Bats surveys - pre-investigations for offshore wind farms in the area North Sea I

Bat surveys – North Sea I

Energinet Eltransmission A/S

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Preface

This report on 'Bat surveys – pre-investigations for offshore wind farms in the area North Sea I' was commissioned by Energinet to NIRAS. The report includes a summary of existing knowledge about bats for the North Sea in general and for the North Sea I project area, in addition to the baseline data on bats obtained in the bat survey programme conducted as part of the pre-investigations for the North Sea I area.

Front page illustration: Early morning deployment of buoy station for passive acoustic monitoring of bats and marine mammals.

Declaration of contributions

The first three paragraphs of chapter 1: Introduction and objective were written by Energinet.
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Energinet commented on a first and second draft of the report. The comments and author replies will be available here: https://dce.au.dk/udgivelser/oevrige-dce-udgivelser/eksterne-udgivelser/2024.

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We thank Vattenfall A/S for access to and assistance with PAM deployments on wind turbines in Horns Rev 3, the landowners for access to deployment sites for the onshore detectors and Motus receivers, and BioConsult and OS Energy (third-party contractors) for their contributions to offshore survey planning and execution.

List of key terms

A list of terms (in English and Danish) and their explanations in relation to the North Sea I pre-investigations.

Table 0.1 Terminology including Danish and English terms as well as explanations.

English (abbreviation)	Danish	Explanation
Project area	Projektområde	The area defined by Energinet as North Sea I
Survey area	Undersøgelsesområde	The offshore area for which field investigations have been carried out and supplementary data and information have been collected. The survey area includes the North Sea I project area plus a 20 km buffer zone around it.
Passive acoustic monitoring (PAM)	Passiv akustisk overvågning	Programmed ultrasonic recordings by a stationary recording device
Motus	Motus	Wildlife radio tracking system
NOVANA	Det Nationale Overvågningsprogram for Vandmiljø og Natur	The Danish national monitoring programme for aquatic environment and nature, run by the Danish Environmental Protection Agency
OWF	Havvindmøllepark	Offshore wind farm

Summary

This report presents the results of the first year of bat surveys conducted from April 2023 to April 2024 as part of the environmental pre-investigations for the North Sea I area. The bat baseline surveys included passive acoustic monitoring from offshore stations on buoys, offshore stations on existing wind turbines, and from vessel surveys carried out as part of the bird baseline surveys, all within a survey area covering the 1.400 km^2 project area and a 20 km buffer zone around it. Bats were recorded on 11 out of 22 offshore buoy stations, on four out of 10 deployments on wind turbines in Horns Rev 3, and on one out of 45 nights where bat activity was surveyed during vessel surveys of birds.

There were few records of bats offshore. Most of the recordings were from the buoy and wind turbine stations, were identified to Nathusius' pipistrelle (*Pipistrellus nathusii*), and occurred from mid-August to mid-September 2023. Bat occurrence generally coincided with temperatures > 15°C (estimated at 2 m above mean sea level) and mean wind speeds below 8 m/s (estimated at 10 m above mean sea level). Nearly all bat passes were recorded on stations no more than 40 km off the coast, except for a single record of two bats interacting socially at one of the buoy stations furthest west, approximately 80 km from the coastline.

The survey programme for bats also included passive acoustic monitoring from 11 stations on land along the coastline of western Jutland. There was significant bat activity along the coast during the one-year survey period. For Nathusius' pipistrelle, most activity was recorded at Husby and Kammerslusen, and activity of this species increased notably for nearly all stations at the end of August and was pronounced at seven stations throughout September. The activity peaks observed at the land-based stations likely relate to migration near-shore or over land but were not reflected in similar peaks offshore.

Thirteen Nathusius' pipistrelles were caught in northern and western parts of Jutland and tagged with radio-transmitters in autumn 2023 as part of the survey programme. Two of the individuals tagged in Thy, in the northern part of Jutland, were since registered on receivers in the northern part of Germany. The tagging effort documents migration of Nathusius' pipistrelle over at least 270 km and 400 km, respectively, between northern Jutland and Germany. Since no further registrations were made on additional receiver stations in between the site of tagging and the receiver where each of the two individuals was registered, the tagging results did not provide detailed information about the migratory flight paths but based on the most direct line of flight, the two individuals appear to have stayed over or close to land, with one potentially following the coastline.

If autumn migration of bats occurs over the area of the North Sea surveyed as part of the North Sea I pre-investigations, it is either sporadic or focused through flight paths outside the detection range of the passive acoustic monitoring stations deployed during the bat baseline surveys. Based on the results of the bat surveys, it is equally likely that the observed activity offshore reflects exploratory flights during a period of mainly land-based intense foraging activity which may be related to migration activity. Notably, however, 99% of the bat recordings from the buoy stations were from autumn 2023, starting from mid-August. The buoy stations were active earlier in August but recorded no offshore activity before this date, although no major weather changes occurred. In contrast, 93% of the activity recorded on PAM stations on wind turbines in Horns Rev 3 occurred in spring 2023 and included numerous feeding buzzes. Offshore activity thus occurred specifically during the expected migration periods. The addition of data from the second year of bat baseline surveys currently underway will help elucidate if this is a consistent pattern.

1. Introduction and objective

In order to accelerate the expansion of Danish offshore wind production, it was decided with the agreement on the Finance Act for 2022 to offer an additional 2 GW of offshore wind for establishment before the end of 2030. In addition, the parties behind the Climate Agreement on Green Power and Heat 2022 of 25 June 2022 (hereinafter Climate Agreement 2022) decided, that areas that can accommodate an additional 4 GW of offshore wind must be offered for establishment before the end of 2030. Most recently, a political agreement was concluded on 30 May 2023, which establishes the framework for the Climate Agreement 2022 with the development of 9 GW of offshore wind, which potentially can be increased to 14 GW or more if the concession winners – i.e. the tenderers who will set up the offshore wind turbines – use the freedom included in the agreement to establish capacity in addition to the tendered minimum capacity of 1 GW per tendered area.

In order to enable the realization of the political agreements on significantly more energy production from offshore wind before the end of 2030, the Danish Energy Agency has drawn up a plan for the establishment of offshore wind farms in three areas in the North Sea, the Kattegat and the Baltic Sea respectively.

The North Sea I area has a total area of 1.400 km^2 which is divided into three sub-areas planned for offshore wind farms. The North Sea I area is located 20-80 km off the coast of West Jutland and from each of the three sub-areas there will be corridors for export cables connecting the offshore wind farms to the onshore grid.

The overall purpose of this service is to undertake a series of surveys for birds, bats, and marine mammals in a specified area of the North Sea, named North Sea I, to establish an environmental baseline for the future environmental impact assessment of the specific offshore wind farm projects in the North Sea I area.

This report concerns baseline data and information on the species group bats for the environmental pre-investigations of the North Sea I area. The investigation was carried out on behalf of Energinet Eltransmission A/S by Aarhus University/DCE in collaboration with NIRAS during 2023-2024 and includes offshore and onshore field surveys based on passive acoustic monitoring and tagging of bats. Data from the surveys are used to map the spatial and temporal presence of bats in and around the North Sea I area, with reference to the west coast of Jutland.

1.1 Objective

The objective of the environmental pre-investigations is to collect new data and compile existing data and information to be handed over to the future concessionaires as environmental baseline information for the concessionaires' environmental permitting processes.

This technical report provides data obtained from bat surveys based on passive acoustic monitoring from: 22 offshore stations on temporary buoys deployed in the project area and a 20 km buffer zone surrounding the project area, a variable number of offshore stations on existing wind turbines in Horns Rev 3, a single recorder deployed on vessels conducting surveys as part of the pre-investigation programme for birds, and 11 stations on land along the west coast of Jutland (Figure 1.1). As part of the field program, radio-tracking data from bats migrating from Jutland towards Germany and further southwest were collected in addition to passive acoustic monitoring.

The first year of pre-investigations were initiated in April 2023 and concluded in April 2024. For buoy stations these include four main deployments in April, August, November, and March, respectively. Deployments on wind turbines in Horns Rev 3 were facilitated by Vattenfall A/S as part of their service schedule, which dictated the number and locations of stations deployed over the year. Stations onshore were serviced with bi-monthly intervals with the aim to keep them running nightly throughout the year with emphasis on spring, summer and autumn.

The results from the field surveys are supplemented with existing data and information compiled from available sources. A second year of baseline investigations is ongoing in 2024-2025. Data from the second-year surveys will be reported separately.

