, we did not find an effect for *rain* at sea; thus, bats were recorded with and without rain at sea. High *cloud cover* was negatively correlated with the presence of bats at sea, but was positively correlated with the presence of bats at the coast.

The sea model predicts a higher probability of presence in the northwestern corner of the study area. However, we think that this is an artefact caused by the relatively high number of nights with bat activity at the P6A platform, in comparison to the presence at the other offshore monitoring locations. This may be just be a coincidence, but it is also possible that a spatial pattern of occurrence at sea is actually present. For example if bats follow their general migration direction (WSW) after leaving the Afsluitdijk they will pass closely to P6-A.

The recorded bat activity at nearshore monitoring locations (between 22 and 25 km from the coast) peaks approximately 4 hours after dusk. It seems likely that these animals departed the same night from the coast. However, bat activity at the locations further offshore (between 58 and 69 km from the coast) starts often close to dusk. This means that these animals must have spent the day at the monitoring location at sea, or in its vicinity. This pattern of occurrence means that the observed bat activity at a particular night may depend on their departure decision in the previous night, or even earlier.

Other species recorded during this study included Common pipistrelle which was occasionally recorded offshore, but was common at the coast throughout the monitoring season. Nyctaloids were recorded uncommonly offshore from June until October and from May until late October at the coast. Nyctaloids identified to species level included Common noctule, Particoloured Bat, Leister's Bat, Northern Bat and Serotine Bat. Pond bats were not recorded offshore but were regular at the Afsluitdijk and rare elsewhere along the coast. Finally, there were some occasional records of Daubenton's bats and Soprano pipistrelles at the coast.

The results of this study show that the occurrence of bats at sea is highly seasonal which indicates that individuals recorded at sea are on migration. The peak period runs from late August until the end of September. After that it levels off throughout October. Spring migration is much less pronounced but the duration seems to be quite extensive; from late March until the end of June. Records of bats in July and early August are rare. At the coast bats are much more common in general and their presence is both shaped by migratory movements and the presence of foraging individuals from local populations. Therefore, the relevant period to consider the presence of bats at sea off the western coast of the Netherlands and Belgium seems to be from 15 March until 30 June and from 15 August until 31 October, whereas bats should be considered the entire active season at the coast.

Based on the monitoring results of the 2012 – 2014 studies a precautionary mitigation measure was issued using 5 m/s as cut-in wind speed for the wind farms in the Borssele area in the period 15 August until 1 October. The current study however shows that other environmental parameters, in addition to the wind speed, are important as well. The model developed in this study is likely to predict the presence of bats at sea more accurately, despite the fact the model can be improved.

In order to improve the sea model it is recommended to continue monitoring offshore to increase the number of observations in the dataset. The model can furthermore be improved by monitoring in a denser grid to reveal spatial patterns and include information on the availability of insects (bat migration fuel). In addition, we urgently need monitoring data from higher altitudes as bat migration may occur at altitudes beyond the detection range of the current monitoring network at sea.

1 Introduction

1.1 Background

For quite some time there have been indications of bat movements over the North Sea. Observers of bird migration at the Dutch coast regularly report bats flying in from sea (Lagerveld *et al.* 2014a). Bats have also been observed during ship-based bird surveys in the North Sea and have been found on oil and gas platforms, ships and remote islands (Skiba *et al.* 2007, Walter *et al.* 2007, Boshamer and Bekker 2008, Petersen *et al.* 2014). Recently a few ringing recoveries of Nathusius' pipistrelles (*Pipistrellus nathusii*) have shown that bats are able to cross the North Sea successfully[1].

To gain a better understanding of bat activity at the North Sea, several acoustic monitoring studies have been carried out there in recent years. Hüppop & Hill (2016) monitored at the offshore research station FINO 1 in the German territorial Sea from 2004 – 2015 and in the Dutch territorial sea offshore bat activity was monitored at several locations from 2012-2014 (Jonge Poerink *et al.* 2013, Lagerveld *et al.* 2014a, 2014b & 2015). During these studies bats were regularly recorded, in particular during the migration season in spring and autumn.

Numerous studies have shown that onshore wind turbines can cause high fatality rates amongst bats (e.g. Kunz *et al.* 2007, Baerwald *et al.* 2008, Bach *et al.* 2014, Brinkmann *et al.* 2011, Cryan *et al.* 2014, Dürr 2013, Jones *et al.* 2009, Lehnert *et al.* 2014, Rydell *et al.* 2010a, b) Therefore it cannot be ruled out that offshore wind turbines can also have a negative impact on bat populations, if these animals regularly use the North Sea as fly zone, thus taking the risk of barotrauma (physical damage caused by rapid fluctuations in air pressure) and/or death due to getting close to or colliding with a turbine. A preliminary assessment by Leopold *et al.* 2014 indicated that negative population effects on Nathusius' pipistrelle and possibly also Noctule *Nyctalus noctula* and Particolored bat *Vespertilio murinus* cannot be excluded when the planned roll-out of new offshore windfarms is implemented based on the Energy Agreement for Sustainable Growth[2].

In order to reduce this potential negative effect a mitigation measure was issued for the planned wind farms in the Borssele area. The initial bat monitoring projects in 2012-2014 showed a substantial increase in bat activity in the autumn migration periods during nights with low to moderate wind speeds and therefore the cut-in wind speed for the wind turbines in this area was increased to 5 m/s between 15 August and 30 September.

Given the fact that bats have a strictly protected status by national and international regulations, 'Rijkswaterstaat' (RWS) commissioned a bat monitoring programme for 2015 and 2016 (hereafter referred to as 'RWS-project') in order to reduce uncertainties about possible impacts. To make maximum use of available resources and facilities, the RWS monitoring study was linked with a study conducted by Eneco as part of the Monitoring and Evaluation Programme (MEP) for the offshore windfarm Luchterduinen and in cooperation with three Belgian research institutes: the Royal Belgian Institute of Natural Sciences (RBINS), the Flanders Marine Institute (VLIZ), and the Research Institute for Nature and Forest (INBO). Furthermore, Gemini commissioned a bat monitoring campaign in 2016 in windfarm Buitengaats and Wageningen Marine Research executed a bat monitoring programme at Wintershall platform P6-A and offshore research station FINO3 in the same year. The first part of this report describes the monitoring results of the RWS, Eneco, Gemini & WMR projects. The second part of this report describes the analysis of the spatiotemporal occurrence of Nathusius' pipistrelle during the autumn migration in relation to the environmental conditions.

[1] http://www.bats.org.uk/pages/national_nathusius_pipistrelle_project.html
[2] https://www.ser.nl/en/publications/publications/2013/energy-agreement-sustainable-growth.aspx

1.2 Aim of the project

The objective of this study is to obtain relevant information which can be used to determine the effect of the development of the offshore wind energy sector at the southern North Sea in relation to bats. The specific aims of this study are to assess:

1. The species composition at sea and at the coast
2. The spatiotemporal pattern of occurrence, including the flight height
3. The relation between environmental conditions and the occurrence of bats
4. The function of the Dutch Territorial Sea for bats

1.3 Project team

The project team that conducted this study included: employees of Wageningen Marine Research (WMR; Sander Lagerveld, Daan Gerla, Jan Tjalling van der Wal, Pepijn de Vries, Jasper Manshanden, and Michaela Scholl); the Fieldwork Company (tFC; Bob Jonge Poerink); Royal Belgian Institute of Natural Sciences (RBINS; Robin Brabant); Research Institute for Nature and Forest (INBO; Eric Stienen) and Flanders Marine Institute (VLIZ; Klaas Deneudt).

WMR had the project leadership, both substantive and managerial, performed the statistical analysis and compiled the report. tFC executed the fieldwork and processed the raw ultrasonic sound data of the RWS & Eneco monitoring locations. The data obtained from the added stations Gemini OHVS 2 Buitengaats, Wintershall P6-A, and Fino3 was processed by WMR. KBIN, INBO & VLIZ facilitated the monitoring at the Belgian monitoring location and provided general ecological expertise.

1.4 Acknowledgements

In addition to our partners and sponsors, other parties provided input and support to our project. We would like to thank E-Connection for providing the measuring location at the working island Neeltje Jans and Havenbedrijf Rotterdam for using the Radartower at Hoek van Holland. In addition we are indebted to Belwind, C-Power, Engie E&P, RWE and Wintershall who facilitated the monitoring at Belwind OHVS, C-Power OHVS, the platforms L10A-AC/K12-BP, the IJmuiden Meteomast and the P6-A platform respectively.

2 Materials and Methods

2.1 Study area

The assignment focuses on measuring bat activity in the southern North Sea. Since wind energy production in the coming years in the Dutch Exclusive Economic Zone (EEZ) is expected to be developed mostly to the west of the Dutch Provinces of Noord Holland and Zuid Holland and in Zeeland, most monitoring locations are located in that area. Figure 2-1 shows a map of all offshore and coastal locations where acoustic bat monitoring has been executed in the period 2015 -2016. Offshore Wind Farm Egmond aan Zee (OWEZ) is also shown; this is where bat monitoring was executed during 2012-2014.

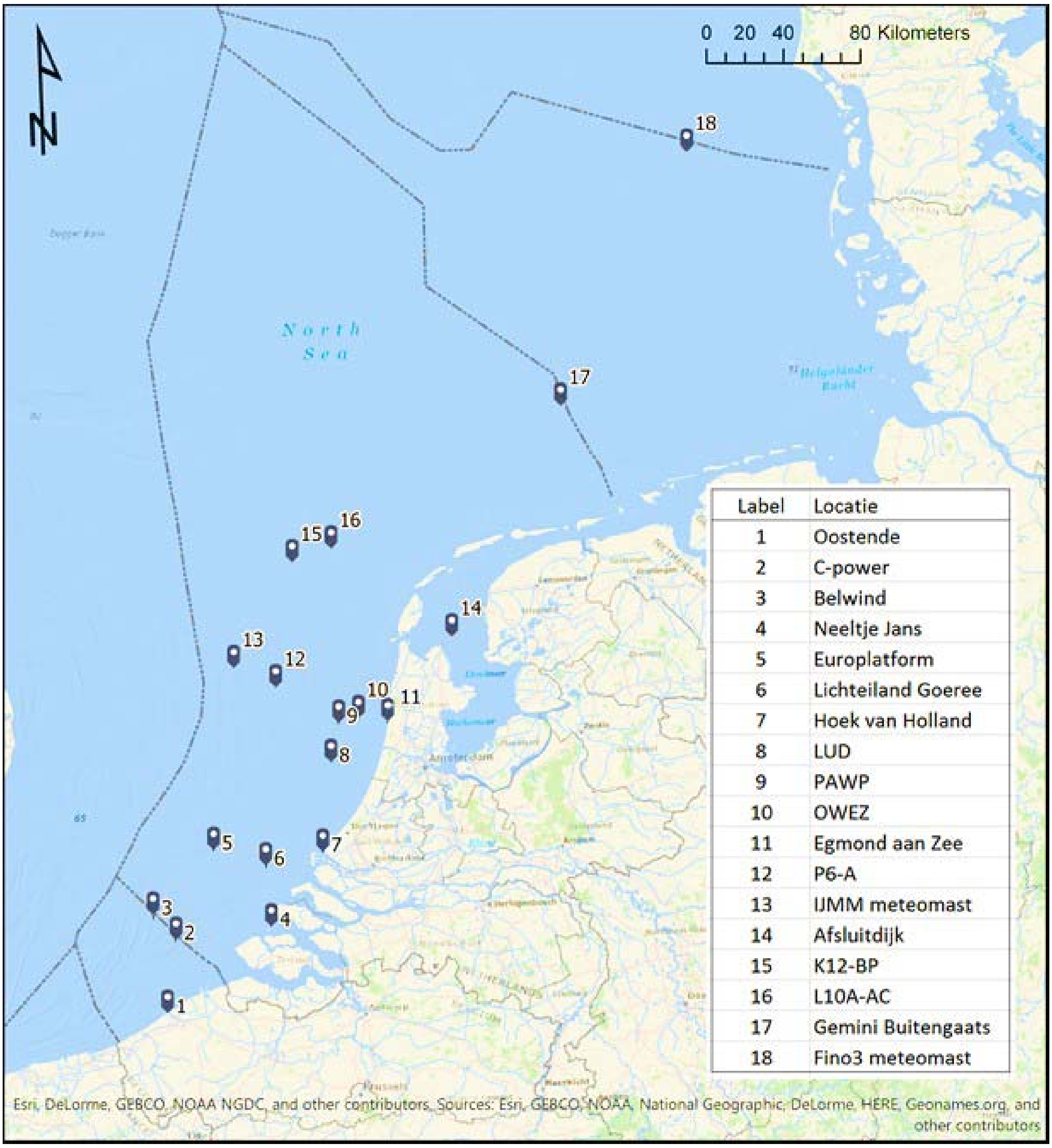

Figure 2.1 *Acoustic monitoring network*

An overview of the 2015/2016 stations per project partner is given in Table 2.1. Photos and detailed descriptions of the monitoring locations can be found in Annex 1.

Table 2.1 *Monitoring locations in 2015/2016*

No.	Location	Object	2015	2016	Sponsor	Remarks
1	Oostende	Building	●	●	KBIN/INBO/VLIZ	
2	C-Power OHVS	Platform	●	●	KBIN/INBO/VLIZ	
3	Belwind OHVS	Platform	●	●	RWS	
4	Neeltje Jans mast	Mast	●	●	RWS	
5	Europlatform	Platform	●	●	RWS	
6	Lichteiland Goeree	Platform	●	●	RWS	
7	Hoek van Holland radar mast 3	Mast	●	●	RWS	
8	Luchterduinen OHVS	Platform	●	●	Eneco	
9	PAWP OHVS	Platform	●	●	Eneco	
11	3D mast Egmond beach	Mast	●	●	RWS	
12	Wintershall platform P6-A	Platform		●	WMR	EZ (KB) funds
13	IJmuiden meteo mast (low & high)	Mast	●		RWS	
14	Afsluitdijk	Mast	●	●	RWS	
15	Engie platform K12-BP	Platform		●	RWS	replacement IJmuiden low
16	Engie platform L10A-AC	Platform		●	RWS	replacement IJmuiden
17	Gemini OHVS 2 Buitengaats	Platform		●	Gemini	
18	Fino3	Mast		●	WMR	EZ (KB) funds

2.2 Equipment

The bat activity was monitored with ultrasonic recorders (Batcorder 3.0 / 3.1 EcoObs Ltd., Germany) which were placed in a waterproof box. The recorders do not record continuously but only after being triggered by a bat sound, or bat call-like sound in the range of 16 – 150 kHz. Sounds are usually recorded at a distance of 15-100 m from the recorder depending on their species-specific echolocation characteristics, the actual environmental conditions, and the recorder settings (Barataud 2015). The bat recorders used in this project were equipped with a cellular modem. By sending a daily status update, the following recorder functions can be monitored:

- Identifier of the bat detector
- Free memory on the SDHC card
- Total number of recordings
- Number of recordings previous night
- Microphone-signal level: TSL [%]
- Warning messages, e.g. low battery, memory card (almost) full, read or write error memory card

This information, in principle, allows for the timely response to malfunctions, e.g., a recorder can be replaced if the capacity of the memory card has reached its limits, if TSL levels are low, or other technical issues occur. Note, however, that the modem can only be used if there is network coverage, which was not the case at the far offshore locations (P6-A, K12-BP, L10A-AC, Gemini and Fino3).

Where recorders had to be mounted by third parties, because of restricted access to the location, an installation manual was provided, and advice and instructions given to the authorised staff, e.g. subcontractors of the windfarm owners, regarding the preferred location/orientation and way of attachment of the recorder.

Preferably the recorders are orientated in an easterly direction to avoid salt spray during strong westerlies. Table 2.2 shows the geographical location of the recorders, including their orientation and height above sea level.

Table 2.2 *Geografical location and orientation of the recorders*

No.	Location	Longitude	Latitude	Height above sea level [m]	Orientation [degrees]	Distance to shore to the east [km]
1	Oostende	2.93	51.24	4	360	-
2	C-Power OHVS	2.99	51.58	15	60	40
3	Belwind OHVS	2.82	51.69	20	90	60
4	Neeltje Jans mast	3.71	51.64	10	90	-
5	Europlatform	3.28	52	15	90	58
6	Lichteiland Goeree	3.67	51.92	15	90	22
7	Hoek van Holland radar mast 3	4.1	51.99	8	90	-
8	Luchterduinen OHVS	4.17	52.4	15	90	25
9	PAWP OHVS	4.24	52.59	15	90	25
11	3D mast Egmond beach	4.61	52.59	9	90	-
12	Wintershall platform P6-A	3.76	52.76	23	110	60
13	IJmuiden meteo mast (low & high)	3.44	52.85	19 (80)	90	85
14	Afsluitdijk	5.12	52.98	6	60	-
15	Engie platform K12-BP	3.9	53.34	20	135	122
16	Engie platform L10A-AC	4.2	53.4	17	90	69
17	Gemini OHVS 2 Buitengaats	6.04	54.04	26	135	183
18	Fino3	7.16	55.19	22	90	85

In this study, the threshold amplitude of the recorder was set to -36 dB in order to gain microphone sensitivity (default setting is -24 dB). For all other parameters, the default settings of the manufacturer were used; post-trigger: 400 ms; threshold frequency: 16 kHz; recording quality 20 and noise filter: 1.