1.2 Survey design

The study design for the baseline surveys of bats included several components. Based on the assumption that bats may occur in the entire project area, the baseline surveys included numerous offshore passive acoustic monitoring stations (PAM), including anchored buoys, wind turbines in the Horns Rev 3 area, and three additional stationary points visited during planned bird surveys (Figure 1.1). The location of the offshore buoy stations used to survey bats was partly decided by the grid pattern of the 42 overall offshore stations distributed across the survey area for the North Sea I marine mammal PAM programme, as this allowed for synergistic servicing of stations. The survey design included 22 buoys stations, but 23 stations are indicated in Figure 1.1 as one station was put out at a wrong location for a single deployment. This is further explained under Results but for any given deployment period, no more than 22 offshore buoy stations were active. Most of the offshore buoy stations were distributed within the project area and in the buffer zone between the project area and the coastline, where most bat activity was expected. A latitudinal transect of four stations were included near the northern and southern boundary of the project area, respectively, to examine how bat activity differs with distance to the coastline. The bat baseline surveys also included 11 coastal PAM stations to serve as a reference for offshore bat activity, plus the installation of five radio-receiver masts to track radio-tagged bats, and associated capture and tagging of bats during the migration period in autumn 2023 (Figure 1.1).

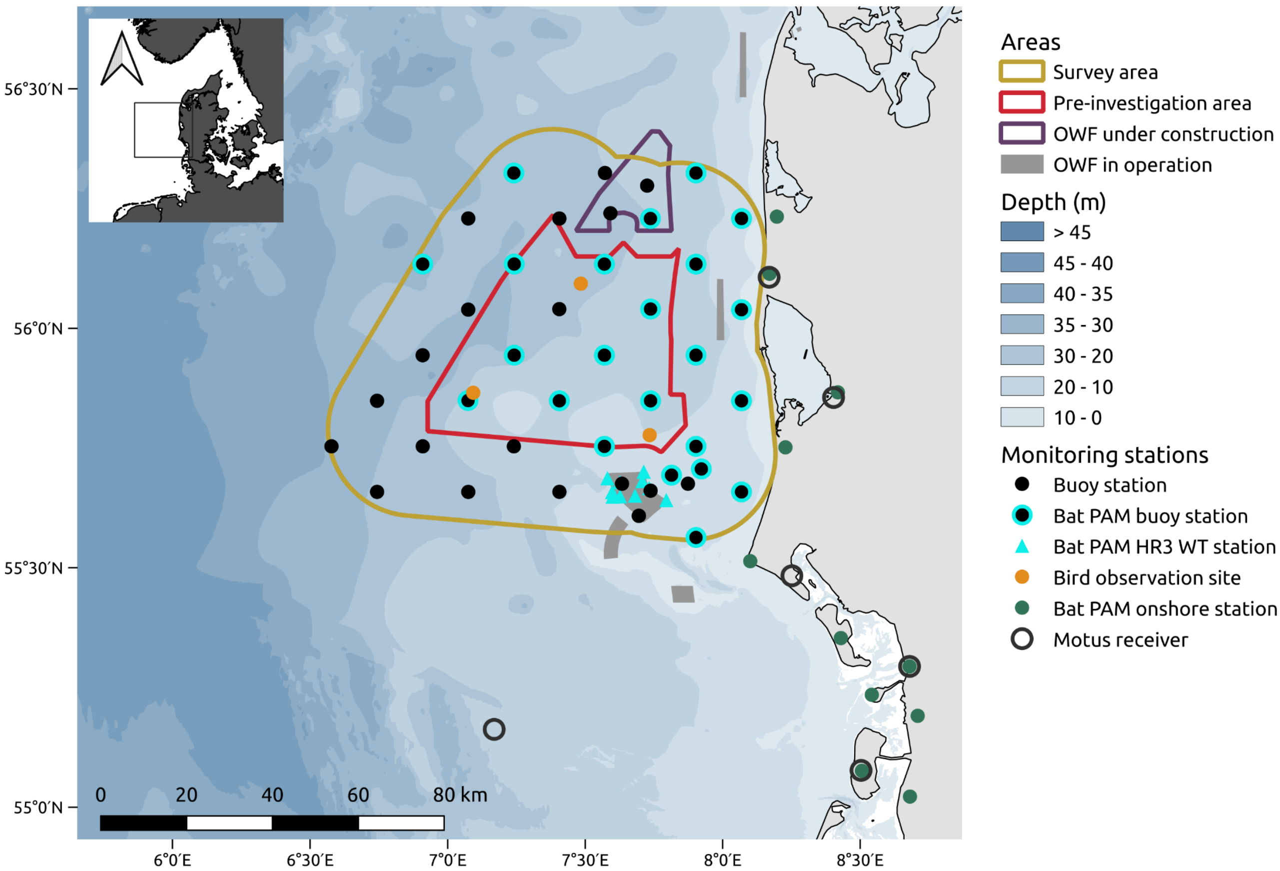

Figure 1.1. Overview of onshore and offshore PAM stations and Motus radio-receivers deployed in the North Sea I baseline surveys for bats. Red outline: North Sea I pre-investigation area. Yellow outline: offshore survey area, including the project area and a 20 km buffer zone around it. Light grey areas (from south to north) indicate the OWFs (offshore wind farms) Horns Rev (HR) 1, HR2, HR3, Vesterhav Syd and Vesterhav Nord. Purple outline: Thor OWF under construction. The three orange points indicate the stationary observation sites from the ship-based bird surveys. Open black circles: approximate locations of Motus radio receivers (note that these overlap with the approximate locations of onshore PAM stations at Kammerslusen and Rømø). Open circle offshore: Motus radio receiver from another project. WT = wind turbine.

1.2.1 Passive acoustic monitoring from offshore buoys

A total of 22 bat passive acoustic monitoring stations were deployed as part of the offshore survey efforts on a subset of 39 yellow spar buoys deployed in a grid pattern across the project area for North Sea I plus a 20 km buffer zone surrounding the project area (Figure 1.1). The buoys were serviced in synergy with the marine mammal baseline surveys. Nine of the 22 offshore buoy stations were located within the project area and 13 more within its surrounding 20 km buffer zone, with emphasis on the area between the coastline and the eastern border of the project area (Figure 1.1). The positions of the export cable tracks were not specified for the pre-investigations and were therefore not considered in the survey design. The numerous stations were included in the survey design to optimize the chance of detection bats offshore.

1.2.2 Passive acoustic monitoring from offshore wind turbines

In addition to the offshore buoy stations, the bat baseline surveys included deployment of passive acoustic monitoring stations on operational wind turbines in the Horns Rev 3 area. Horns Rev 3 is operated by Vattenfall A/S and is located south of the North Sea I project area, within the southern part of the buffer zone included in the survey area (Figure 1.1). The timing, exact location (which turbine) and the duration of these deployments, was subject to the operator service schedule. Consequently, these stations were rotated between the wind turbines, and ultimately included data from single deployments on a total of 10 separate locations (wind turbines) but not all during the same time interval. The wind turbines in Horns Rev 3 are spaced by 1-1.5 km and the stations were deployed at the level of the transition piece platforms, approximately 15 m above mean sea level.

1.2.3 Passive acoustic monitoring on offshore bird surveys

Adding to the offshore bat survey effort, a bat detector was also installed on vessels used for bird surveys in relation to the pre-investigations. This was done to record any bat passes at three predefined bird observation points within the survey area (Figure 1.1), including transit between these and to and from harbours.

1.2.4 Passive acoustic monitoring from stations on shore

The offshore bat baseline surveys were supplemented by 11 onshore passive acoustic monitoring stations, installed along the western coast of Jutland to map bat activity over land as a reference to offshore activity. From north to south, the approximate locations of the land-based stations were: Husby, Stadilø, Skjern Enge, Nyminde Plantage, Blåvand, Fanø, Kammerslusen, Mandø, Rejsby, Rømø, and Ballum (Figure 1.1).

1.2.5 Radio-tracking of bats

As a final component of the bat baseline survey programme, five radio receiver stations were installed along the west coast of Jutland at the following locations (listed from north to south): Stadilø, Skjern Enge, Ho Plantage, Kammerslusen, and on Rømø (Figure 1.1). The receivers were part of the Motus wildlife tracking system (www.motus.org), and were installed to record individual migration patterns of bats caught and radio-tagged as part of the baseline surveys (further explained in section 3.2).

2. Existing data and knowledge

Global biodiversity is under pressure from a range of factors, most of which stem from anthropogenic impact. Bats are evolutionary successful, and the more than 1450 extant species worldwide represent close to a quarter of the global mammalian biodiversity (Burgin et al. 2018) and provide several ecosystem services, such as pest control, pollination and seed dispersal (Ancillotto et al. 2017, Ghanem & Voigt 2012). Bats are long-lived and have slow reproductive rates, as females give birth to a single to few young per year (Wilson & Mittermeier 2019). This leaves them sensitive to ecological pressures including habitat degradation or destruction (Voigt & Kingston 2016, Frick et al. 2020). Even slight changes in annual mortality rates may impact their conservation status (Frick et al. 2017, Voigt et al. 2012, 2022). Consequently, there is an urgent and widely acknowledged need to monitor bat populations and adequately inform management and conservation initiatives. Due to the volant and nocturnal nature of bats, they are not straightforward to monitor and information about their presence, movement patterns and activity offshore is severely data limited.

2.1 Conservation status of bat species recorded in Denmark

Denmark is a member state of the European Union, and all 18 bat species recorded in Denmark (including the newly registered grey long-eared bat, *Plecotus austriacus*) are under legal protection by the Habitats Directive (https://eur-lex.europa.eu). All bats are adopted in Annex IV of the directive, which obliges member states to establish and ensure strict measures of protection within their natural range, including the adoption of monitoring schemes and prevention of disturbances and incidental killings of bats that may threaten the conservation status of bat populations. In addition, some species appear in Annex II of the directive where they inform the designation of special areas for conservation as part of the Natura 2000 network.

According to the Danish red list, several species are listed as data deficient, vulnerable, near threatened or endangered, whereas eight species are of least concern (Elmeros et al. 2019). In the context of bat migration, it is important to note that the status according to the Danish red list and the Article 17 assessments of conservation status applies to populations occurring in Denmark during the breeding season and does not consider the status of the flyway populations. The more common species, including the serotine bat (*Eptesicus serotinus*), Nathusius' pipistrelle (*Pipistrellus nathusii*), common pipistrelle (*P. pipistrellus*), soprano pipistrelle (*P. pygmaeus*), particoloured bat (*Vespertilio murinus*), common noctule (*Nyctalus noctula*), Daubenton's bat (*Myotis daubentonii*) and the pond bat (*M. dasycneme*), have a favourable conservation status in both (Atlantic and continental) biogeographic regions in Denmark (Fredshavn et al. 2019). However, these national assessments are primarily based on distribution range, while the population size and trends are unknown.

For the long- and medium distance migratory species documented offshore over the North Sea, the conservation status is generally Unfavourable or Unknown (Table 2.1, https://nature-art17.eionet.europa.eu/article17/). Given the migratory behaviour of many bat species, an international or fly-way population level approach is needed to manage the species and the threats from wind turbines (Voigt et al. 2012, 2024).

*Table 2.1. Migratory behaviour and current EU Conservation status of bat species observed over the North Sea. The species list was compiled from Petersen et al. 2014 and Seebens-Hoyer et al. 2021 and migratory behaviour is adapted from Hutterer et al. 2005. The EU conservation status is listed for each of the three most relevant biogeographic regions (https://www.eea.europa.eu) from which bats might migrate to and from across the North Sea and potentially the project area. Some of the observations and studies on occurrence of the bat species included in the table predate the split of Pipistrellus pipistrellus and P. pygmaeus into two species (Jones & Barratt, 1999). The two species have very similar ecology and until documented otherwise both species must be expected to occur offshore. ATL: Atlantic biogeographic region, CON: Continental bio-geographic region, BOR: Boreal biogeographic region. FV: Favourable, U1: Unfavourable-Inadequate, U2: Unfavourable-Bad, XX: Unknown (https://nature-art17.eionet.europa.eu/article17/). Asterisks indicate species at high** or medium* level of collision risk with wind turbines in open habitats according to Rodrigues et al. 2015.*

Scientific Name	Common Name	Migratory behaviour	EU conservation status		
			ATL	CON	BOR
*Eptesicus nilssonii**	Northern bat	Short - Medium	XX	U1	FV
*Eptesicus serotinus**	Serotine bat	Short - Medium	U1	U1	XX
*Nyctalus leisleri***	Leisler's bat	Long	U1	U2	XX
*Nyctalus noctula***	Common noctule	Long	XX	U1	U1
*Pipistrellus nathusii***	Nathusius' pipistrelle	Long	XX	U1	U1
*Pipistrellus pipistrellus***	Common pipistrelle	Short - Medium	U1	U1	XX
*Pipistrellus pygmaeus***	Soprano pipistrelle	Short - Medium	FV	U1	XX
*Vespertilio murinus***	Parti-coloured bat	Medium - Long	XX	U1	FV

2.2 Potential impact of offshore wind turbines on bat populations

All bat species move over a species dependent range between their summer and winter habitats. Some species can migrate over ranges up to 2,000 km, including significant ranges offshore (e.g., Hutterer et al. 2005). Evidence from wind turbines onshore show that they may pose a population level threat to both local and migratory bat species, due to mortality and potential barrier or displacement effects (Voigt & Kingston 2016, Rodrigues et al. 2015). Bat fatalities caused by wind turbines are difficult (onshore) or impossible (offshore) to quantify as even on land, bat carcasses quickly decay or are removed by scavengers, leaving little physical evidence. Fatalities seem to be generally caused by direct impact (Rollins et al 2012, Lawson et al. 2020), although Baerwald et al. (2008) based on findings in their study suggested that barotrauma could be a major cause of bat fatalities at wind turbines, arising from internal injuries caused by pressure differences over the volume surrounding the wind turbine. However, the exact cause of death is irrelevant to the level of mortalities and the need to mitigate the impact of wind turbines on bat populations.

The level of collision risk for European bat species with wind turbines in open habitats is indicated for the relevant species in Table 2.1 (based on Rodrigues et al. 2015 and Elmeros et al. 2024). The risk assessment builds on a combination of fatality studies and knowledge of the species-specific ecology, including flight and migratory behaviour. While this information is primarily derived from onshore studies, the Eurobats guidelines for consideration of bats in wind farm projects are applicable both on- and offshore (Rodrigues et al. 2015). The numerical mortality per wind turbine is often low (ca. 14 bats per wind turbine per year on average on onshore wind turbines across Central Europe, Voigt et al. 2022), but the cumulative effect of the wind turbines in a species' distribution range may threaten the conservation status of populations (Frick et al. 2017, Friedenberg & Frick 2021). More solid baseline information is therefore vital to assess and potentially predict large-scale cumulative effects, especially in this age of massive green energy expansion.

2.3 Existing knowledge of bat activity offshore and over the North Sea

Studies of bat movements over the North Sea are in general sparse and extremely sparse for the part of the North Sea surrounding Denmark. The following paragraphs summarize available background information, e.g., from scientific literature and consultancy reports.

Petersen et al. (2014) reviewed historic and non-systematic bat records from structures (e.g., oil rigs) and vessels in the North Sea over a period from 1960 to 2012. The total number of findings included single individuals from five species: Nathusius' pipistrelle (*Pipistrellus nathusii*, 20 records), northern bat (*Eptesicus nilsonii*, one record), Leisler's bat (*Nyctalus leisleri*, one record), common noctule (*Nyctalus noctula*, two records), and the particoloured bat (*Vespertilio murinus*, six records). Other records also include the common pipistrelle (*Pipistrellus pipistrellus*), and the serotine bat (*Eptesicus serotinus*), but Nathusius' pipistrelle is the most frequently observed bat species offshore in the North Sea (Lagerveld et al. 2021, Seebens-Hoyer et al. 2021). It is also one of the species found in highest numbers killed under wind turbines (Rodrigues et al. 2015, EUROBATS 2017, Voigt & Kingston 2016). Apart from the species listed above, offshore accounts of bats from the inner Danish waters and the Baltic Sea include Daubenton's bat (*Myotis daubentonii*), the pond bat (*Myotis dasycneme*), the soprano pipistrelle (*Pipistrellus pygmaeus*), the common pipistrelle (*Pipistrellus pipistrellus*), and the brown long-eared bat (*Plecotus auritus*) (Ahlén et al. 2009, Seebens-Hoyer et al. 2021, Christensen & Hansen, 2023). Although these records are useful for documenting which species are likely to occur at sea, they are not representative of activity as most encounters are likely not documented. Notably, even the vessels hired for these baseline surveys shared verbal accounts of bats sightings onboard the vessel fleet during activities in the North Sea but as no formal documentation system is in place, such encounters are most often not reported or quantified systematically.