The microphones of the recorders should be calibrated regularly (at least one time per year, or sooner when TSL levels are continuously low) to ensure the comparability of the measurements taken by the different recorders and the data series from one year to the next.

2.3 Data management

Echolocating bats emit ultrasonic pulses to gain information about their environment. Ultrasonic sounds are however also sometimes produced by maintenance or production activities at offshore structures. All sounds in the range of 16 – 150 kHz are recorded onto an SD memory card. We used BcAdmin 2.0 (EcoObs GmbH) to separate sound files containing bat calls from sound files with 'noise'. The bat call recordings were analysed and identified using the automated identification software BcAnalyze 3 (EcoObs GmbH). As automated identification is currently not very reliable we also evaluated the identifications manually using the criteria provided by Barataud (2015).

All monitoring data (date/time/monitoring location/number of echolocation calls/automated and manual identification) including the bat detector status-updates are stored in a database (the Batbase). The same applied for the metadata (e.g. detector, monitoring location, monitoring period).

The properties of each field in the Batbase are pre-defined (and enforced) in order to ensure the quality of the data.

Environmental data are not stored in the database. Weather data are maintained by the Royal Netherlands Meteorological Institute (KNMI) and can be retrieved per weather station directly from the KNMI website (http://www.knmi.nl). The same applies to sunrise/sunset and lunar cycle data which are also available from the internet (http://aa.usno.navy.mil/data/docs/RS_OneYear.php). All environmental data were retrieved at 29 May 2017.

Data extracted from the Batbase are processed to obtain a dataset in which one or more recordings are allocated to a certain time interval with an indication of whether bat detection had occurred in that particular time interval. Time intervals where bats were not recorded are also flagged. All time intervals have the same length with a chosen interval length (e.g. 10 minutes, 1 hour, 1 night). Time intervals that lie entirely in the daylight period (between sunrise and sunset) are excluded from the dataset. Intervals that overlap only partially with a daylight period are, however, included. Time intervals are distributed over the night in such a manner that the amount of daylight time in the first interval equals the amount of daylight time in the last interval of each night.

Next, to each bat monitoring location a KNMI (Royal Netherlands Meteorological Institute) weather station was assigned which was assumed to have weather representative for the bat monitoring location. Weather stations were assigned to monitoring locations based on proximity to the monitoring station and quality of the weather data required for the interval data. Here, quality was determined by the amount of missing data and obvious errors (for example, at one weather station the atmospheric pressure was constant over weeks from a certain moment onwards). Because for several monitoring stations no satisfactory weather data could be found from a single weather station we averaged the data from KNMI offshore stations 203 PB11 (52° 21' N 03° 20' E) and 212 Hoorn-A (52° 55' N 04° 09' E) with missing data removed before averaging (if both data were missing, the result was a missing value). We used these data for the monitoring locations C-Power offshore high voltage station (OHVS), Belwind OHVS, Europlatform, Lichteiland Goeree, Luchterduinen OHVS, PAWP OHVS, Wintershall platform P6-A, IJmuiden meteo mast, Engie platform K12-BP and Engie platform L10A-AC. We used data from offshore weather station 239 F3-FB-1 for the monitoring locations Gemini OHVS 2 Buitengaats and Fino3. Data from the land based stations 310 Vlissingen (51° 27' N 03° 36 E) were used for Oostende, Neeltje Jans mast & Hoek van Holland radar mast 3 and 235 De Kooy/Den Helder (52° 56' N 04° 47' E) were used for 3D mast Egmond and Afsluitdijk. A map of the locations of the offshore KNMI weater stations is shown in figure 2.2.

Figure 2.2 *Offshore KNMI weather stations (source www.knmi.nl)*

The KNMI weather data are stored per hour (00:00, 1:00... 23:00). If a time interval falls between two hour-values, then the average was used as the weather parameter for that particular interval. If the interval is longer than one hour, the average of all hour-values included in the time interval was used as the value of the weather parameter.

The weather variables included in the dataset are: *wind direction* averaged over the last 10 minutes, *wind speed* averaged over the last 10 minutes measured at an altitude of 10 m above sea level, *temperature* at 1.5 m height, *atmospheric pressure* at sea level, horizontal *visibility* in meters, *cloud cover* in octants, relative *humidity* at 1.5 m and *rain*. For the latter variable a 1 indicates it did occur in the last hour, 0 indicates it did not, an average over hourly data of these indicates the fraction of hours in which the weather condition did occur. Definitions and background information on the measurements of the weather parameters can be found at http://projects.knmi.nl/hawa/pdf/Handbook_H01_H06.pdf.

Horizontal visibility in the meteorological data from the KNMI is given as a range of visibility in which the observation lies, expressed in meters. We transformed these ranges to a numerical value by taking the midpoint of the range (also in measured in meters).

The average of any weather parameter is simply the arithmetic mean, except for wind direction. The average of this parameter was calculated by:

a_mean = atan2(sum_i(sin(a_i)), sum_i(cos(a_i))) mod 2*pi

where a_mean is the wind direction measured in radians, a_i is the i_th wind direction to be averaged (measured in radians) and atan2 is the arctangens function with two arguments, as implemented in the R programming language.

2.4 Statistical analyses

We only included Nathusius' pipistrelle in the analysis as this species is the most frequently recorded species at the North Sea. Due to a limited amount of data in spring we analysed the late summer/autumn data from mid-August (day number 225) until late October (day number 395). We performed two separate analyses; one for the land-based stations and one for the offshore monitoring stations. For the analysis of the offshore data we only used the data from the monitoring locations off the western coastline as these locations are likely to receive bats from the Netherlands and Belgium. We did not use the data from Fino3 and Gemini as it seems likely that bats recorded here originate from areas further away (Germany and Denmark).

Since bats are nocturnal it makes more sense to analyse their occurrence per night instead of a calendar day. An analysis per hour resulted in a 98% zero-inflation for the offshore dataset which made a proper analysis impossible. Therefore we used the presence per night as response variable for both analyses. In order to investigate spatiotemporal patterns we modelled the response variable as a function of the covariates and applied the following model.

Y_i ~ Bernoulli(Pi_i)
E(Y_i)   = Pi_i
var(Y_i) = Pi_i * (1 - Pi_i)
logit(Pi_i) = Intercept + Covariates

Covariates included in both analyses were *night in year*, *moon illumination*; the fraction of the illuminated Moon's visible disk and the weather parameters *cloud cover*, ranging from 0 okta (clouds absent) to 8 okta (completely overcast), *atmospheric pressure* in mB, *fraction of hour intervals with rain*, *temperature* in ºC, *visibility* in km, *humidity* in %, *wind direction* in degrees and *wind speed* in m/s. All fixed covariates were continuous.

We used the protocol provided by Zuur & Ieno (2016) as guidance for the actual analysis in R (R Core Team 2014). During the data exploration we assessed outliers in the covariates using Cleveland dotplots. The potential presence of zero inflation was considered by checking the number of zeros in the response variable. Collinearity between the continuous covariates was assessed with multipanel scatterplots, Pearson correlation coefficients and variance inflation factors. The relationships between the response variable and the continuous covariates were checked with multipanel scatterplots.

We used a generalized additive mixed model (GAMM) as a starting point for the analysis (Pinheiro *et al.* 2017) and first evaluated the need for a dependency structure in the data by comparing the base model with alternative models with dependency structures. We evaluated the following dependency structures:

1. a random effect *monitoring location*
2. an AR1 (temporal) correlation structure *night in year* per *monitoring location*
3. a random effect *monitoring location* + an AR1 (temporal) correlation structure *night in year* per *monitoring location*

To capture seasonal patterns the covariate *night in year* was included with a (default) thin-plate regression spline smoother in the model and the covariate *wind direction* was incorporated as cyclic smoother. The other continuous covariates were included as linear covariates. All fixed covariates were standardized to avoid numerical problems.

In order to reduce model complexity we investigated which covariates in the fixed structure were significant using backward selection based on a likelihood ratio test (Zuur et al 2009). When the optimal model was found a model validation was applied where we plotted the Pearson residuals against fitted values, and against each covariate in the model and each covariate not in the model. In addition, variograms were used to assess potential spatial and temporal autocorrelation in the Pearson residuals. Finally a graphical representation of the model was made using ggplot2 (Wickham 2009).

3 Results

3.1 Monitoring effort

We tried to monitor at the predefined locations (Table 3.1: location 1-11 and 13) throughout the entire active season of bats (roughly from mid-March until November). However, logistical problems and malfunctioning recorders caused downtime. In particular it was a pity that the 'high' recorder at the IJmuiden meteo mast could not be installed as the crew was caught by a storm which made installation works near the top of the mast impossible during their only maintenance visit of the season. Therefore we could not obtain monitoring data at 'hub-height'. The IJmuiden meteo mast was dismantled in 2016 and we moved to the alternative monitoring locations K12-BP and L10A-AC which were provided by Engie E&P.

Although a recorder was in operation throughout 2015 and 2016 at C-Power OHVS we did not include the monitoring data in this report as the microphone appeared not to be calibrated.

The effective monitoring period per location per year is shown in Table 3.1.

Table 3.1 *Monitoring periods in 2015/2016*

No.	Location		2015	2016
1	Oostende	coast	09-09 / 03-12	04-07 / 23-10
2	C-Power OHVS	offshore	-	-
3	Belwind OHVS	offshore	04-06 / 05 -11	23-03 / 24-10
4	Neeltje Jans mast E-connection	coast	04-06 / 05-11	31-07 / 24-10
5	Europlatform	offshore	03-04 / 20-10	11-04 / 22-11
6	Lichteiland Goeree	offshore	17-03 / 27-10	12-04 / 15-11
7	Hoek van Holland radar mast 3	coast	26-05 / 05-11	09-03 / 24-10
8	Luchterduinen OHVS	offshore	02-03 / 09-10	16-03 / 24-10
9	PAWP OHVS	offshore	23-03 / 20-10	03-04 / 17-10
11	3D mast Egmond beach	coast	26-05 / 22-10	15-03 / 28-10
12	Wintershall platform P6-A	offshore		01-08 / 17-11
13	IJmuiden meteo mast (low & high)	offshore	18-03 / 14-05 (low)	
14	Afsluitdijk	coast	28-07 / 22-10	15-03 / 15-10
15	Engie platform K12-BP	offshore		23-04 / 15-06
16	Engie platform L10A-AC	offshore		27-04 / 01-11
17	Gemini OHVS 2 Buitengaats	offshore		25-03 / 16-11
18	Fino3 meteomast	offshore		19-07 / 29-09

3.2 Performance of the equipment

During the monitoring season the microphone of a bat detector may lose sensitivity, in particular when it is exposed to humidity or frost. Every time the bat detector (Batcorder 3.0 / 3.1, EcoObs GmbH) is switched off the microphone sensitivity level (TSL) is determined by comparing a test signal with a calibrated reference value. The TSL, however, should not be considered as an absolute performance indicator. Values considerably less than 100% frequently occur, as well as strong fluctuations (e.g. caused by fog or rain). TSL values between 30-70% and occasionally between 10 and 90% can be considered normal, but when the TSL drops to values between 0-10% during several days the microphone needs replacement (EcoObs GmbH).

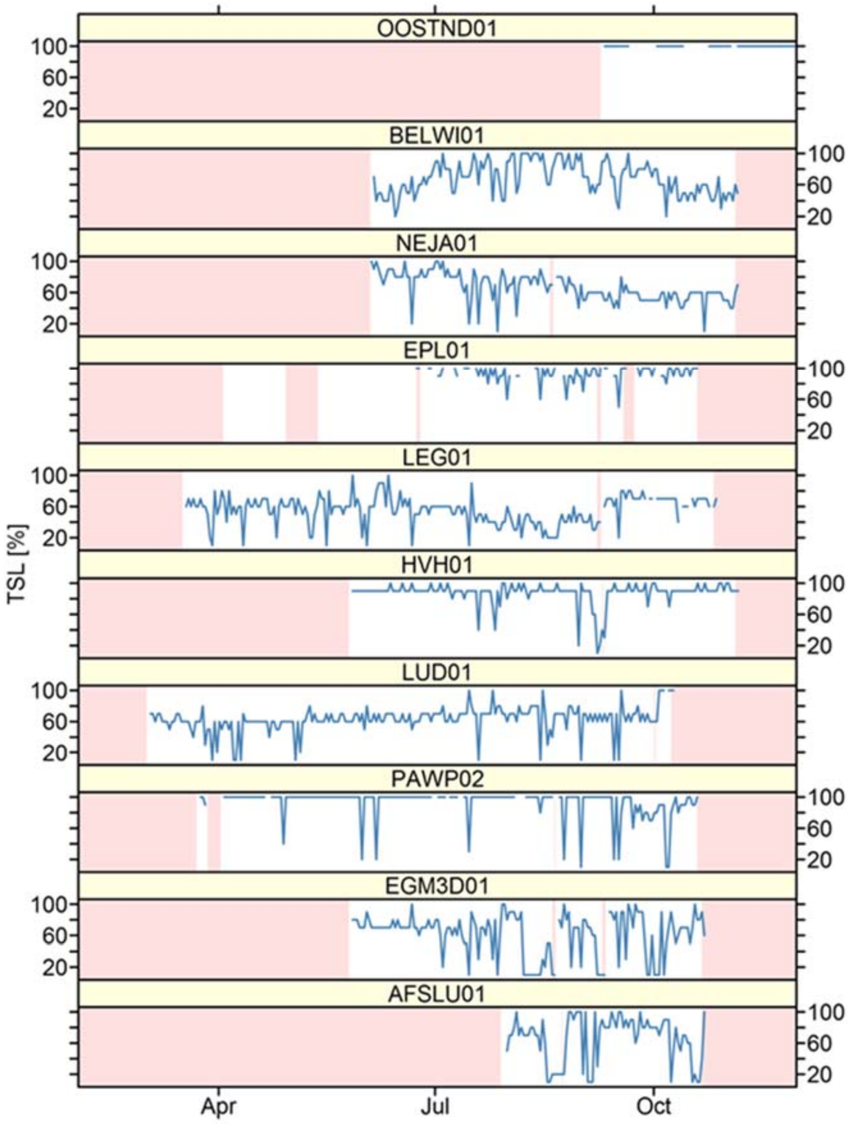

Figure 3.1*: Microphone sensitivity level (TSL) of the microphones per monitoring location in 2015. Missing values are caused by a (temporary) lack of coverage by the GSM network. Note that the actual monitoring period is indicated by a white background.*

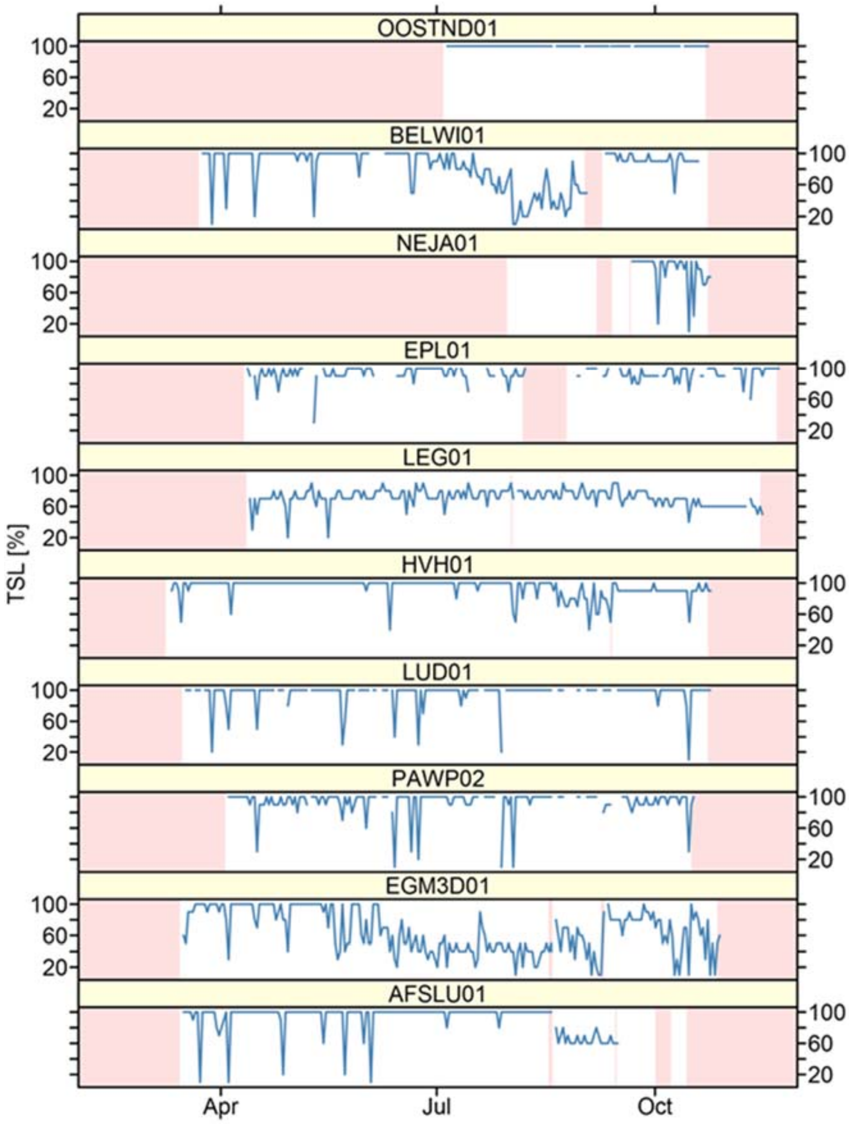

Figure 3.2: *Microphone sensitivity level (TSL) of the microphones per monitoring location in 2016. Missing values are caused by a (temporary) lack of coverage by the GSM network. Note that the actual monitoring period is indicated by a white background.*

Figure 3.1 and 3.2 show the TSL for all monitoring locations in 2015 and 2016 respectively within reach of the GSM network. At Egmond aan Zee TSL levels were low during consecutive days early August and mid-September 2015, which may have resulted in under recorded bat activity. However, in general the TSL values of the equipment within reach of the GSM network indicated no problems.