There are no previous studies of bats from the North Sea I project area, but there is evidence of bat migration across the southern parts of the North Sea (Lagerveld et al. 2021, Seebens-Hoyer et al. 2021), including southern parts of the Danish North Sea (Lagerveld et al. 2021). Migration may also occur between southern Norway, Denmark and The British Isles (Petersen et al. 2014). Lagerveld et al. (2021) used passive acoustic monitoring over 480 autumn nights between 2012 and 2016 from four locations 15-25 km off the coast of the Netherlands to document the presence of bats and model the offshore occurrence of Nathusius' pipistrelle as a function of weather parameters. The recorders were located 15 m above sea level. Based on their results, they conclude that migration activity of Nathusius' pipistrelle is strongest in the beginning of September and is correlated with wind direction (east-northeasterly tailwinds), low wind speeds (< 5 m/s, measured at 10 m above sea level), and relatively high temperatures (> 15°C). Although bat activity was higher at wind speeds < 5 m/s (67 % of observations), another 31 % of the observed activity occurred at wind speeds up to 8 m/s, whereas little activity (2 %) occurred at wind speeds > 8 m/s. The results of the model are only predicted to be valid for low altitudes (< 45 m above sea level). The study used presence/absence of bats per night as a measure of occurrence, as absolute numbers of the individual bats recorded were not possible to derive. They recorded bat activity on 11-25 % of nights at the four monitoring stations. The highest occurrence (25 %) was found at the station closest to shore (15 km).

Brabant et al. (2021) also found a negative correlation between wind speed and bat activity. They did not find a significant correlation of migration activity for Nathusius' pipistrelle with moon phase, cloud cover, atmospheric pressure, rain, and visibility. The correlations were only made for Nathusius' pipistrelle, but studies of other species offshore indicate that the wind speed tolerance in bats is likely species dependent and higher for other species (Hatch et al. 2013).

A study of offshore and coastal bat activity in inner Danish waters and the Baltic Sea found that bats migrating northward in the Spring arrive at the coastline widely dispersed and do not seem to follow narrow flight corridors, whereas autumn departures from shore were characterized by accumulated activity at specific departure points consistent between years (Ahlén et al. 2009). These periods of pronounced activity comprised from a few up to circa 250 individuals, differed between years and species, and occurred between mid-August and early October, peaking at the end of August. The migration periods observed by Ahlén et al. (2009) and Lagerveld et al. (2021) for Nathusius' pipistrelle are also confirmed by observations from Germany, where offshore migration activity occurs in spring from end of April to May and in autumn from August to beginning, or occasionally, end of October (Seebens-Hoyer et al. 2021).

Ahlén et al. 2009 also found that bats moving towards coastal departure points over land often followed linear features of the landscape, such as forest edges, tree rows or coastlines to these points, and that bats took off from the coast alone or in small groups of a few individuals. Further, the study indicated that foraging activity is not uncommon several kilometers from the coast, that all bats observed flying over the sea echolocated, and that they often flew low (< 10 m) above the water surface during migratory and foraging flights offshore. Several other sources support the observation of low flight height for bats flying offshore (Meyer 2011, Skiba 2007, summarized in Seebens-Hoyer, et al. 2021), but also note that noctules may fly at heights of 40+ m above the water surface. Further, Seebens-Hoyer, et al. (2021) note that bats are regularly observed on anthropogenic structures offshore and may change flight height once they encounter such structures, which may affect their collision risk with turbine blades. Most bats recorded offshore at wind turbines in the southern North Sea were recorded at detectors 16 m above sea level, but 10% of the bat records were made with detectors at 93 m above sea level (Brabant et al. 2020).

No dedicated bat investigations have been carried out for the offshore wind development areas Vesterhav Nord and Vesterhav Syd. For the Thor area, no initial bat pre-investigations were planned, but supplementary investigations of bats were carried out in the autumn (September to November) 2023 in response to the increasing focus on bats in relation to wind energy, including offshore wind energy structures. Thor is located just north of the North Sea I project area and is partially overlapped by the 20 km buffer zone included in the North Sea I survey area (Figure 1.1). The bat investigations from Thor include passive acoustic monitoring with a single SM4BAT FS recorder from each of the two vessels conducting geophysical surveys in the area (https://ens.dk/sites/ens.dk/files/Vindmoller_hav/bilag_8_-_notat_om_bygherres_flagermusundersoegelser_i_efteraaret_2023.pdf). The microphone was positioned circa 8 m above sea level. A total of 12 bats (six per vessel) were recorded offshore during the surveys, all records were from September, occurred circa 25 km from the coast and included two species of bats: Nathusisus' pipistrelle and a single registration of Daubenton's bat. The bats were recorded on nights with wind speeds below 6 m/s measured at sea level, but the vessel returned to port at wind speeds > 8-11 m/s.

Baseline surveys of bats have been conducted for the formerly planned area for the North Sea Energy Island. These pre-investigations included two surveys, one in autumn 2022 and one in spring 2023, each including the deployment of eight buoy-based bat PAM stations at distances ranging from 75 to 125 km from shore. No bats were recorded during either of these two surveys. A subset of data from the bat baseline surveys described in the present report were made public in a preliminary form ahead of publication of this technical report by the Danish Energy Agency as per agreement with Energinet and are accessible here: https://ens.dk/sites/ens.dk/files/OlieGas/initial_results_-_bat_survey_2023_.pdf.

2.4 Biology and behaviour of Nathusius' pipistrelle

The long-distance migrant Nathusius' pipistrelle occurs commonly across most of Denmark (Elmeros et al. 2024). It is a relatively small insect-eating bat species (forearm length 32-37 mm, body mass 5-11 g (Dietz et al. 2009, Russ 2022) feeding primarily on dipterans but also moths and beetles (Elmeros et al. 2024). Bats also forage during migration. Nathusius' pipistrelle emits echolocation calls of either downward frequency modulated sweeps or quasi-constant frequency with most energy around 36-40 kHz and often seen following linear features, such as tree rows, parkways, etc. as guidelines during flight. The species has been recorded both migrating and foraging at sea in the Baltic (Ahlén 1997, Ahlén et al. 2009, Kruszynski et al. 2020, Rydell et al. 2014) and migrating over the southern North Sea (Lagerveld et al. 2021). Spring migration likely occurs in April-May where the bats arrive at breeding sites in Northern Europe, and the south-west bound autumn migration during August-September (Pētersons 2004, Voigt et al. 2012, Rydell et al. 2014).

3. Methods and surveys

Besides non-systematic visual observations from the coastline, offshore structures, or vessels, available techniques to survey bats offshore include radar, video, and acoustic monitoring. Radar and video techniques are not widely used, are highly costly and are in general not yet well developed for bat monitoring, particularly in the rough offshore environment. Passive acoustic monitoring is cost-effective, enables species identification to a large degree, and is used extensively in bat studies and investigations worldwide. It is also the main method used here. Efforts to tag and radio-track bats were also included in the survey programme.

3.1 Passive acoustic monitoring

To map bat activity in the survey area for North Sea I based on passive acoustic monitoring, autonomous ultrasound recorders from Wildlife Acoustics (model SM4BAT FS with waterproof SMM-U2 microphone) were used. These commercial detectors are capable of real-time, full-spectrum recordings that maintain spectral and amplitude information, and have user-adjustable settings for sample rate, filtering, recording schedule and triggering of recordings. The microphone characteristics (sensitivity and directional response) are available from the manufacturer website: https://www.wildlifeacoustics.com/products/song-meter-sm4bat (under Ultrasonic microphone plots). The recorders save data to two SD memory cards and were used with external 12V batteries to optimize run time.

The detection range for ultrasonic bat calls depends on a variety of factors. These include the intensity and frequency of the bat call, the angle between the bat and the microphone and the directionality of both as bats emit their calls in a directional sound beam, and the microphone may not be equally sensitive from all angles of sound reception. Detection range further depends on ambient temperature and humidity, which contribute to frequency-dependent attenuation of the call, internal noise of the recording system, and ambient noise, e.g., from wind, waves, rain, vessels, and electrical sources (Brinkløv et al. 2023). Even under optimal conditions, realistic estimates of detection range do not extend beyond 25 m for Nathusius' pipistrelle (echolocating at 35-40 kHz) and 50 m for the common noctule (echolocating at 20-25 kHz) (Voigt et al. 2021). Such limitations are inherent to passive acoustic monitoring studies of bats and important to keep in mind. The use of multiple detectors increases the chance of recording bat presence, but bats still go unnoticed if they pass outside the detection range of the recorders.

The recorders were programmed to save recordings when triggered by sounds above a set amplitude and frequency threshold. A frequency trigger setting of 15 kHz was used, meaning that sound above this threshold needs to be present for recordings to be saved on the device. Echolocation calls from the bat species hypothesized to occur in the area do not extend below 18 kHz. The frequency setting was combined with a dynamic amplitude threshold determining at which signal-to-noise level an acoustic signal triggers a recording. This amplitude threshold was set at 6 dB for the first set of deployments offshore and onshore but was so low that recordings were triggered nearly continuously each night (i.e., triggered predominantly by ambient noise from wind or waves and not by bat calls). Consequently, to maintain battery and memory, the threshold was adjusted to 12 dB in subsequent deployments. Two of the offshore stations were programmed to record continuously each night during active deployments to collect information about background noise.

The recorders on buoy stations were programmed to ensure battery power for at least one month per each of the four seasons including the predicted spring (April-May) and autumn (August-October) migration periods. Prior to and after each deployment/service offshore, and during regular service checks onshore (every one to two months), the microphone sensitivity was tested to ensure functionality and limit data loss. The recorder deployed on each bird survey was installed with the microphone positioned either along the midline or to the lee side of the vessel pointing skyward at an angle of 45° and away from reflecting surfaces.

3.2 Radio-tracking

3.2.1 The Motus-system

The Motus wildlife tracking system was developed in Canada and has gained momentum primarily across Canada, the Americas and Northern Europe (www.motus.org). Based on telemetry, where each tag transmits a unique radio signal which can be recorded by receiving stations at ranges up to 20 km, the system tracks animal movements, including the migratory movements of birds and bats (Bach et al. 2022, True et al. 2023). Twenty kilometres is the maximum detection estimate provided by the manufacturer, but actual detection range depends on several factors, including weather conditions, the transmission strength of the tag model, topography of the landscape and the flight behaviour of the tagged bat. Lagerveld et al. 2017 gives detection ranges of at least 6 km and likely over 10 km in favourable conditions. Detection range also depends on the position of the transmitter in relation to the antennas on the receiver stations, height of the antennas above ground, the transmitter strength, remaining battery power, and the length of the antenna. The data collected from tagged animals across receivers installed within the Motus network are compiled in a collective database (https://motus.org/explore) forming a collaborative foundation for research and environmental investigations.

As part of the bat baseline surveys, five Motus VHF-radio receivers were installed in August and early September 2023 along the west coast of Jutland at Stadilø, Skjern Enge, Ho Plantage, Kammerslusen, and on Rømø (Figure 1.1). The Motus receiver stations consist of a mast with four 6-element yaki-antennas installed at heights of 5, 6, 7 and 8 m with a 90-degree spacing, a control box with electronics to record and store data, and a solar panel and battery to power the system. Data from the receivers were downloaded manually circa every other month during the autumn and winter 2023.

3.2.2 Trapping and tagging

Bats were caught for tagging in mist nets or from bat boxes during September and October 2023 at select locations north of the North Sea I area and at the northern edge of where the Motus receivers and the land-based PAM stations were located. Specifically, mist nets were used at Klosterheden, Husby Plantage, Vemb Kirke, and Nørre Vosborg. Bats were also caught from bat boxes pre-installed at Østerild Klitplantage in Thy. An acoustic bat lure was used to attract bats to the mist nets. The bats were released once they had been fitted with small (< 0.32 g) VHF-transmitters (Lotek Nanotag NTQB2-2). The tags were carefully glued onto the back of each bat and were predicted to stay on for up to four weeks. Only Nathusius' pipistrelles were tagged. Other species were released at once at the trapping site. The aim of this effort was to obtain vectors with directional information from tagged bats passing by our receivers or other receivers in the Motus network, e.g., along the German and Dutch coastal regions, during southbound movements.

3.3 Analyses of passive acoustic monitoring data

3.3.1 Bat call detection

Thousands of hours of audio data were collected. Once recovered from the passive acoustic monitoring (PAM) stations, the acoustic recordings were processed with sound analysis software to automatically detect and extract recordings with bat call sequences as it was not feasible to manually go through it all. For a subset of deployments, this was done using the commercial software SonoChiro® (v. 4.1.4, south boreal classifier, run at maximum sensitivity, https://sonochiro.biotope.fr/en/). To further increase processing speed, a neural network was trained based on the open-source algorithm AnimalSpot (Bergler et al. 2022), which is designed to detect and classify animal vocalisations and can be run on a high-performance computing cluster.

Once the detection performance of AnimalSpot had been tested and exceeded the performance of the commercial software, AnimalSpot was used for further detection analysis. Data from the first few deployments were used to optimize the detection model, by adding additional vocalisations and noise examples to ensure high performance despite the occurrence of new noise types. The final models used to analyse the data included roughly 10,000 vocalisations and 10,000 noise examples. The model sequentially analysed each recording (of up to 15 s duration) in 20 ms windows with a 10 ms overlap, i.e., 0-20 ms, then 10-30 ms, and so forth, to predict if bat vocalisations were present.

Bat recordings are sometimes interpreted as being from the same individual if they are spaced closely in time. It is indicated in the results section if clusters of 2 or more recordings occurred less than 15 minutes apart but as it cannot conclusively be determined whether they represent the same or different individuals, the absolute number of recordings with bat call detections is used as the basic measure to describe bat activity.

3.3.2 Bat call species classification

The limited number of bat detections offshore (from buoys, wind turbines in Horns Rev 3 and from bird surveys) allowed us to review, verify and identify all offshore detections manually to species or species complex after the automated analysis by SonoChiro and/or AnimalSpot, based on species-specific echolocation call characteristics (e.g., Barataud 2015, Runkel et al. 2021). Verification was done by reviewing spectrograms, spectra and listening to recordings at 1/10 real time speed in Raven Lite, v. 2.0.5 (K. Lisa Yang Center for Conservation Bioacoustics 2024). As part of the manual verification process, call sequences indicative of specific behaviours – explorative behaviour (approach phase), foraging (buzzes) and social calls – were also noted.

For the 11 PAM stations on land, AnimalSpot's detection model output over 10 million detections, not feasible to review manually. Instead, a second model was trained to classify bat calls into the following categories: Nathusius' pipistrelle (Pnat), common pipistrelle (Ppip), soprano pipistrelle (Ppyg), a low frequency species complex including *Nyctalus*, *Vespertilio* and *Eptesicus* sp. (hereafter referred to as ENV), *Myotis* sp. (M) and brown long-eared bat (Paur). Three additional categories: buzz (B), social call (S), and noise (noise), were computed but were not included in further analysis as the main purpose of the onshore monitoring was to provide a frame of reference for the activity recorded offshore, rather than investigate specific behaviours onshore. The noise and social call categories were included, because initial models often misclassified buzzes into the *Myotis* sp. category and social calls into the ENV category regardless of the actual species that produced these calls due to structural similarities.

More than 12,000 training examples were used for the classification model. Training data were extracted from files stored as species documentation in the NOVANA programme for bats, recorded from locations across Denmark between 2013 and 2021 and verified to species by experts (e.g., Søgaard et al. 2018, Brinkløv et al. 2021, Kjær et al. 2023). The noise examples used in the model were errors identified during development of the detection model (where the model predicted a vocalisation, but manual verification found no vocalisation) and additional sound clips from the NOVANA recordings. The model made predictions in 20 ms windows with 5 ms overlap for all detections. Despite high performance, the model still occasionally misclassified a vocalisation. To make sure the classification results were robust, a species (complex) was only considered as present, if there were at least five vocalisations within a 3-5 s window (files longer than five seconds (up to 15 s) were split into five second windows, windows shorter than three seconds were not included). The performance of the automated species classifier was validated with a set of 99 recordings including buoy and land locations, six species or species complexes, and several noise classes. The validation files had not been used as training data and not all species (complexes) could be included as they were too rare to find manually.