3.3 Date/time plots per monitoring location

The figures in this paragraph show the occurrence of bats in 10-min intervals per night throughout the monitoring season (time interval between sunset and sunrise is represented by grey) at the various monitoring locations. Different species (or species groups) are represented by different colours (Pnat = Nathusius' pipistrelle *Pipistrellus nathusii*, Ppip = Common pipistrelle *Pipistrellus pipistrellus*, Ppyg = Soprano pipistrelle *Pipistrellus pygmaeus*, Pipistrelloid = species group, includes genus *Pipistrellus*, Mdas = Pond bat *Myotis dasycneme*, Mdau = Daubenton's bat *Myotis daubentonii*, *Myotis* = species group, includes genus *Myotis*, Eser = Serotine bat *Eptesicus serotinus*, Nnoc = Common noctule *Nyctalus noctula*, Nlei = Leisler's bat *Nyctalus leisleri*, Vmur = Parti-coloured bat *Vespertilio murinus*, Nyctaloid = species group, includes genera *Nyctalus*, *Vespertilio*, *Eptesicus*. The actual monitoring period is indicated by a white background, whereas a pink background indicates no monitoring or recorder switched off.

Onshore monitoring locations

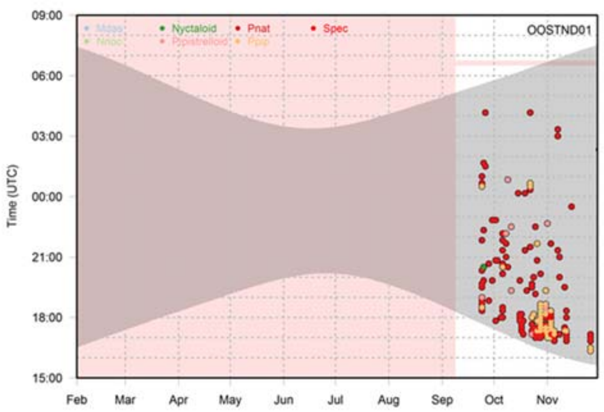

Figure 3.19 Oostende 2015

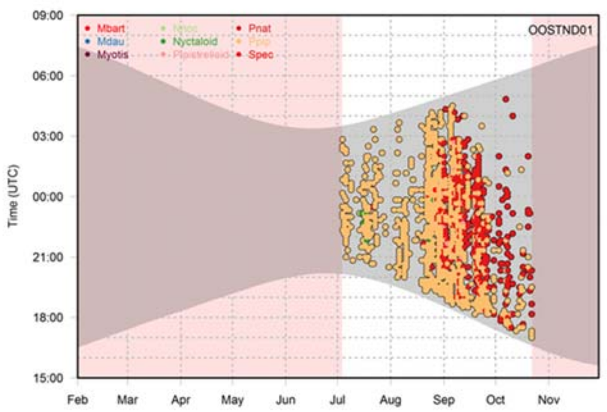

Figure 3.20 Oostende 2016

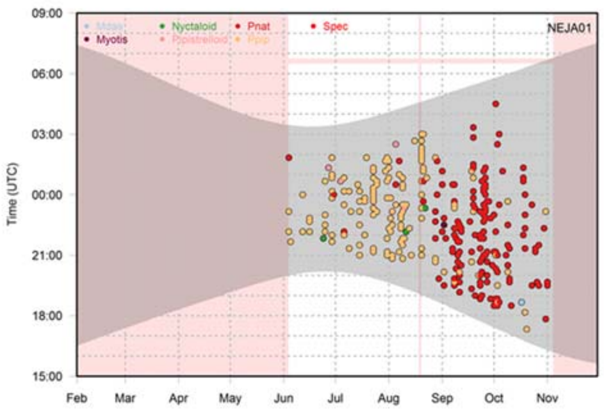

Figure 3.21 Neeltje Jans 2015

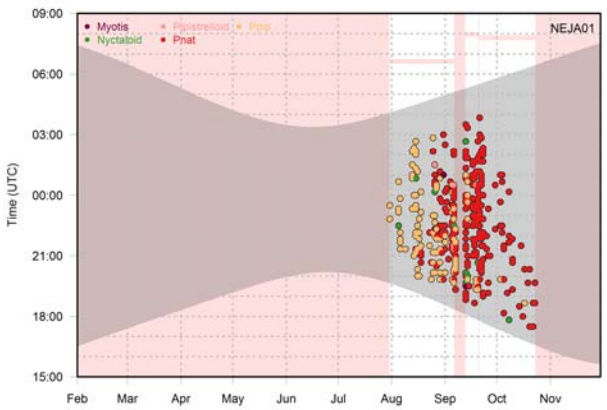

Figure 3.22 Neeltje Jans 2016

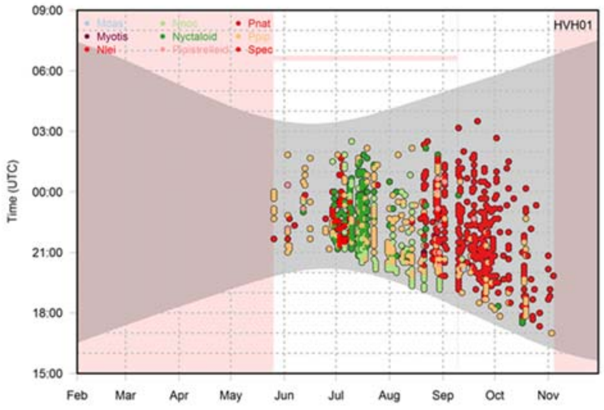

Figure 3.23 Hoek van Holland 2015

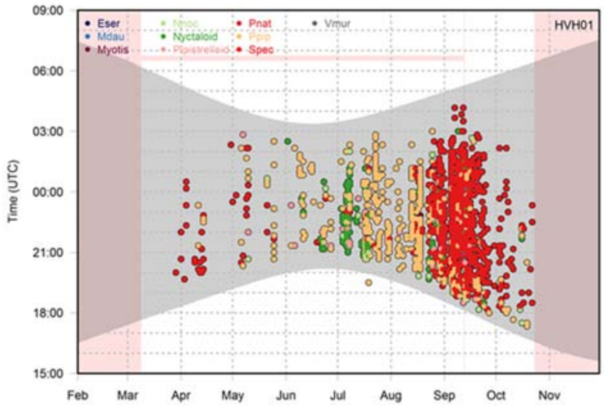

Figure 3.24 Hoek van Holland 2016

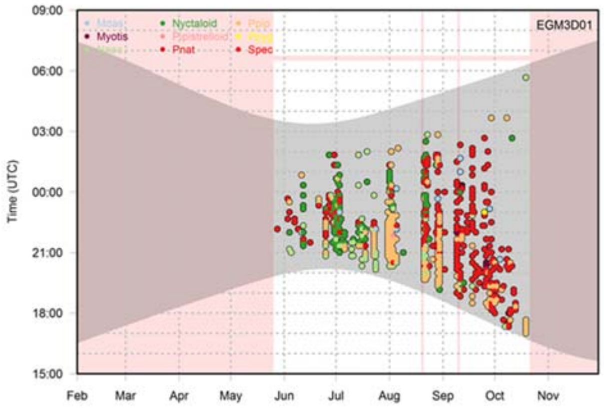

Figure 3.25 Egmond aan Zee 2015

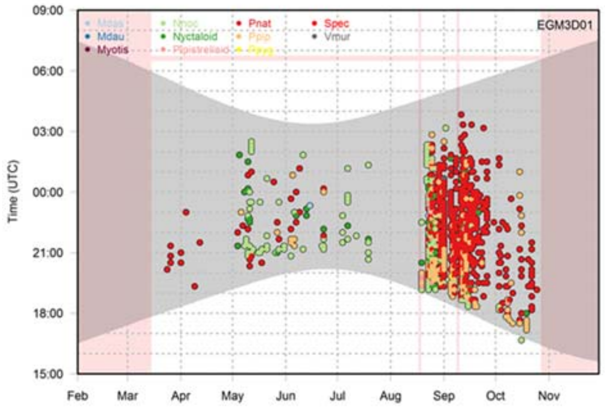

Figure 3.26 Egmond aan Zee 2016

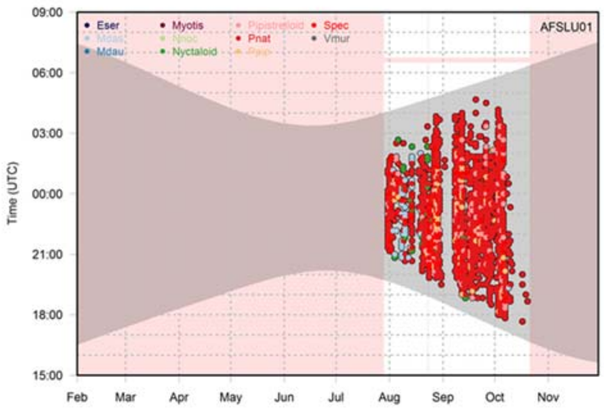

Figure 3.27 Afsluitdijk 2015

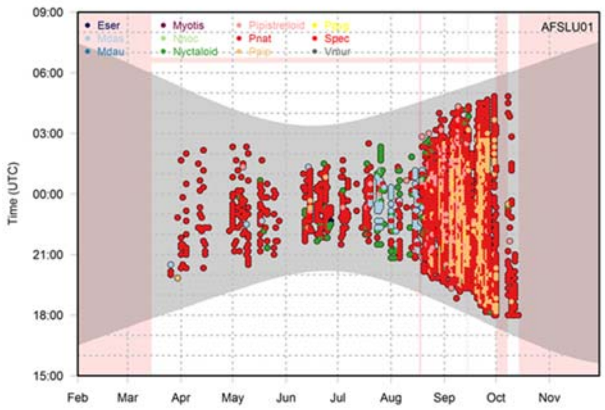

Figure 3.28 Afsluitdijk 2016

At the coastal locations bats are commonly recorded throughout the monitoring season and during the night. In the summer months Common pipistrelle is the dominant species, whereas Nathusius' pipistrelle is the most recorded species from late summer onwards and in spring. Nyctaloids (including Common noctule, Serotine & Particolored bat) are also recorded frequently, from early May until late October. Pond bats are regular in July and August at the Afsluitdijk, but rare elsewhere. Other *Myotis* species included a few scattered records of Daubenton's bats and one Whiskered bat *Myotis mystacinus* or Brandt's bat *Myotis brandtii* (Mbart) at Oostende (30-08-2016 23:22 UTC). Other rarities recorded during this study are Leisler's bat at Hoek van Holland (11-09-2015 00:55 UTC) and Soprano pipistrelles at Egmond aan Zee (25-09-2015 23:08 UTC & 06-09-2016 19:50 UTC) and at the Afsluitdijk (01-09-2016 21:34 UTC, 07-09-2016 23:54 UTC, 08-09-2016 00:30 UTC & 14-09-2016 22:03 UTC).

Noteworthy are the gaps (periods without bat activity) in the monitoring data (figure 3.19 – 3.28). These gaps are caused by their seasonal occurrence in general, periods with adverse weather conditions, but possibly also by the equipment. Especially the period mid-July – mid-August 2016 at Egmond aan Zee (figure 3.26) looks doubtful, as it is unlikely that bats were not present during such a prolonged time.