All vocalisations that could either be seen in the spectrogram or heard at 1/10 times real time playback, including vocalisations too faint to trigger the SM4BAT FS recorders, were then annotated. The recordings were run through the detection and classification models to quantify the performance, using two main parameters: precision and recall. Precision is the fraction of detections that are true positives (true positive / (true positive + false positive)). Recall is the fraction of calls detected by the model (true positive / (true positive + false negative)). The precision and recall of the model for detecting and classifying Nathusius' pipistrelle was 1.00 (precision), and 0.71 (recall). For the ENV species complex, the model performed at precision and recall of 0.97.

4. Results of surveys

4.1 Offshore passive acoustic monitoring

The results of the offshore passive acoustic monitoring conducted from buoys over the course of the first year of bat baseline surveys from 10 April 2023 to 10 April 2024 are illustrated in Figure 4.1 and summarized below in Table 4.1. The total number of bat offshore recordings was 203, with 90 from PAM stations on buoys, 86 from the wind turbines in Horns Rev 3 and 27 from the bird surveys. Seven of the recordings included two individuals, resulting in a maximum estimate of 210 individuals based on the assumption that all recordings represent distinct individuals.

Table 4.1. Summary of recorded bat activity on offshore PAM stations on buoys, on wind turbines in Horns Rev 3, and on bird vessel surveys. The table lists stations surveyed where bats where detected, the number of nights surveyed per station, how many of the surveyed nights (# in column three, % in column four) included recordings of bats, the number of bat recordings per station, which species were detected, the distance from the station to the coastline, how many individuals were present per recording and whether the recordings contained feeding buzzes (indication of foraging activity) and/or social calls. Several stations did not record any bat passes and are excluded from the table but listed here, with the number of survey days per station listed in parentheses. These included 11 buoy stations: NS08 (171), NS12 (176), NS13 (120), NS14 (161), NS16 (190), NS20 (158), NS21 (150), NS24 (111), NS27 (83), NS29 (104), NS32 (61), and six wind turbine stations: A01 (18), C06 (42), E05 (14), F01 (45), F03 (9), J01 (33). Pipnat = Nathusius' pipistrelle, ENVSp = Eptesicus/Nyctalus/Vespertilio species complex, Myosp. = Myotis species, Pippyg = soprano pipistrelle.

Station	Nights surveyed	Nights with bats	% of nights with bats	Recordings with bats	Species detected	Distance to coast (km)	Individuals per recording	Feeding buzz	Social calls
NS06	80	1	1	1	Pipnat	78	2	No	Yes
NS19	178	1	1	1	Pipnat	40	1	No	No
NS25	163	2	1	2	Pipnat	25	2	Yes	No
T3/NS26	126	4	3	8	Pipnat, ENVSp	27	1	Yes	No
NS28	127	4	3	4	Pipnat, ENVSp	18	1	No	No
NS30	128	4	3	10	Pipnat, ENVSp	16	1-2	Yes	No
NS31	180	4	2	4	Pipnat, ENVSp	16	1	No	No
NS33	143	6	4	17	Pipnat, ENVSp	7	1-2	Yes	No
NS34	185	9	5	21	Pipnat, ENVSp, Pippyg, Myosp.	4	1	No	No
NS35	173	9	5	19	Pipnat, ENVSp	6	1-2	Yes	No
HR3-4	140	3	2	3	Pipnat, ENVSp	24	1	No	No
A02	38	3	8	3	Pipnat	38	1	No	No
A05	61	2	3	70	Pipnat	36	1	Yes	No
A06	56	2	2	10	Pipnat	35	1	Yes	No
C03	27	2	7	3	Pipnat, ENVSp	35	1	No	No
SW (bird survey)	45	1	2	27	ENVSp	68	1	No	No

Bats were recorded at 11 out of the 22 buoy stations with bat detectors (Table 4.1, Figure 4.1-4.3). The following stations recorded bat passes (parentheses indicate the number of bat recordings per station): HR3-4 (3), NS06 (1), NS19 (1), NS25 (2), NS28 (4), NS30 (10), NS31 (4), NS33 (17), NS34 (21), and NS35 (19), and T3-NS26 (8), see Figure 4.1 for the station locations.

Most of the recorded bat activity occurred at stations located in the north-eastern corner of the survey area and within the buffer zone between the project area and the coastline of western Jutland (Figure 4.1). There was, however, one notable exception at NS06, to the far west in the survey area, close to the outer limit of the 20 km buffer zone and west of the project area (Figure 4.1, left side of map).

Out of the 90 verified bat recordings made in total on buoys offshore during the first year of the bat baseline surveys, the majority (89) were from autumn 2023 and a single was from spring 2024. Nathusius' pipistrelle was the bat species most frequently recorded (76%), and this species occurred on all eleven stations where bats were recorded. In addition, 22% were identified to the ENV species complex, which was found at eight of the 11 buoy stations that had bat passes. The recordings also included one record each of soprano pipistrelle and *Myotis* sp. (likely Daubenton's bat). During the survey period in autumn 2023, the recorded bat activity occurred on 16 nights in total, including seven nights in the last half of August (17/8, 19/8, 25/8, 27/8, 28/8, 30/8 and 31/8) and nine nights from beginning to mid-September (1/9, 5/9, 6/9, 7/9, 8/9, 9/9, 10/9, 15/9 and 16/9). Of these, one single night (31/8) accounted for 31% of the bat activity observed in autumn 2023, and four nights accounted for 69% of the autumn activity: 27/8, 31/8, 7/9, and 8/9.

Bats were also present on four out of the 10 deployments on wind turbines in Horns Rev 3 (Table 4.1 and Figure 4.4) with a total of 86 recordings, 80 of which were recorded in late spring 2023 on three nights (12/5, 20/5 and 2/6) from two different wind turbines. The rest were from two other wind turbines that did not have any deployments during spring. One of those two wind turbines recorded three bat passes over two nights (9/9 and 15/9) in autumn 2023. The other also recorded three bat passes but on different dates (8/9, 16/9 and 2/10) in autumn 2023. Nathusius' pipistrelle was also the bat species most frequently recorded at the wind turbines, including all but one record from autumn 2023, which was identified to the ENV species complex.

The bat PAM station included on the vessels conducting the bird surveys only had bat recordings from one stationary observation point (SW), and potentially all from the same individual identified to the ENV species complex (Table 2.1). The total number of days with nightly bat monitoring from bird survey vessels are indicated in Table 4.2.

Bat passes generally occurred during the first half of the night, except the activity recorded at the bird survey station, which occurred early in the morning.