<u>Offshore monitoring locations</u>

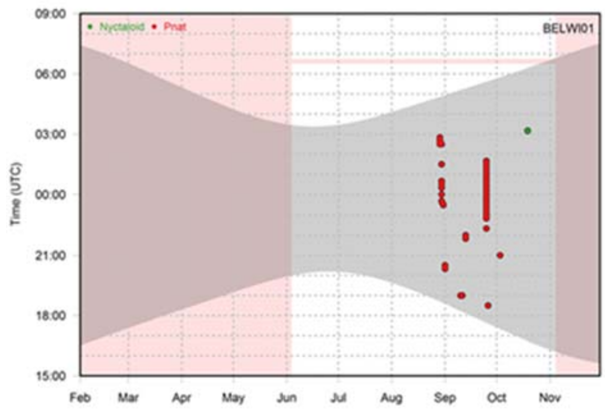

Figure 3.29 Date/time plot Belwind 2015

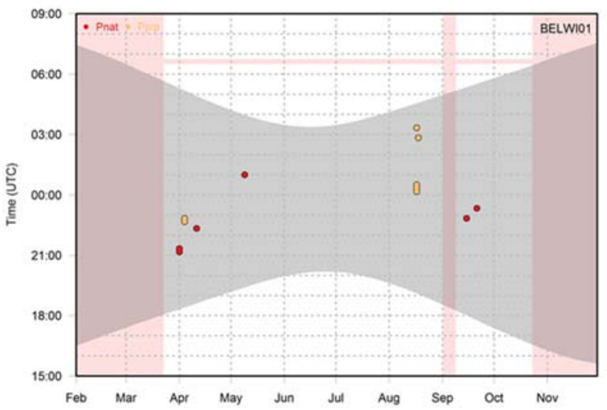

Figure 3.30 Date/time plot Belwind 2016

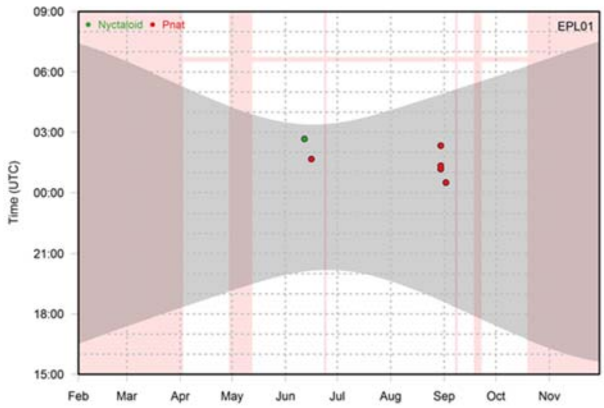

Figure 3.31 Date/time plot Europlatform 2015

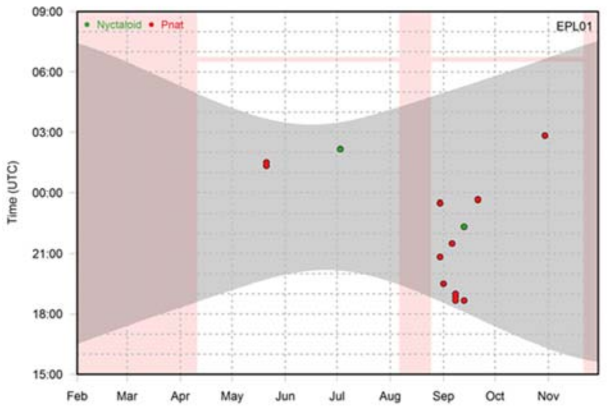

Figure 3.32 Date/time plot Europlatform 2016

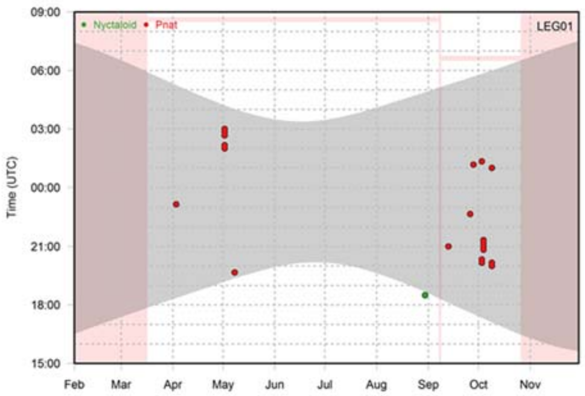

Figure 3.33 Date/time plot Lichteiland Goeree 2015

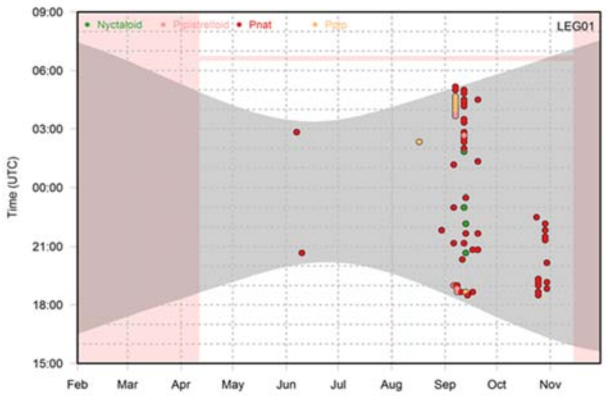

Figure 3.34 Date/time plot Lichteiland Goeree 2016

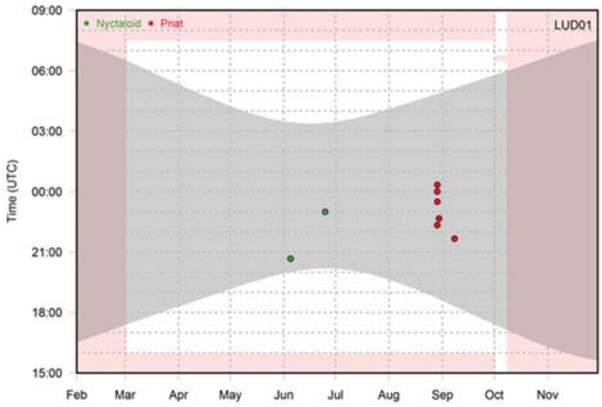

Figure 3.35 Date/time plot LUD OHVS 2015

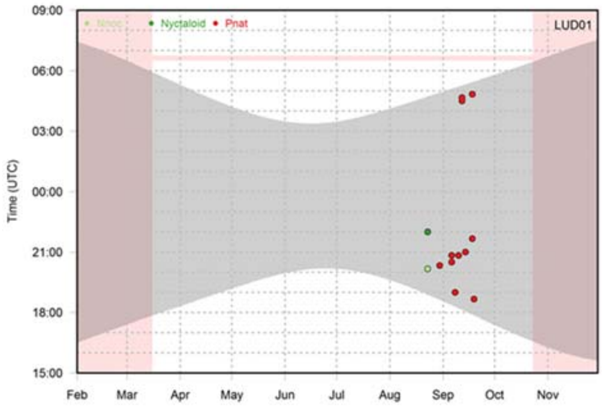

Figure 3.36 Date/time plot LUD OHVS 2016

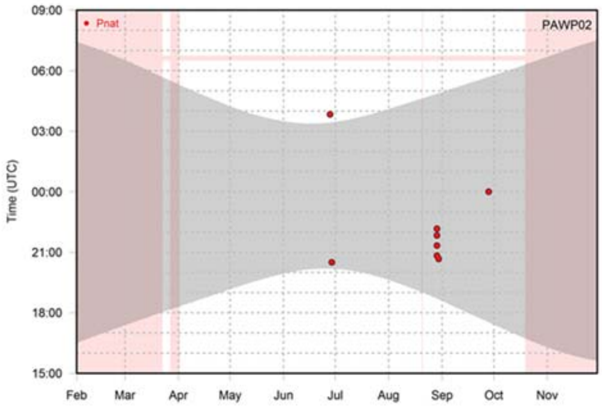

Figure 3.37 Date/time plot PAWP OHVS 2015

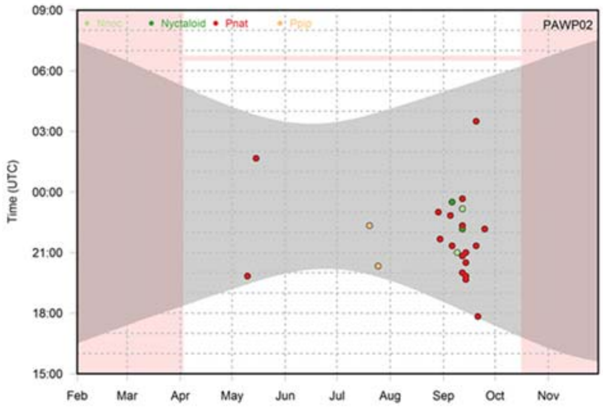

Figure 3.38 Date/time plot PAWP OHVS 2016

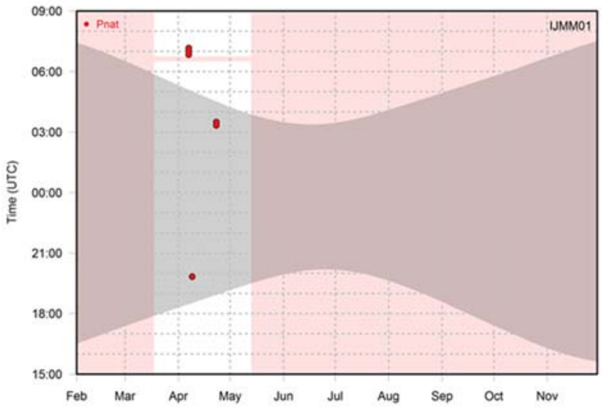

Figure 3.39 Date/time plot IJmuiden meteo mast 2015

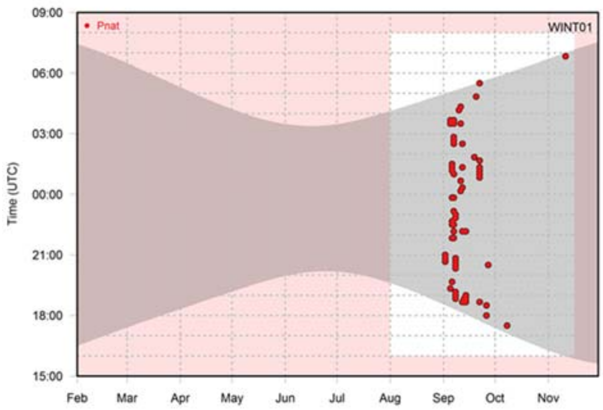

Figure 3.40 Date/time plot P6 Wintershall 2016

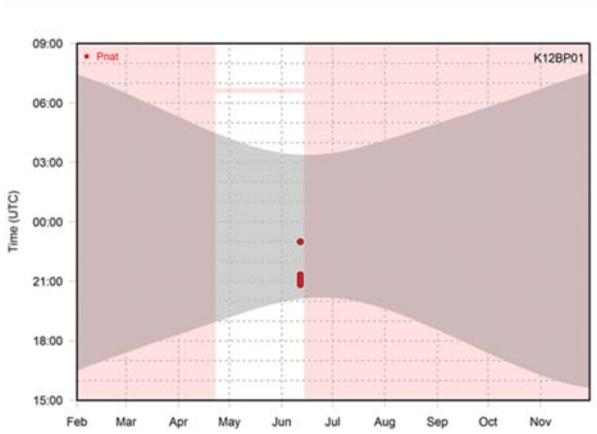

Figure 3.41 Date/time plot Engie K12-BP 2016

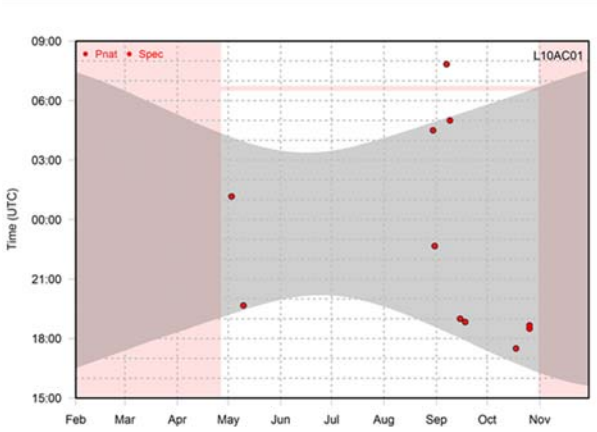

Figure 3.42 Date/time plot Engie L10-AC 2016

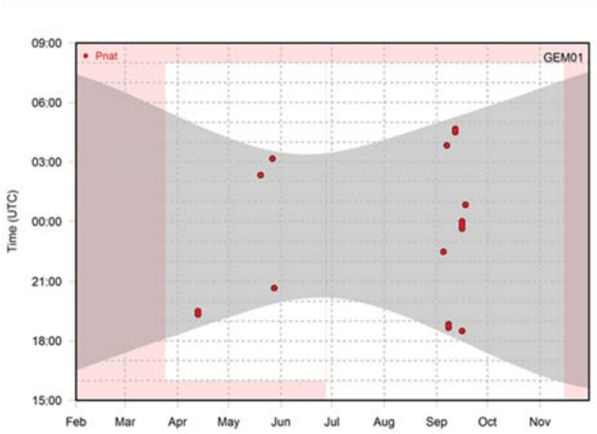

Figure 3.43 Date/time plot Gemini 2016

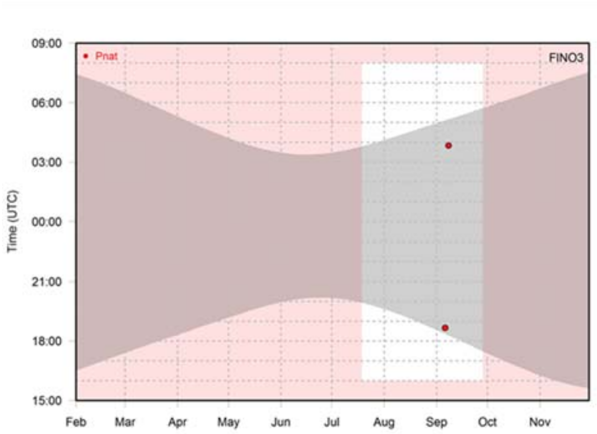

Figure 3.44 Date/time plot Fino3 2016

At sea there are only three species (groups) recorded, and there are significantly less recordings in comparison to the coast (figure 3.29 - 3.44). Nathusius' pipistrelle is by far the most frequently recorded species at sea, occurring mainly from late August until late October, and - to a lesser extent - from early April until the end of June. In some cases it is recorded early in the morning during daylight hours, up to three hours after sunrise, which indicates a late arrival at the monitoring location. A few times Common pipistrelle has been recorded (in April, July, Augustus and September) and Nyctaloids have been recorded from June until October.

3.4 Nathusius' pipistrelle

The barplots in this paragraph show the number of 10-min intervals in which Nathusius' pipistrelle has been recorded per night throughout the monitoring season for all onshore and offshore monitoring stations respectively. The actual monitoring period per monitoring station is indicated in the header by a white background, whereas a pink background indicates no monitoring or recorder switched off. Note that the scale of the Y-axis differs for onshore and offshore monitoring locations, and differs per season.

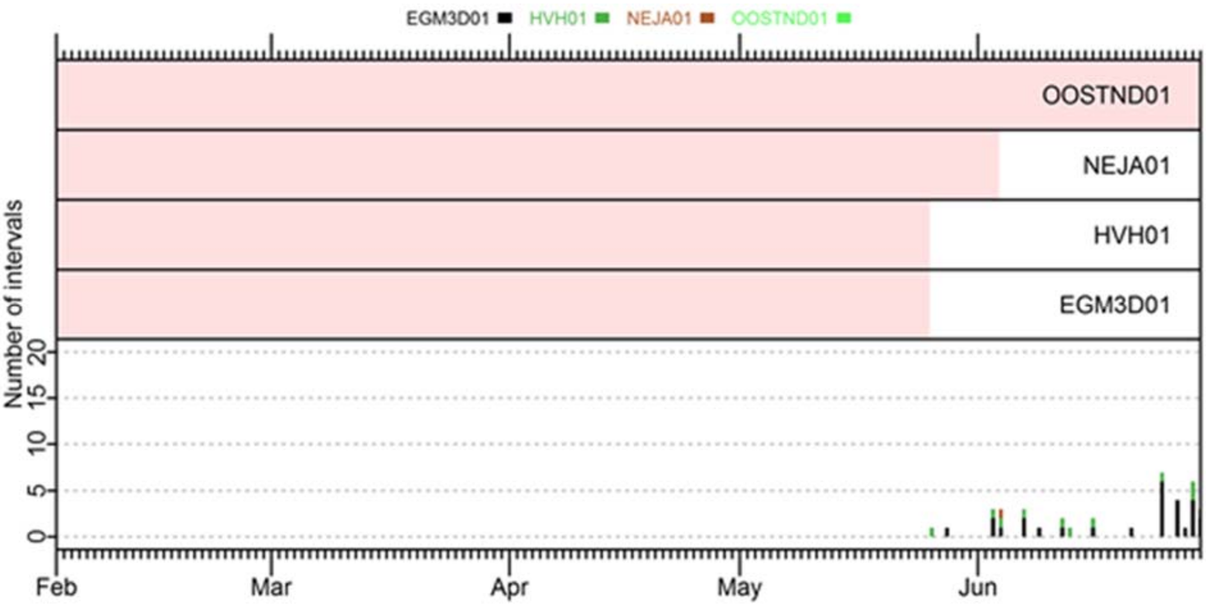

Figure 3.45 *Barplot of the number of 10 min intervals in which Nathusius' pipistrelle is recorded in spring 2015 for the onshore monitoring stations*

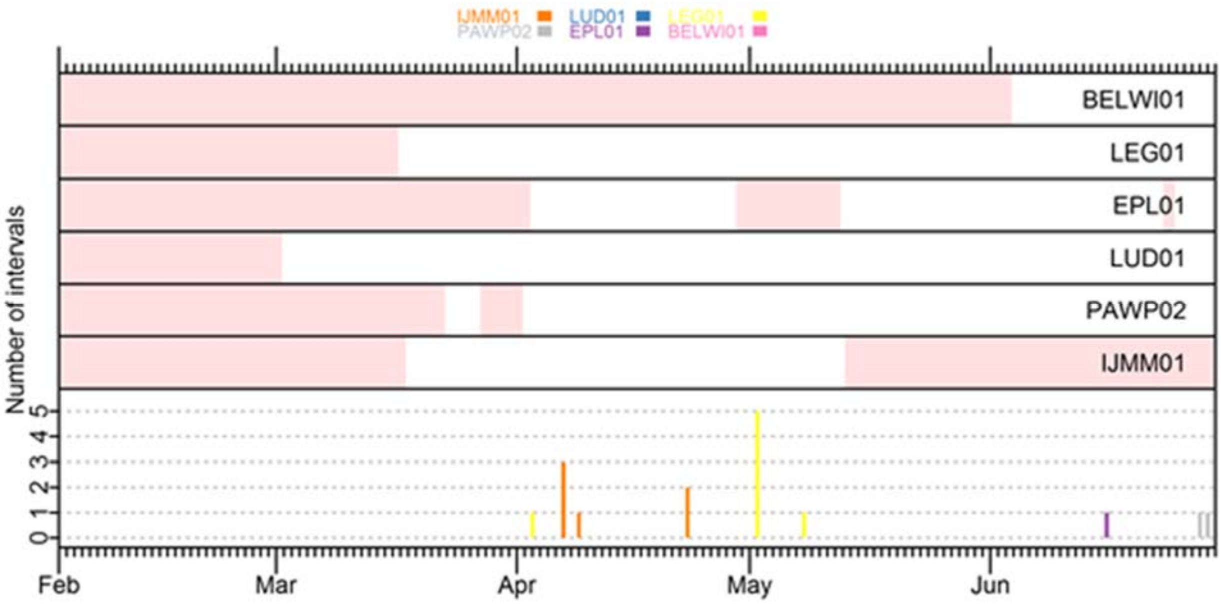

Figure 3.46 *Barplot of the number of 10 min intervals in which Nathusius' pipistrelle is recorded in spring 2015 for the offshore monitoring stations*