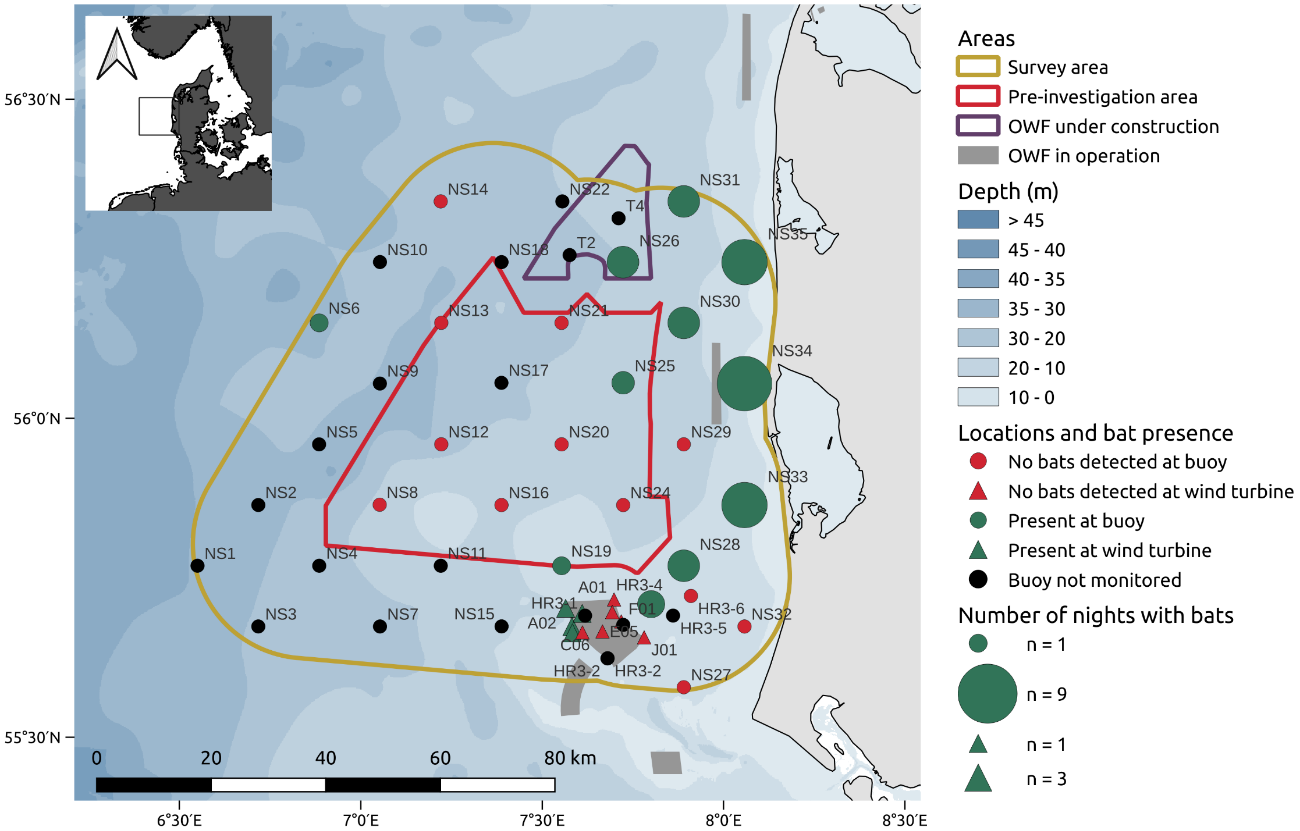

Figure 4.1. Map of offshore PAM stations on buoys and wind turbines where bats were detected during the baseline surveys. Bat PAM stations are shown with station numbers and are scaled and color-coded by the number of nights they recorded bats. Triangles: PAM stations on wind turbines in Horns Rev 3. Points: buoy locations. No bats were recorded on locations shown in red. Black locations were not monitored. Green locations are scaled by the number of nights they have registered bat passes (up to nine nights per station = largest green point). Observations from the bird surveys are not shown in the figure. OWF: Offshore wind farm.

4.1.1 Passive acoustic monitoring from offshore buoys

The results from the 11 buoy stations that recorded bats are summarized below per station in Figure 4.2 and 4.3. All records are from autumn 2023, except one (specified below at station NS31) from spring 2024. Out of the total number of nights surveyed per station over the course of the entire year, the fraction of surveyed nights with bats did not exceed 5% for the buoy stations.

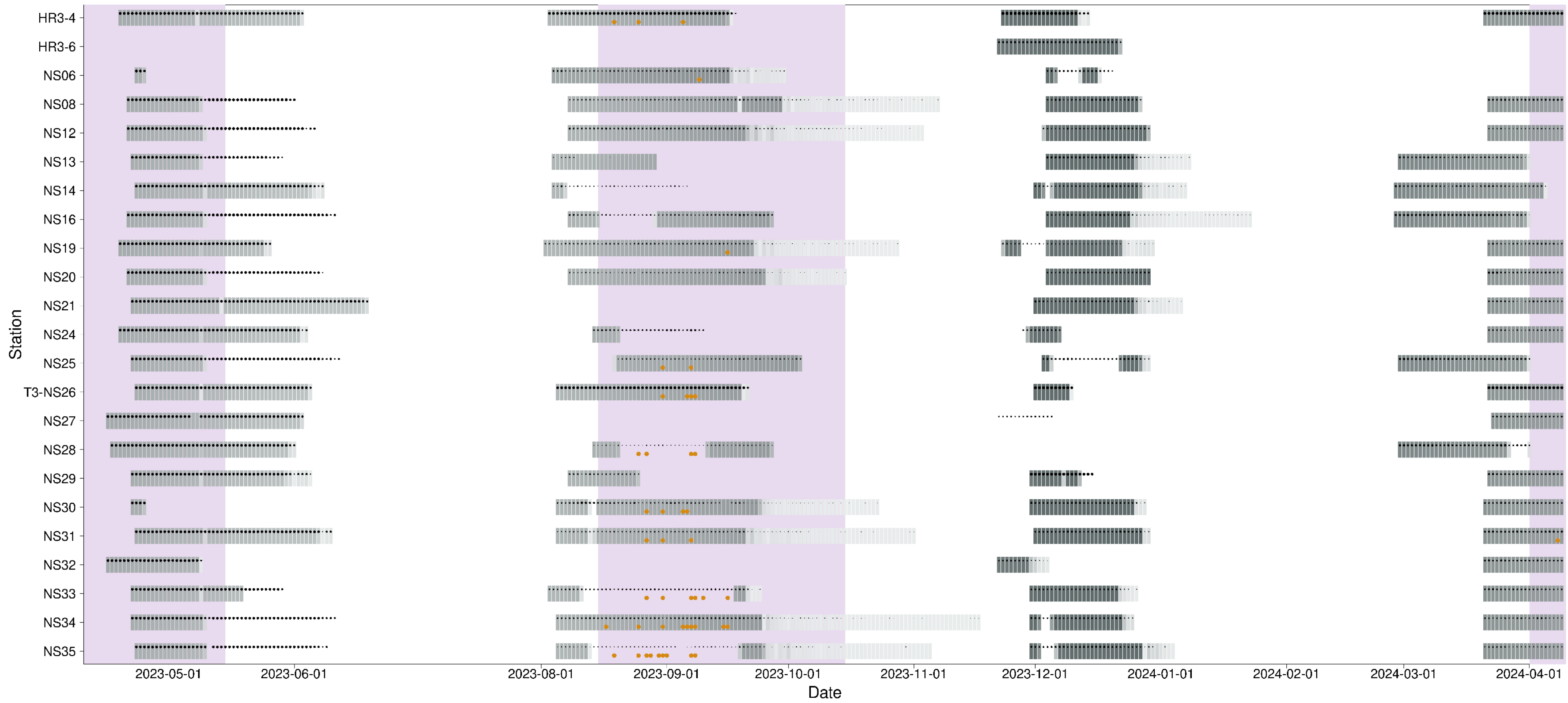

Figure 4.2. Deployment overview for the 22 bat PAM stations on buoys over one year, from April 10, 2023, to April 10, 2024 (x-axis). Due to a mix-up during the deployment in winter, 2023, NS28 was deployed at the location of HR3_6 and for this reason, the deployment overview includes 23 stations. This was corrected during the following deployment. Orange dots represent nights where bats were recorded and are of same size regardless of the number of detections that occurred on any given night. Grey bars and black dots are both indicators of recorder functionality. Grey bars indicate that the recorders were active throughout the night, fading into lighter shades of grey as the recorders ran out of power and recorded partially through the night. Black dots indicate that a recorder was triggered during that night and made recordings, but these only included bats if an orange dot is also present for that same night. The black dots are scaled by the number of trigger events (larger dots: more recordings triggered, smaller dots: fewer recordings triggered). Black dots are present without grey bars for deployments where recorder log files could not be recovered, but the fact that recordings were still triggered during this period indicates that the recorder functionality was intact. No black dot means that no recording was triggered. Purple shading: expected migration periods based on literature.