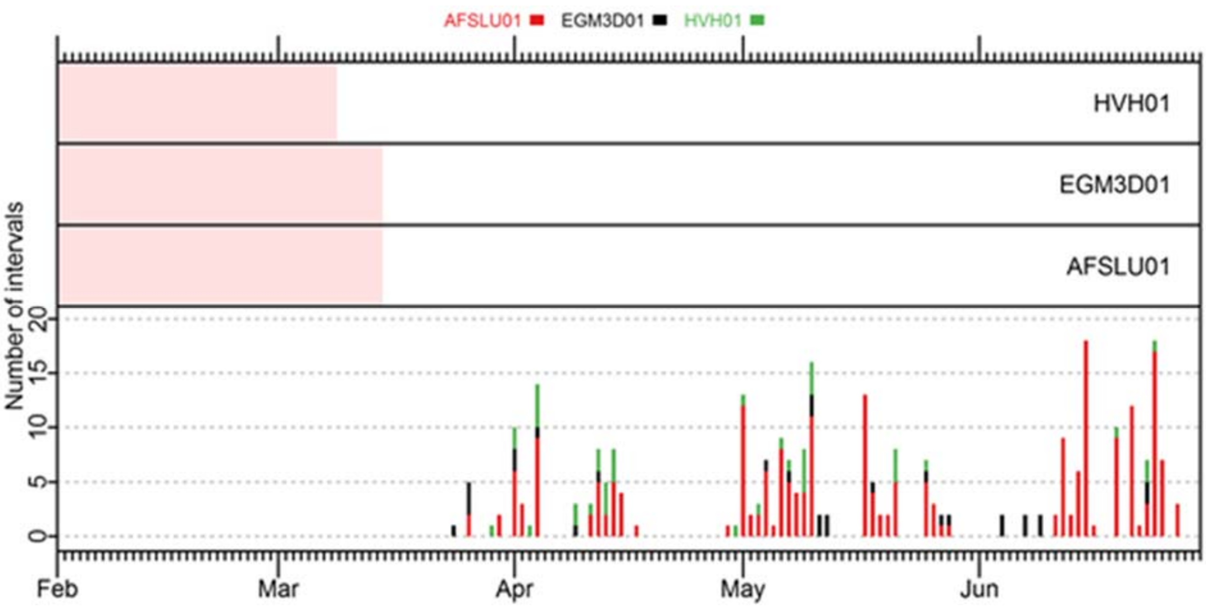

Figure 3.47 *Barplot of the number of 10 min intervals in which Nathusius' pipistrelle is recorded in spring 2016 for the onshore monitoring stations*

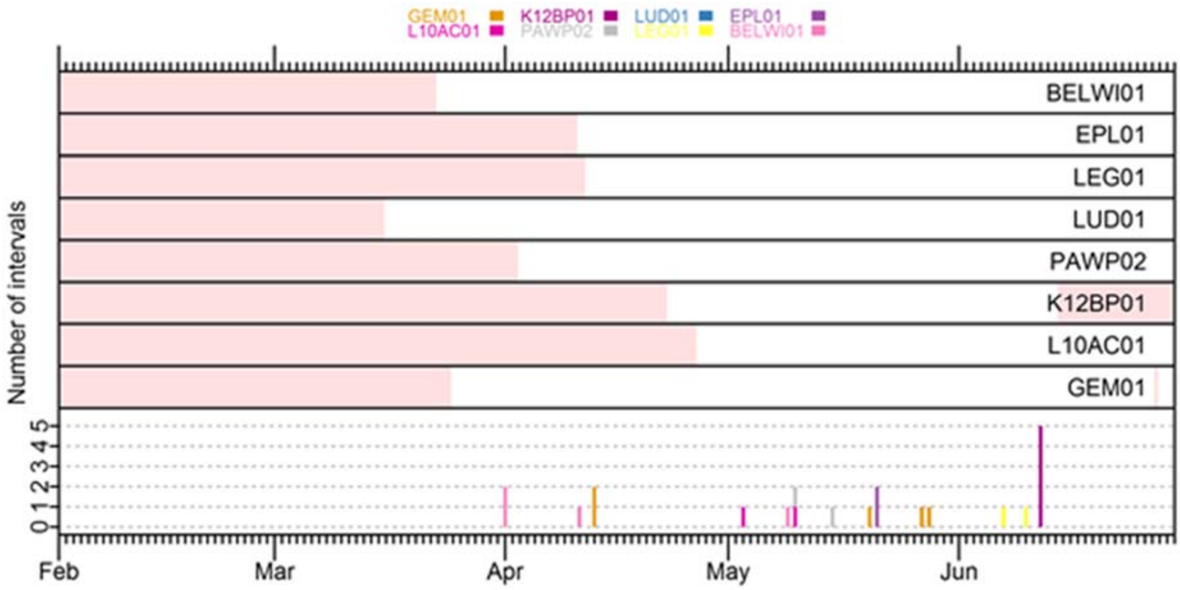

Figure 3.48 *Barplot of the number of 10 min intervals in which Nathusius' pipistrelle is recorded in spring 2016 for the offshore monitoring stations*

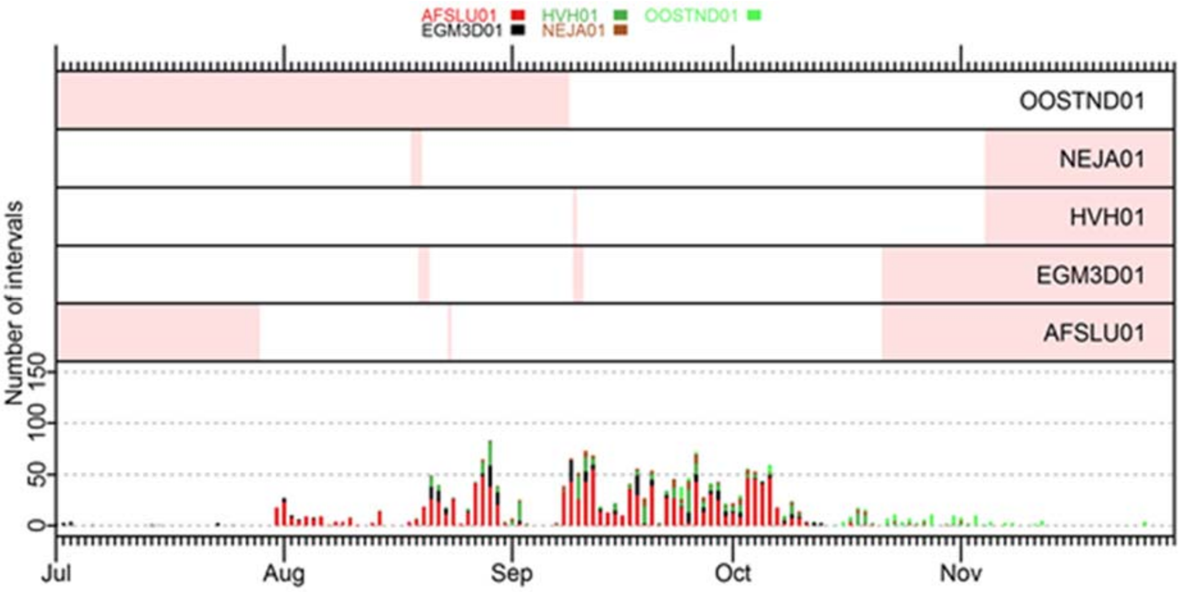

Figure 3.49 *Barplot of the number of 10 min intervals in which Nathusius' pipistrelle is recorded in autumn 2015 for the onshore monitoring stations*

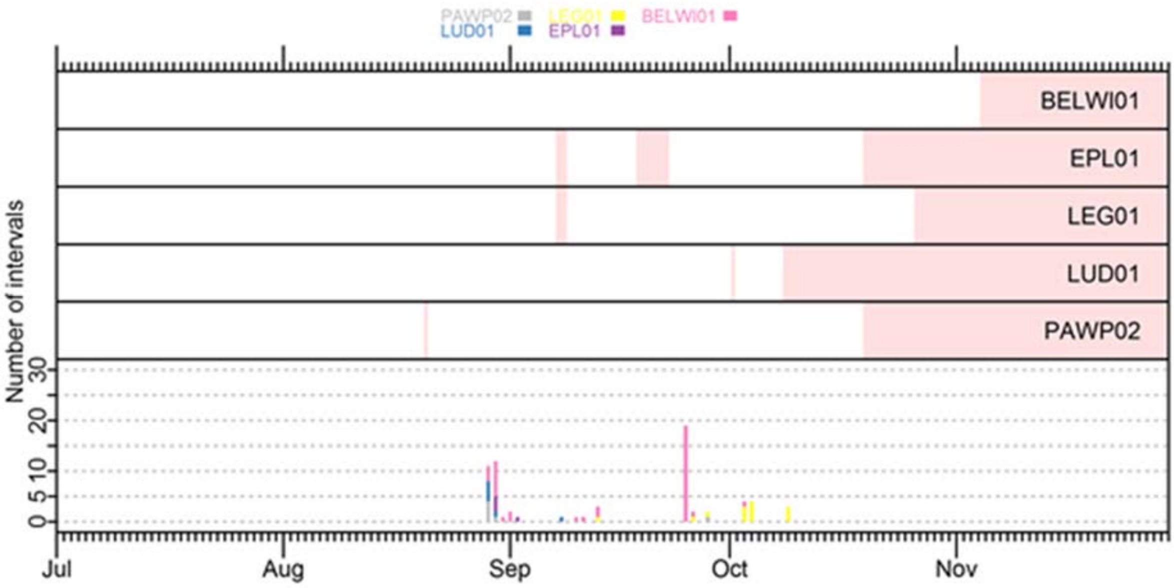

Figure 3.50 *Barplot of the number of 10 min intervals in which Nathusius' pipistrelle is recorded in autumn 2015 for the offshore monitoring stations*

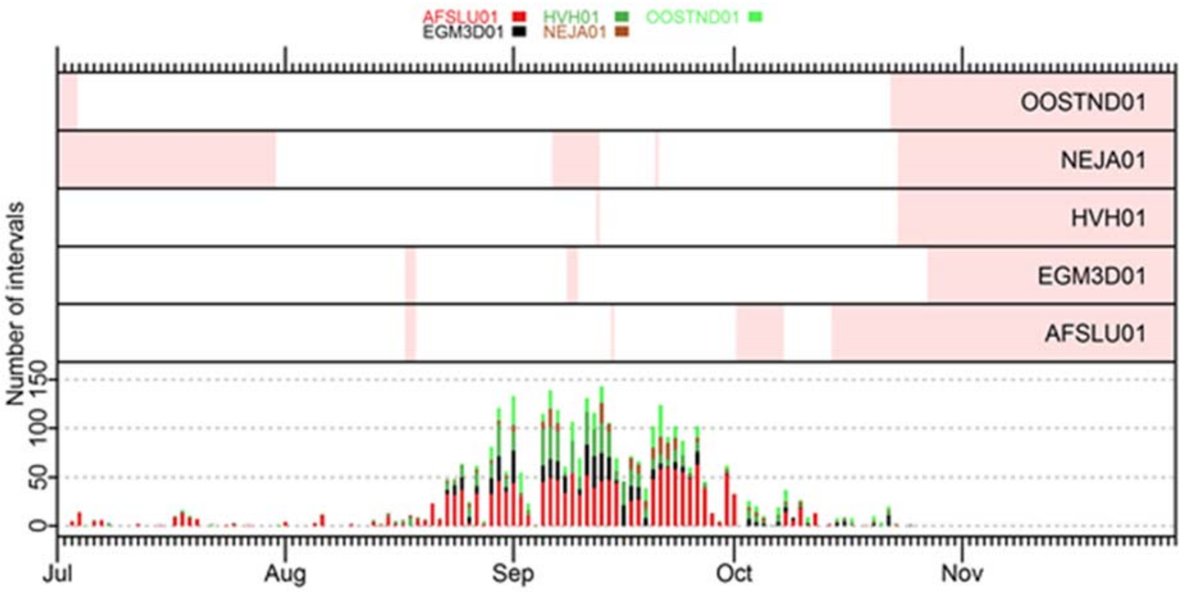

Figure 3.51 *Barplot of the number of 10 min intervals in which Nathusius' pipistrelle is recorded in autumn 2016 for the onshore monitoring stations*

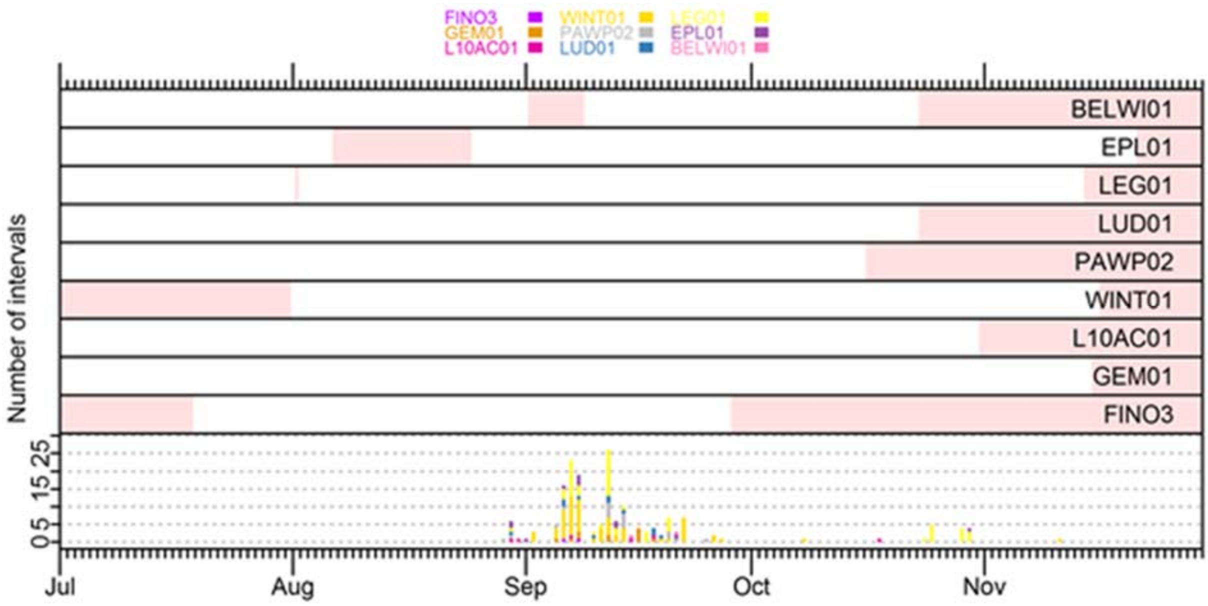

Figure 3.52 *Barplot of the number of 10 min intervals in which Nathusius' pipistrelle is recorded in autumn 2016 for the offshore monitoring stations*

The seasonal pattern of occurrence of Nathusius' pipistrelle on land and at sea is illustrated in the barplots (figures 3.45 – 3.52). On land the activity builds up late March and continues until late June. July until mid-August is the quiet period and the activity peaks late August until late September. Early October the activity flattens off rapidly and low levels of activity continue to at least mid-November. At sea the same general pattern is obvious, albeit in a much lower number of observations.

Figure 3.53 shows the hour intervals during the night in which Nathusius' pipistrelle has been recorded at the various distances from the coast. At the nearshore monitoring locations (Lichteiland Goeree, LUD and PAWP) bat activity peaks 3-5 hours after darkness, whereas at the offshore locations (Europlatform, Belwind, P6A and L10AC) bat activity starts often at dusk and slowly levels off during the course of the night. This is even more obvious if we fit GAM's to the nearshore and offshore dataset (Figure 3.54 & 3.55).

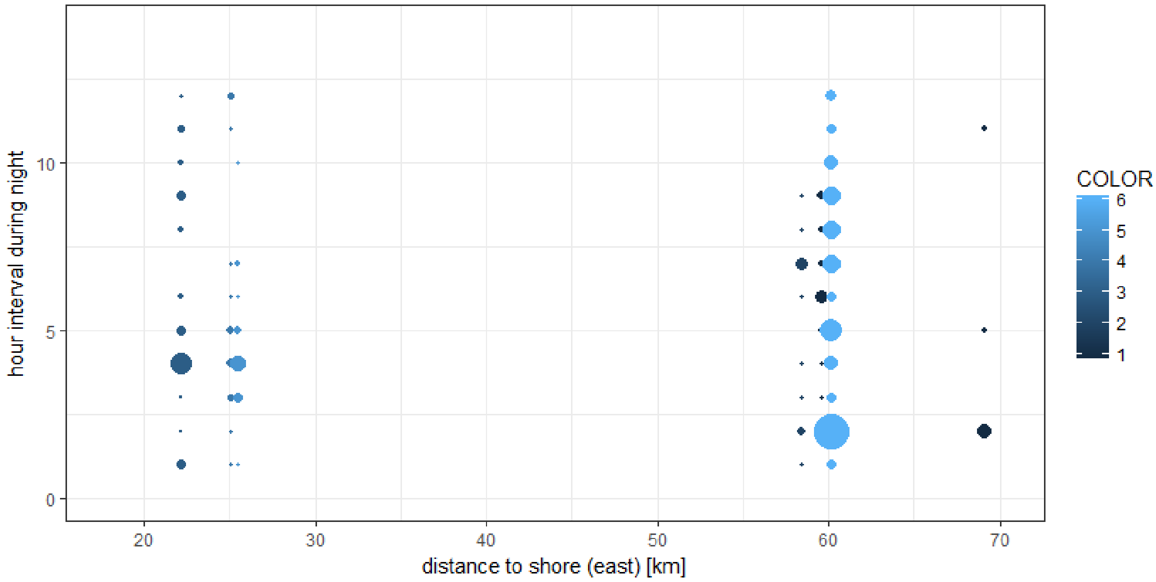

Figure 3.53 *Hour intervals during the night in which Nathusius' pipistrelle has been recorded. Note that the first and the last hour interval of the night include time before dusk and after dawn (depending on the night length). The dot sizes are proportional to the fraction of hours with recorded bat activity particular hour interval at a specific monitoring location. The different monitoring locations are indicated by different colors and are ranked by their distance to the coast (to the east). From left to right: Lichteiland Goeree, LUD, PAWP, Europlatform, Belwind, P6A and L10AC.*

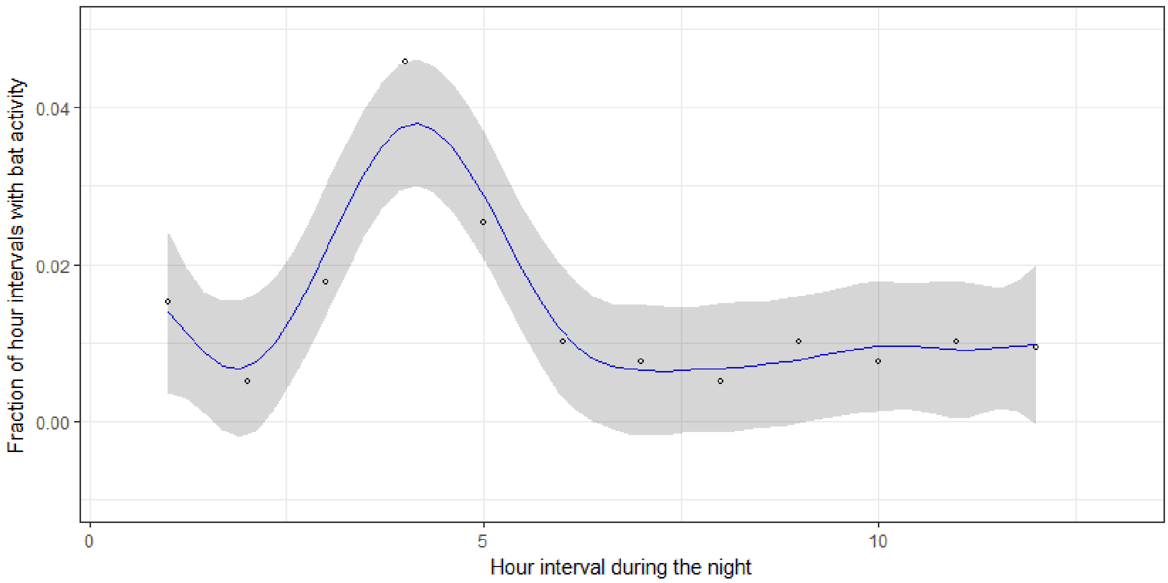

Figure 3.54 *Fraction of hour intervals during the night in which Nathusius' pipistrelle has been recorded at the nearshore monitoring locations (Lichteiland Goeree, LUD, PAWP). Note that the first and the last hour interval of the night include time before dusk and after dawn (depending on the night length).*

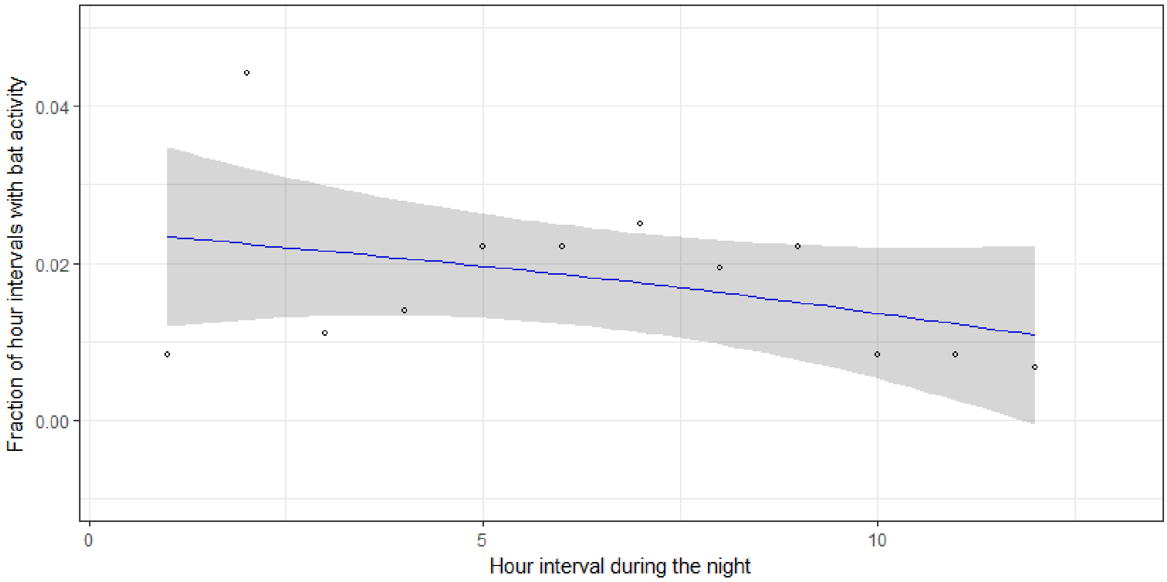

Figure 3.55 *Fraction of hour intervals during the night in which Nathusius' pipistrelle has been recorded at the monitoring locations further offshore (Europlatform, Belwind, P6A and L10AC). Note that the first and the last hour interval of the night include time before dusk and after dawn (depending on the night length).*

3.5 Statistical analysis

We analysed the presence/absence of *Nathusius' pipistrelle* per night from mid-August (night number 225) until late October (night number 295). We performed two separate analyses; one for the land-based stations and one for the offshore stations (with the exception of Fino3 and Gemini). In Table 3.2 the total monitoring effort per location is shown, including the number of nights with presence of Nathusius' pipistrelle.

Table 3.2 *Monitoring effort, period concerned and indication of bat incidence.*

No.	Location	Number of monitoring nights	Number of nights with Pnat	Percentage positives
LAND	Oostende	115	69	60%
	Neeltje Jans mast E-connection	133	77	58%
	Hoek van Holland radar mast 3	142	102	72%
	3D mast Egmond beach	137	78	57%
	Afsluitdijk	125	104	83%
	subtotal	**652**	**430**	**66%**
SEA	Belwind OHVS	135	12	9%
	Europlatform	84	8	10%
	Lichteiland Goeree	141	17	12%
	Luchterduinen OHVS	121	11	9%
	PAWP OHVS	134	12	9%
	Wintershall platform P6-A	71	16	23%
	Engie platform L10A-AC	71	5	7%
	subtotal	757	81	**11%**

Data-exploration

First we checked for zero-inflation in the response variable; the land dataset contained 34,1% zeros and the sea dataset 89,5% zero's. As a Bernouilli distribution was chosen for the response variable this amount of zeros did not imply an immediate concern for the analysis.

There were no obvious outliers in the covariates of both datasets. The covariate *visibility* was removed from the sea data as it appeared colinear with covariate *humidity*. After that all variance inflation factors were well under 3. Colinearity was also present in the land dataset, here the covariate *humidity* was colinear with *visibility* and was removed. XY plots showed an obvious non-linear pattern in the covariate *night in year* in both datasets.

Model selection

We modelled the response variable of the sea model (SM) as a function of the covariates *X-coordinate*, *Y-coordinate*, *night in year*, *moon illumination*, *cloud cover*, *atmospheric pressure*, *fraction of hours per night with rain*, *temperature*, *humidity*, *wind direction* and *wind speed*. For the land model (LM) *visibility* was also included as covariate. To capture seasonality in the model we included *night in year* as a thin plate regression spline. We used cyclic cubic regression splines for the covariates *wind direction*. A tensor product smooth was used for the *X and Y-coordinate* to capture spatial patterns. See Wood (2011) for background information on smoothers.

As a first step we used a generalized additive mixed model (GAMM) to evaluate the need for a dependency structure in the data by comparing the base models (one for each dataset) with alternative models; one model with a random effect (*monitoring location*), an additional alternative model with an AR1 (temporal) correlation structure (*night in year* per *monitoring location*), and eventually an alternative model with the random effect + the correlation structure.

Table 3.3 Evaluation dependency structure

SM	df	AIC	LM	df	AIC
Base model	16	6178.467	Base model	16	3762.861
Base model + random effect	17	6180.492	Base model + random effect	17	3767.952
Base model + temporal autocorrelation	17	6253.687	Base model + random effect + temporal autocorrelation	17	3806.380
Base model + random effect + temporal autocorrelation	18	6255.685	Base model + random effect + temporal autocorrelation	18	3815.960

Table 3.3 shows that both base models perform better than the alternative models (lowest AIC) and therefore we applied a generalized additive model (GAM) for both datasets (apparently no need for a dependency structure). We investigated which covariates in the fixed structure were important using backward selection based on a likelihood ratio test (Zuur *et al.* 2009). This resulted in dropping consecutively the covariates *humidity*, *fraction of hours per night with rain* and *atmospheric pressure* from the SM, and *atmospheric pressure* and *visibility* from the land model.

When the 'optimal' models were found (Table 3.4) validations were applied where we plotted the Pearson residuals against fitted values, and against each covariate in the model and not in the model. In addition, variograms were used to assess potential spatial and temporal autocorrelation in the Pearson residuals. There were no indications that model assumptions (independence, heterogeneity, and normality) are violated. Finally a graphical representation of the model was made using ggplot2 (Wickham 2009).

Table 3.4 Model selection results

Sea Model (SM)	Land Model (LM)
Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) -65.4398 20.9802 -3.119 0.00181 ** windspC -1.0879 0.2408 -4.518 6.24e-06 *** moonC 0.6880 0.2127 3.234 0.00122 ** tempC 0.8563 0.3111 2.753 0.00591 ** cloudsC 0.3198 0.1815 1.762 0.07810 . Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value te(XkmC,YkmC) 4.681 5.033 9.832 0.084403 . s(nightnrC) 8.917 8.992 30.316 0.000388 *** s(winddirC) 1.755 8.000 4.128 0.070104 . --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.293 Deviance explained = 36.7% UBRE = -0.51981 Scale est. = 1 n = 751	Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 1.2015 0.1311 9.164 < 2e-16 *** windspC -1.0948 0.1469 -7.450 9.30e-14 *** moonC 0.2941 0.1307 2.251 0.024398 * tempC 1.2934 0.2482 5.212 1.87e-07 *** cloudsC -0.6175 0.1714 -3.603 0.000315 *** rainC -0.3307 0.1408 -2.349 0.018847 * Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value te(XkmC,YkmC) 3.938 3.996 40.52 3.40e-08 *** s(nightnrC) 7.793 8.631 78.90 2.41e-13 *** s(winddirC) 3.001 8.000 19.74 2.57e-05 *** Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.442 Deviance explained = 39.6% UBRE = -0.16116 Scale est. = 1 n = 652

<u>Model equations, based on the original (non-standardized) covariates</u>

SM logit(Pi_i) = -68.86073
-0.46064 * windspeed_i
+ 1.92705 * moon illumination_i
+ 0.30297 * temperature_i
+ 0.11968 * cloud cover_i
+ te(X[km]_i, Y[km]_i)
+ s(nightnumber_i)
+ s(wind direction_i)

LM logit(Pi_i) = 0.22107
-0.53889 * windspeed_i
+ 0.82842 * moon illumination_i
+ 0.35625 * temperature_i
- 0.22203 * cloud cover
- 1.23390 * fraction rain_i
+ te(X[km]_i, Y[km]_i)
+ s(nightnumber_i)
+ s(wind direction_i)

The model quality of the LM is better than the SM as indicated by the null deviance explained (39.6% versus 36.7%), despite the higher number of monitoring nights of the SM.

Both models include the same smooth terms; the spatial term *te(XY)*, s(*night in year*) and *s(wind direction).* In the LM they are all highly significant, in the SM only s(night in year) is significant. Nevertheless, te(XY) and s(wind direction) are apparently also important covariates in the SM, otherwise they would have been dropped during the model selection. The parametric terms *wind speed*, *moon illumination* and *temperature* are significant in both models. The covariate *cloud cover* is significant in the LM and almost significant in the SM. The covariate *fraction of hours per night with rain* only occurs in the LM.

Graphical representation of the model

Graphical representations facilitate the interpretation of the models. In order to visualize the influence of individual covariates we can calculate the predicted values from the models using a range of values between the minimum and maximum observed value of that particular covariate and the mean value of the other covariates. The results are shown in Figure 3.56 – 3.44. The dots represent the actual monitoring data and the predicted values are shown including their 95% confidence intervals.

Wind

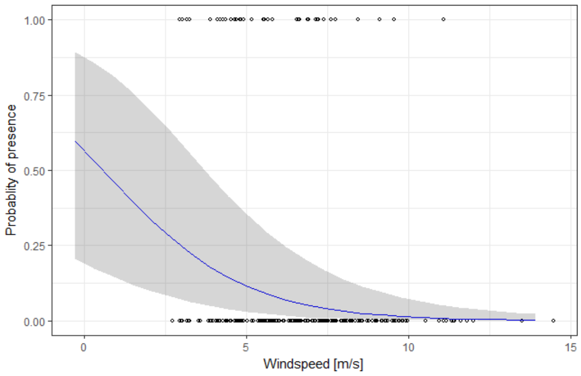

Figure 3.56 Probability of presence SM as a function of the covariate wind speed.

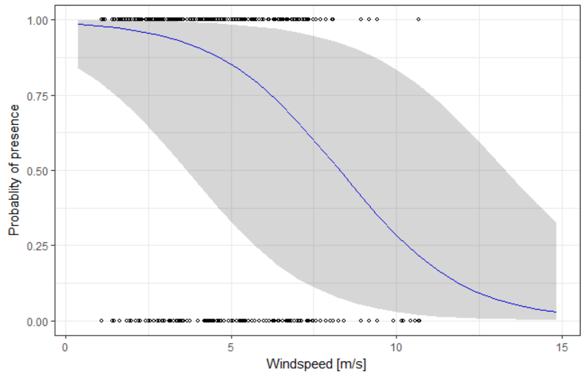

Figure 3.57 Probability of presence LM as a function of the covariate wind speed.

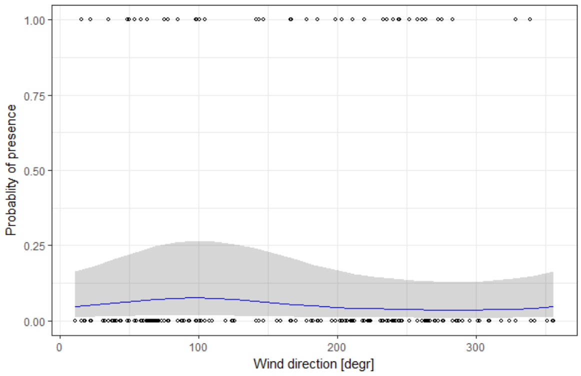

Figure 3.58 Probability of presence SM as a function of the covariate wind direction.

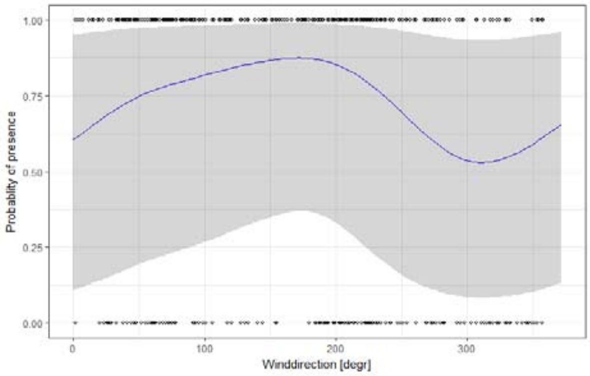

Figure 3.59 Probability of presence LM as a function of the covariate wind direction.

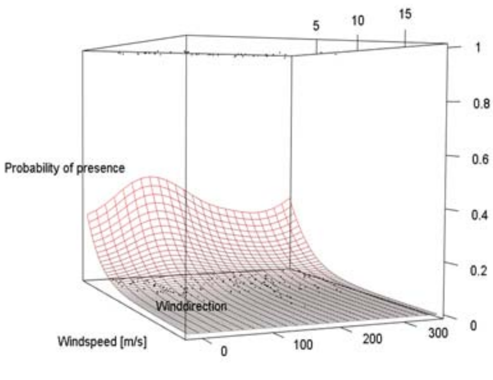

Figure 3.60 Probability of presence SM as a function of the covariates wind speed and wind direction.

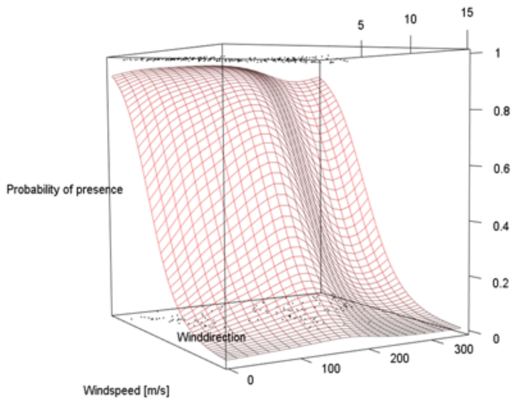

Figure 3.61 Probability of presence LM as a function of the covariates wind speed and wind direction.

The probability of presence decreases rapidly with increasing *wind speeds* in both models (Figures 3.56 -3.57). Note that the general probabilty of presence at sea is lower than on land and therefore the shapes of the curves differ. However, *wind speed* seems to have a similar effect on the presence of Nathusius' pipistrelle on land as at sea. Note also that *wind speeds* at sea less than 3 m/s are rare in the period concerned. Both models also share a *wind direction* influence, but the 'optimal' *wind direction* differs markedly (Figure 3.58 – 3.59). In the SM it peaks at 94 degrees (approximately east), whereas in the LM the peak is at 170 degrees (almost south). Figures 3.60 and 3.61 show the combined influence of *wind speed* and *wind direction*.

Night in year

Figure 3.62 and 3.63 represent the seasonal pattern of occurrence. On land the probability increases rapidly after mid-August (night number 230) and reaches a high level late August (around night number 243) that is maintained until late October (night number 295). At sea the occurrence is obviously more peaked in comparison to land. There seem to be two peaks in occurrence; one late August/early September and the second late September (note that the first migration wave at sea occurred almost two weeks later in 2016 compared to 2015 causing different peaks in Figure 3.62).

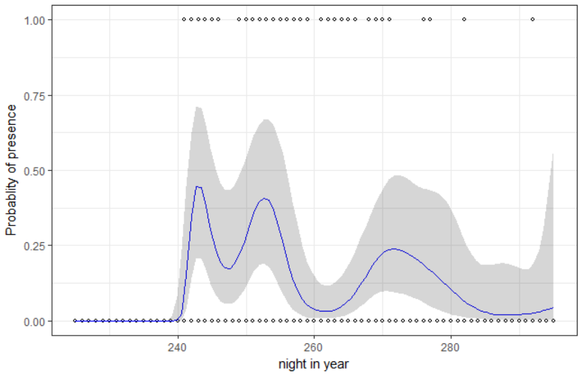

Figure 3.62 Probability of presence SM as a function of the covariate night in year.

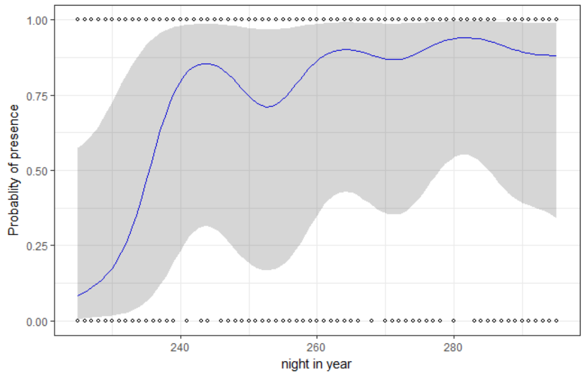

Figure 3.63 Probability of presence LM as a function of the covariate night in year.

Temperature

The probability of presence increases with increasing *temperatues* in both models (Figures 3.64 - 3.65).

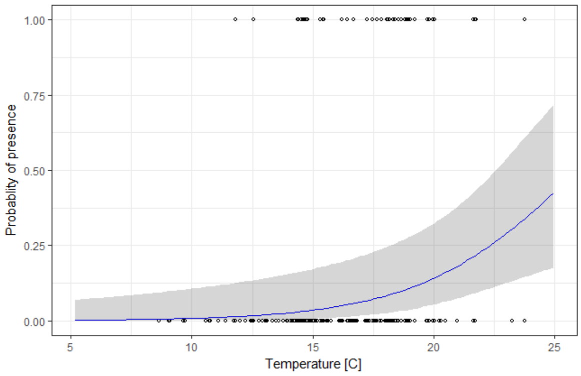

Figure 3.64 Probability of presence SM as a function of the covariate temperature.

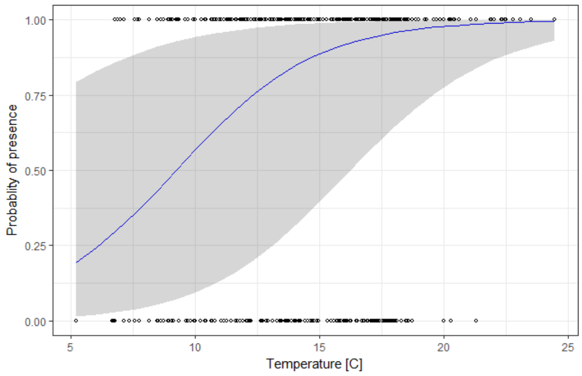

Figure 3.65 Probability of presence LM as a function of the covariate temperature.

Moon illumination

The probability of presence increases with increasing *moon illumination* in both models (Figures 3.66 - 3.67).

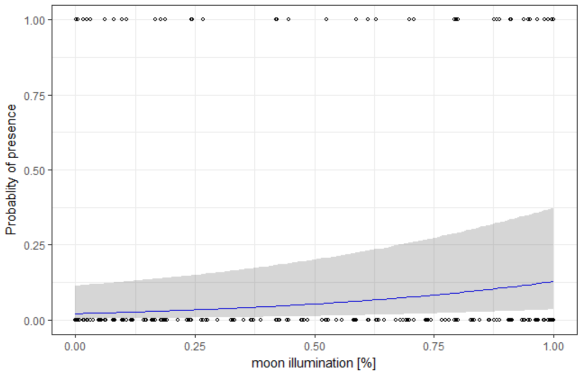

Figure 3.66 Probability of presence SM as a function of the covariate moon illumination.

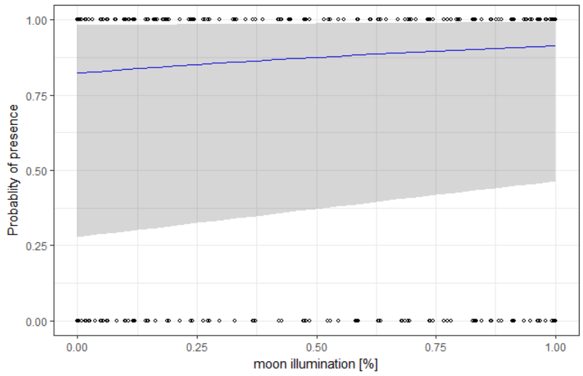

Figure 3.67 Probability of presence LM as a function of the covariate moon illumination.

Cloud cover

The probability of presence increases with *cloud cover* in the SM, but decreases in the LM (Figures 3.68 -3.69).

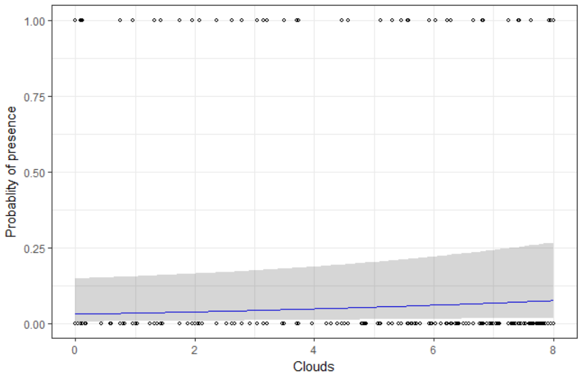

Figure 3.68 Probability of presence SM as a function of the covariate cloud cover.

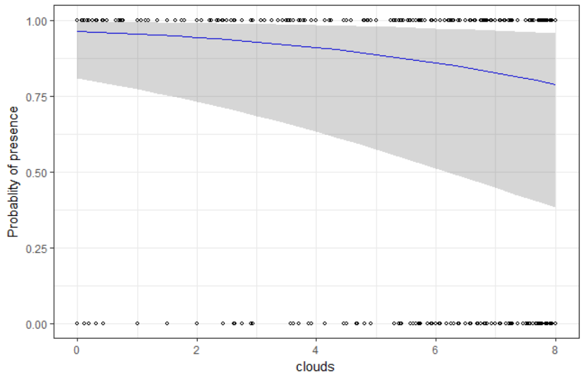

Figure 3.69 Probability of presence LM as a function of the covariate cloud cover.

Rain

The probability of presence decreases with the *fraction of hours per night with rain* in the LM (Figure 3.70). This covariate was dropped from the SM during the model selection.

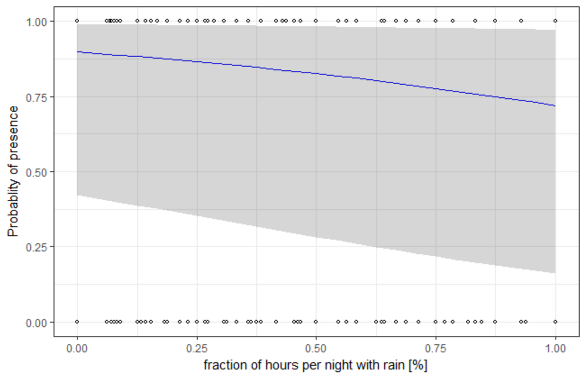

Figure 3.70 Probability of presence LM as a function of the covariate rain.

Figure 3.71 shows the probability of presence in relation to the spatial coordinates in a 'heatmap' for both the SM and the LM. The predictions of the LM are shown in a strip along the coast from the Afsluitdijk to the French border. The LM predicts 'everywhere' along the coast high probabilities of presence; in northern North Holland the predicted values are slightly smaller. The SM shows a rather odd spatial pattern. It predicts the highest probablities in the upper left corner of the study area. This is likely to be caused by the monitoring results at location P6-A and at L10A which lie next to this area. At P6-A bat activity was recorded during 23% of the monitoring nights wheares at L10A it was 7% (10% is the average for the other offshore locations excluding Gemini and Fino3). Therefore, it seems likely that the monitoring results at P6-A in combination with those at L10A 'lifted' the spatial field in the northwestern range of the study area.

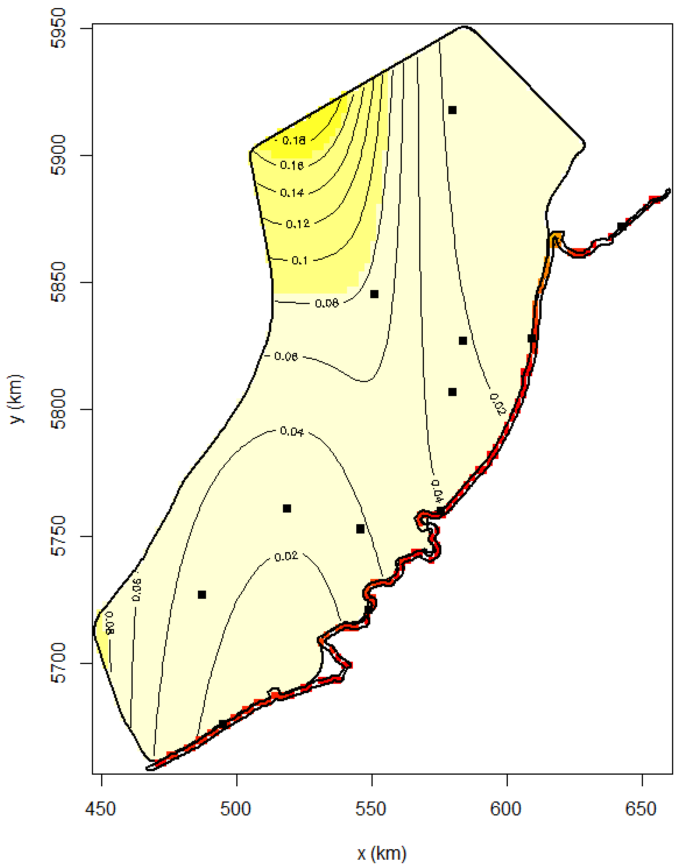

Figure 3.71*: Probability of presence SM + LM as a function of the covariates Xkm and Ykm. Note that the red/orange along the coast concerns model predictions.*

4 Discussion & Conclusions

4.1 Acoustic monitoring of bats

At this moment it is not possible to estimate the number of individual bats from individual call records or presence/absence data. Individual bats may trigger the detector multiple times and stay for a prolonged time at the monitoring locations, even during consecutive nights. It is also possible that multiple bats are detected at the same time. During the 2012 monitoring at OWEZ it was noted that up to three individuals were present simultaneously (Lagerveld *et al.* 2014b). Furthermore, bats can easily escape detection. The detection range of small bats like Nathusius' pipistrelle is rather limited (15-25 m) and offshore platforms are huge and have much more alternative habitat to explore besides the immediate vicinity of the detector. In addition, the sensitivity of the microphones of bat detectors decreases over time, especially when they are exposed to humidity (rain) and salt spray, and this can also be a cause for under-recorded bat activity.

Small bats, likely to have been Nathusius' pipistrelle, which have been seen during daylight hours at open sea (n=3) flew between 5-20 m altitude (Lagerveld *et al.* 2014b) and Ahlén *et al.* (2009) observed that most bat activity at the Baltic Sea occurs below 10 m. On land an average migration height of 11.5 m has been reported for Nathusius' pipistrelle (Šuba 2012). However, Hatch *et al.* (2013) photographed several Eastern red bats (*Lasiurus borealis*) at heights of over 200 m at sea off the American east coast, and suggested that bats use supporting tailwinds at greater heights when crossing over sea. Therefore, we cannot exclude the possibility that bats may fly at heights beyond the range of the detectors which have been mounted between 15 – 26 m above sea level, in particular the high-flying species (Nyctaloids). Unfortunately the 'high' detector at the IJmuiden meteo mast could not be installed during this study and therefore we still lack offshore monitoring data at hub-height.

4.2 Spatiotemporal occurrence of Nathusius' pipistrelle

The breeding areas of Nathusius' pipistrelle are located in (north)eastern Europe. Late summer these areas are abandoned and the females and juveniles migrate to southern and western Europe. The males are more sedentary, they do migrate but in general stay in the southern/western part of the species-range after their first calendar year. The mating season coincidences with the autumn migration and males wait for the females along the migration routes. After the mating season the males follow the rest of the population to their winter quarters (Limpens *et al.* 2007). Nathusius' pipistrelle is the most common migratory bat species in the Netherlands. The migration direction of individuals passing through western Europe appears to run from ENE to WSW in autumn and vice versa in spring (Hüppop & Hill 2016). Bats migrating over sea wait for favourable conditions to cross (Ahlén *et al.* 2009).

The monitoring results at the coast showed that Nathusius' pipistrelle is very common during both spring and autumn migration, but is also regular throughout the summer. Most bat activity was recorded at the Afsluitdijk, which is known to be an important migration corridor in the Netherlands (Leopold *et al.* 2014).

Nathusius pipistrelle was the most frequently recorded species at sea. During this study it was recorded from late August until late October (and one observation in November). It was also recorded - to a lesser extent - from early April until the end of June. There were no records in July until mid-August. The observed pattern of occurrence matches previous offshore monitoring studies in the German and Dutch North Sea (Hüppop & Hill 2016, Jonge Poerink *et al.* 2013, Lagerveld *et al.* 2014a, 2014b & 2015) and also corresponds to the findings of Boshamer & Bekker (2008), Petersen *et al.* (2014) and Walter *et al.* (2007).

The timing of migration is essential for migratory animals. By choosing the right moments for departures and stopovers migratory animals may reduce energy costs and fatality/predation risks. In addition, environmental conditions are important for the ability to navigate and orientate. Therefore, these conditions play an important role in the migration strategy of bats and other animals. During migration, large water bodies act as ecological barriers for many species and consequently funnelling takes place along the coast and along peninsulas/dikes. This effect is intensified when crosswinds push the migrating animals, and possibly also foraging individuals from local populations, to the coast.
We analysed the presence/absence of Nathusius' pipistrelle per night from mid-August until late October. In this period bat activity was recorded during 11% of the nights at sea and at and 66% of the nights at the coast. The higher number of nights at the coast may reflect the relative proportion of bats migrating at the coast and over sea, but the numbers at coast are likely to be higher caused by funnelling, whereas migration over sea is likely to follow a broad front due to the absence of guiding landscape features. However, locally densities at sea may be also inflated as bats are attracted to offshore structures (Ahlén *et al.* 2009). Consequently, based on bat detector-data we cannot estimate the proportion of bats migrating along the coast and over sea.

We developed one statistical model for the offshore stations (SM) and one for the land-based stations (LM) in which we modelled the presence/absence per night as a function of various weather parameters, the moon illumination, the spatial coordinates and the night in year.

Wind speed seems to be the most important predictor for the occurrence of Nathusius' pipistrelle in autumn at sea and at the coast. Their occurrence peaks at low to moderate wind speeds and occurrences with wind speeds over 8 m/s are scarce. This corresponds with the findings of other studies, e.g. Baerwald & Barclay (2011), Brinkmann *et al.* (2011).

Next, the *night in year* is also very important due to the seasonal occurrence of Nathusius' pipistrelle. At the coast their presence increases rapidly from mid-August and continues to be high subsequently. At sea the occurrence is strongly peaked. The first wave of migrating animals occurs in late August/early September and the second late September. Their actual timing can differ between years.

In both our LM and SM, *temperature* is an important predictor for the presence of bats at the coast and at sea. High temperatures increase significantly the recorded bat activity. This results corresponds what is known from land-based studies (e.g. Brinkmann *et al.* 2011).

Wind direction is also important, at sea wind directions between NE and SE (with a peak at 94 degrees) result in highest activity, whereas this is the case with wind directions between E and SW (with a peak at 170 degrees) at coastal locations. As the Dutch/Belgian coastline runs generally between NNE/SSW and ENE/WSW the optimal LM wind direction (170 degrees) is likely to cause funnelling of migrating and foraging individuals from local populations along the coast. The observed optimal wind direction at sea (94 degrees) implies that bats crossing over sea are associated with tailwind, as suggested by Hatch *et al.* (2013). Interestingly, this contradicts the findings of Hüppop & Hill 2016, who observed that bats mainly occur during crosswinds (from the south) implicating that wind drift causes their occurrences at Fino1 in the German Bight.

We also found a *moon illumination* effect in both models. Increasing moon illumination raised the probability of presence at sea and at the coast. High levels of moon illumination may be beneficial for orientation and navigation during migration. However, this contradicts the findings of Cryan & Brown (2007) who concluded that low moon illumination was an important predictor for arriving and departing bats on Southeast Farallon Island, 32 km off the coast of California.

Rain affects the energy expenditure during flight (Voigt *et al.* 2011) and the availability of prey (Winkelman et al. 2008). In the LM the covariate *rain* reduced probability of the presence of bats, like in other land-based studies (e.g. Brinkmann *et al.* 2011). Bats departing from the coast in good conditions may encounter rain when crossing over sea and consequently may seek refuge at the monitoring locations (offshore platforms) during rain. In fact, Hüppop & Hill 2016 recorded most bat activity at Fino1 at the German Bight in rainy or at least overcast conditions. In contrast, we did not find an effect for rain at sea since it was dropped from the SM during the model selection (due to occurrences with and without rain).

Cloud cover was negatively correlated with the recorded presence of bats at sea, in contrast to the findings of Cryan & Brown (2007) and (Hüppop & Hill 2016) who mainly recorded bats in cloudy conditions offshore. At the coast cloud cover was positively correlated with the presence of bats.
The SM indicates higher probabilities of presence in the northwest corner of the study area. However, we think that this is an artefact caused by the limited number of non-zero observations in the overall dataset (81 out of 757), in combination with the high number of nights with bat activity at P6A (23%) and the low number of nights with bat activity at L10AC (7%) and the other monitoring locations further south (average 9%). We therefore do not consider this predicted spatial pattern reliable. At this moment we cannot draw firm conclusions concerning the high number of bat-nights at P6-A, as we only monitored there during autumn 2016. It may be just be a coincidence, but it is also possible that a spatial pattern of occurrence at sea is present. For example if bats follow their general migration direction (WSW) after leaving the Afsluitdijk they will pass closely to P6-A.

The recorded bat activity at nearshore monitoring locations (between 22 and 25 km from the coast) peaks approximately 4 hours after dusk. It seems likely that these animals departed the same night from the coast. However, bat activity at the offshore locations (between 58 and 69 km from the coast) starts often close to dusk. As Nathusius' pipistrelle is known to leave its roost at dusk (Dietz et al 2007) and their directional flight speed ranges between 40 and 47 km/h (Šuba 2014), it is clear that these animals must have spent the day at the monitoring location at sea, or in its vicinity. This pattern of occurrences was also noted during the 2014 offshore monitoring (Lagerveld *et al.* 2015). Furthermore, this pattern of occurrence means that the observed bat activity at a particular night may depend on their departure decision in the previous night, or even earlier. This temporal autocorrelation which is present in the dataset was not detected when evaluating different autocorrelation structures during the development of the SM, and temporal autocorrelation was also not detected in the residuals of the SM.

<u>Other species</u>
Common pipistrelle, a resident non-migratory species (Dietz *et al.* 2007), was occasionally recorded offshore with some scattered records in April, July, Augustus and September, whereas it was common at the coast throughout the monitoring season.

Nyctaloids (including two records of Common noctule) were recorded uncommonly offshore from late August until October and a few records in June and July. This corresponds to the offshore pattern of occurrence reported previously (Jonge Poerink *et al.* 2013, Lagerveld *et al.* 2014a, 2014b & 2015, Leopold *et al.* 2014). Note that in addition to Noctule, other species of Nyctaloids have been reported at sea: Particoloured Bat, Leister's Bat, Northern Bat and Serotine Bat (Boshamer & Bekker 2008, Hüppop & Hill 2016, Lagerveld *et al.* 2014b & 2015, Leopold *et al.* 2014, Petersen *et al.* 2014, Walter *et al.* 2007). Nyctaloids at the coast identified to species level concerned mainly Common noctule, but included also some Particolored, Serotine and Leisler's Bat. Nyctaloids were recorded regularly from early May until late October at the coast.

Myotis species identified to species level included Pond bats, which were regular in July and August at the Afsluitdijk (seaside), but rare elsewhere along the coast and were never recorded offshore. There were also a few coastal records of Daubenton's bats. This pattern of occurrences of these Myotis species is in line what previously has been described by Lagerveld *et al.* (2015) and Leopold *et al.* (2014).

4.3 Quality of the models

We developed two different models, one for sea (SM) and one for land (LM) in which we modelled the presence/absence of Nathusius' pipistrelle at night as a function of environmental covariates. The LM included 652 monitoring nights including 430 nights with bats recorded (66% of the data), whereas the SM included 757 monitoring nights including 81 nights with bats (11% of the data).

Due to the amount of non-zero observations the model fit of the LM is better than the model fit of the SM. This is also indicated by the fact that all covariates in the LM became significant during the model selection (wind speed, wind direction, moon illumination, temperature, cloud cover, rain, night in year and the spatial term), whereas the model selection of the SM resulted in 4 significant covariates (wind speed, moon illumination, temperature and night in year) and 3 almost significant terms (wind direction, cloud cover and the spatial term). There are also two other indications for a non-optimal model fit of the SM. In the first place we detected temporal autocorrelation in the data which was not detected when evaluating temporal correlations structures and which appears to be absent from the residuals. Next, the predicted spatial field appears to be unreliable. This is likely to be caused by a limited amount of positives in the data, in combination with a limited number of monitoring locations.

The models do not include information on the availability of insects which can move in large numbers over sea and other areas (Chapman *et al.* 2004, Drake & Reynolds 2012, Teunissen & Veling 2013). As bats use a fly-and-forage strategy during migration (Šuba *et al.* 2012) the availability of insects may affect the departure decision of bats crossing over sea. Therefore, the quality of the models may be improved by including information on insect abundance as an additional covariate.

4.4 Function of the study area for bats

The results of this study show that the occurrence of bats at sea is highly seasonal which indicates that individuals recorded at sea are on migration. The peak period runs from late August until the end of September. After that it levels off throughout October. Spring migration is much less pronounced but the duration seems to be quite extensive; from late March until the end of June. Records of bats at sea in July and early August are rare. At the coast bats are much more common in general and their presence is both shaped by migratory movements and the presence of local populations (e.g. Common pipistrelle).

The occurrence of Nathusius' pipistrelle in autumn at sea is associated with low or moderate tailwinds; therefore it seems unlikely that wind drift or storms cause its presence off our western coastline. However, wind drift may be the main cause of the occurrence of bats north of the Wadden Islands as indicated by Hüppop & Hill (2016).

4.5 Recommendations

The relevant period to consider the presence of bats at sea off the western coast of the Netherlands and Belgium seems to be from 15 March until 30 June and from 15 August until 31 October, whereas bats should be considered throughout the entire active season at the coast.

Based on the monitoring results of the 2012 – 2014 studies, a precautionary mitigation measure was issued using 5 m/s as cut-in wind speed for the wind farms in the Borssele area in the period 15 August until 1 October. The current study, however, shows that other environmental parameters, in addition to the wind speed, are important as well. The model developed in this study is likely to predict the presence of bats at sea more accurately, despite the fact that the model may also still be improved.

In order to improve the SM it is recommended to gather more data and continue monitoring offshore. In addition, monitoring should be done in a denser grid to assess potential spatial patterns at sea, especially near the P6-A platform where bat densities might be higher than elsewhere. It is expected that more data with a better spatial coverage will result in a significantly better model to predict bat activity at sea. A continuation of the monitoring may eventually also enable the development of a model which predicts bat activity in spring. Another improvement of the model may be the incorporation of a temporal autocorrelation structure and adding the covariate insect availability. Using R-INLA may also be an improvement as the smoothers in this package are less likely to produce artefacts in the predicted spatial pattern (Rob van Bemmelen pers. comm.).

Currently the model predicts the presence/absence per night. As the next step the model may be extended with information on the actual bat activity per night, e.g. based on the number of individual recordings. Although there is no direct relation between the number of recordings and the number of individual bats (paragraph 4.1), the number of recordings may be a more suitable indicator to assess eventually the number of fatalities at sea.

The model predictions are based on monitoring data which are gathered at heights between 15 – 26 m above sea level. There are indications that bat migration occurs at altitudes beyond the detection range of the recorders and therefore we urgently need monitoring data from higher altitudes.

5 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2008 certified quality management system (certificate number: 187378-2015-AQ-NLD-RvA). This certificate is valid until 15 September 2018. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V.

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Justification

Report C090/17
Project Number: 431 51000 06 (RWS) en 431 51000 08 (Eneco; supplementing)

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Steve Geelhoed

Signature: on behalf of

Date: 16 November 2017

Approved: J. Asjes, MSc
Manager Integration

Signature:

Date: 16 November 2017

Annex 1: Monitoring locations

This annex contains photos of the monitoring location (if available).

Figure Annex 1-1. *Monitoring location Afsluitdijk (photo: Bob Jonge Poerink)*

Figure Annex 1-2. *Monitoring location Belwind (photo: Belwind).*

Figure Annex 1-3. *Monitoring location Europlatform (photo: Bob Jonge Poerink).*

Figure Annex 1-4. *Monitoring location Egmond in 2015 (photo: Bob Jonge Poerink).*

Figure Annex 1-5. *Monitoring location Hoek van Holland (photo: Bob Jonge Poerink).*

Figure Annex 1-6. *Monitoring location RWE (low) (photo: Mattias Janke).*

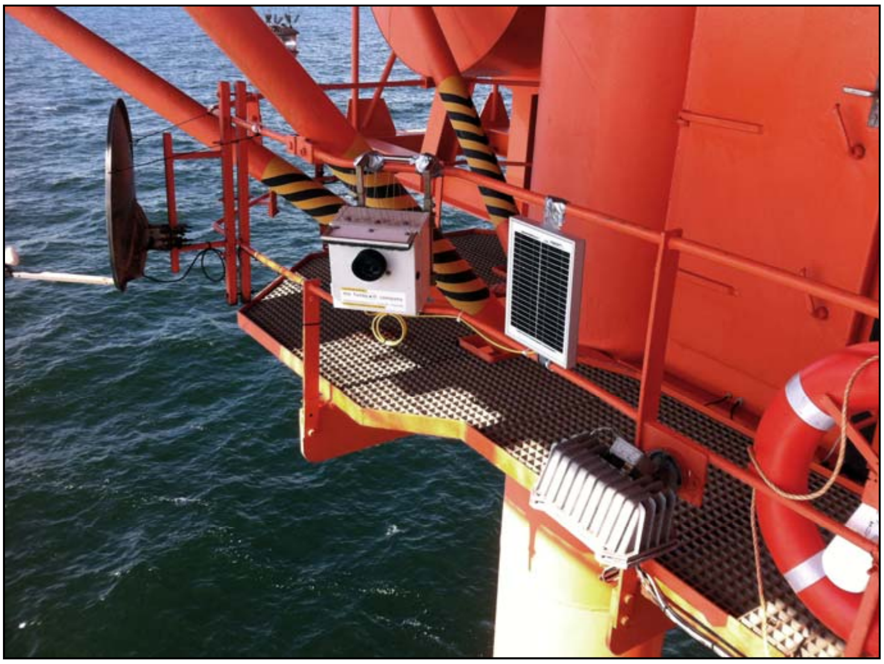

Figure Annex 1-7. *Monitoring location Lichteiland Goeree (photo: Bob Jonge Poerink).*

Figure Annex 1-8. *Monitoring location LUD OHVS (photo: Nienke Ladage).*

Figure Annex 1-9. *Monitoring location Neeltje Jans (photo: Bob Jonge Poerink).*

Figure Annex 1-10. *Monitoring location Oostende in 2015 (photo: INBO).*

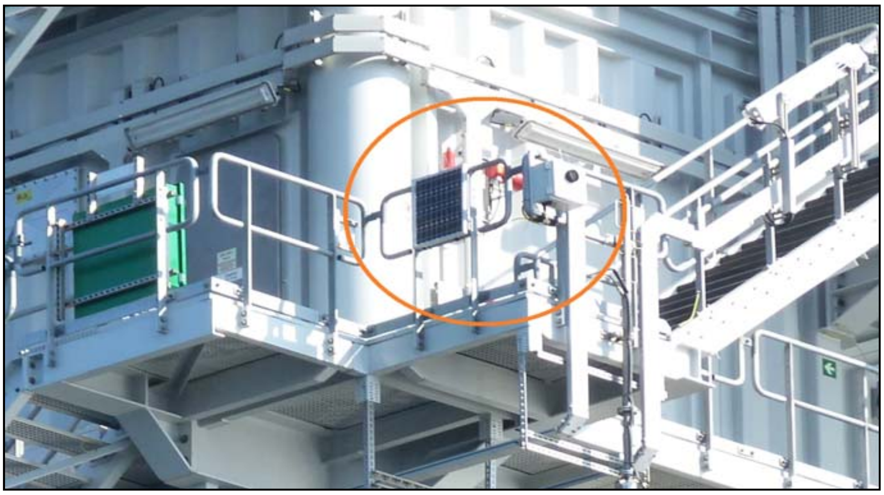

Figure Annex 1-11. *Monitoring location PAWP OHVS (photo: Renzo Schildmeijer).*

Figure Annex 1-12. *Monitoring location Gemini OHVS Buitengaats (photo: Folkert Tazelaar)*

Figure Annex 1-13. *Monitoring location L10-AC Platform (photo: Engie E&P)*

Figure Annex 1-14. *Monitoring location K12-BP Platform (photo: Engie E&P)*

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Wageningen Marine Research is the Netherlands research institute established to provide the scientific support that is essential for developing policies and innovation in respect of the marine environment, fishery activities, aquaculture and the maritime sector.

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