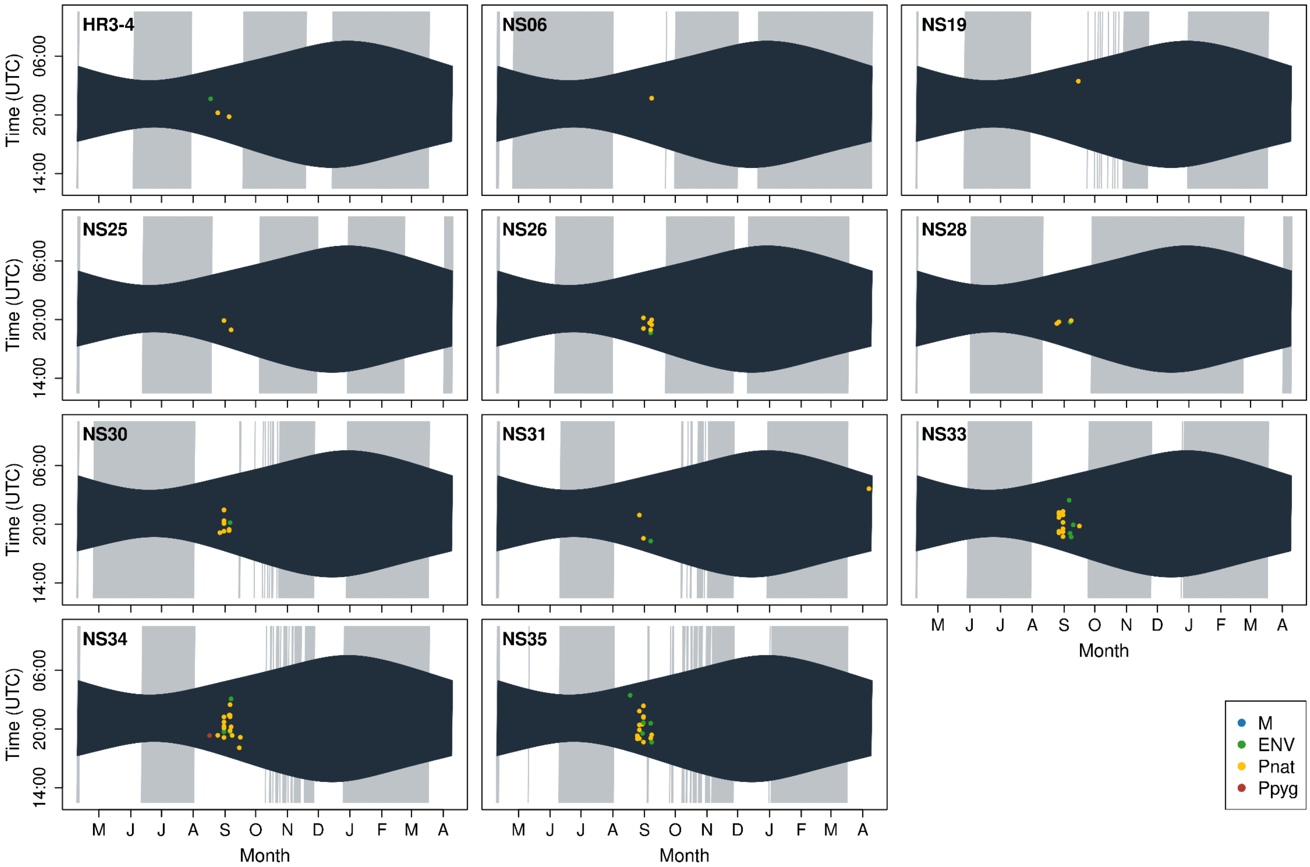

Figure 4.3. Nightly bat activity recorded on the offshore buoy stations over one year, from April 10, 2023, to April 10, 2024. Out of the 22 stations in total, 11 stations recorded bats. Data points are activity minutes. Each point represents a minute with at least five call detections within a 3-5 second window (see section 3.3.2). Black background: nighttime from solar sunset to solar sunrise. Grey background: days without active deployments. The species (or species complex in cases where a positive species identification was not made) recorded are colour-coded: M (blue): Myotis species, ENV (green): Eptesicus/Nyctalus/Vespertilio species, Pnat (yellow): Nathusius' pipistrelle, Ppyg (red): soprano pipistrelle.

The paragraphs below include a brief description of the number of bat records, the species recorded, the date of occurrence and the type of activity.

HR3_4 (55° 44.078', 7° 47.524'): three bat recordings were triggered on separate nights in autumn 2023. One was of a species in the ENV species complex (19/8), and two of Nathusius' pipistrelle (25/8 and 5/9). Only a single individual was present per recording, and no feeding buzzes or social activity was recorded.

NS06 (56° 9.868', 6° 50.645'): recorded two individuals of Nathusius' pipistrelle in one single pass on the night of 9/9, just after midnight UTC time. This recording was the only one from the entire offshore dataset that included a social call. It is also noteworthy that station NS06 was the bat PAM station located furthest from the coast (ca. 80 km).

NS19 (55° 47.572', 7° 32.502'): recorded a single Nathusius' pipistrelle 16/9.

NS25 (56° 4.835', 7° 42.123'): Two recordings of Nathusius' pipistrelle 31/8 and 7/9, both including two individuals per recording and feeding buzzes.

NS28 (55° 47.76', 7° 52.874'): four recordings, including three passes by Nathusius' pipistrelle (25/8, 27/8, 8/9) and one pass by an ENV species (7/8).

T3-NS26 (56° 16.225', 7° 41.616'): The eight bat recordings on T3-NS26 occurred on four separate nights: 31/8, 6/9, 7/9 and 8/9. Six recordings were of Nathusius' pipistrelle and one of these included a feeding buzz (31/8). On 7/9 a species in the ENV complex and not identified to species also passed by and occurred on two recordings back-to-back in time, indicating that they may have been triggered by the same individual.

NS30 (56° 10.582', 7° 52.127'): Ten recordings, and likely at least six passes of Nathusius' pipistrelle on the following dates, 27/8, 31/8, and 5/9. One recording included two individuals and another a feeding buzz. The rest were all single individuals. A single recording was identified as an ENV species (6/9).

NS31 (56° 22.027', 7° 51.741'): This station recorded no feeding buzzes or social activity and only single individuals on a total of four different recordings, all on different nights. Three of these bat passes were identified as Nathusius' pipistrelle (27/8 and 31/8 in autumn 2023, and 8/4 in spring 2024), and one as an ENV species (7/9).

NS33 (55° 53.574', 8° 2.766'): 17 recordings in total. Nathusius' pipistrelle occurred on multiple recordings at this station, but limited to a total of three nights: 27/8 (five recordings within three hours, possibly all of the same single individual), 31/8 (seven recordings within 4.5 hours, some could be of the same individual but two of the recordings included two, rather than a single individual) and 16/9 (a single recording, in the frequency overlap zone between Nathusius' pipistrelle and the common pipistrelle). On three separate days, a single ENV species was also recorded (7/9 (two records), 8/9 and 10/9 2023) at this station.

NS34 (56° 4.959', 8° 2.523'): 21 recordings in total on the following dates: 17/8, 25/8, 31/8, 5/9, 6/9, 7/9, 8/9, 15/9 and 16/9. The majority were of Nathusius' pipistrelle, but this station had the highest species diversity and was also visited by a soprano pipistrelle (17/8), an ENV species (31/8, 6/9 and 8/9) and a *Myotis* species, likely a Daubenton's bat (31/8). No conclusive feeding buzzes were recorded at this station, and each pass included only a single individual.

NS35 (56° 16.384', 8° 2.238'): 19 recordings in total were retrieved from this station over nine different dates of Nathusius' pipistrelle (25/8, 27/8, 28/8, 30/8, 31/8, 1/9, 7/9 and 8/9) or an ENV species (19/8, 30/8, 31/8, 7/9 and 8/9), respectively. Two of these species records have been corrected since the preliminary data delivery published here: https://ens.dk/sites/ens.dk/files/OlieGas/initial_results_-_bat_survey_2023_.pdf.

The single bat recording from spring 2023 occurred at a lower temperature (8 °C, estimated at 2 m above mean sea level) than any of the bat passes from autumn, which all occurred at temperatures from 12-20 °C (Figure 4.7). No bats were registered at wind speeds above 9 m/s offshore and precipitation above 1 mm/hr. Out of all recordings offshore, 87% were from nights with mean wind speeds below 8 m/s (estimated 10 m above means sea level) (Figure 4.8). Two, including the one from spring 2023, were recorded at higher wind speeds of 8 and 9 m/s, respectively. The recordings clustered around two main wind directions, E and SE (Figure 4.9).

4.1.2 Passive acoustic monitoring from offshore wind turbines

The 10 deployments on wind turbines in Horns Rev 3 were placed in space and time contingent on the turbine servicing schedule. Results from these deployments serve as a supplement to those from the buoy PAM stations and provide baseline data about bat activity around anthropogenic structures in the North Sea, in this case wind turbines. Each recorder was active for at least nine and up to 61 nights, corresponding to 2-17% of the nights in a full year (Table 4.1). Bat passes were recorded on four wind turbines and on eight nights (Figures 4.5 and 4.6), three in spring/early summer 2023 (12/5, 20/5 and 2/6) and five in autumn, 2023 (8/9, 9/9, 15/9, 16/9 and 2/10), coinciding with dates where bats were also recorded on buoy stations, except for the early October record.

The spring 2023 records were from two different wind turbines, A05 and A06. On one of those nights, activity could stem from the same individual of Nathusius' pipistrelle foraging first around A05 (58 recordings within 20 minutes, including 137 feeding buzzes, example recording shown in Figure 4.4), and subsequently moving on to station A06, which is the next wind turbine south of A05, where records occurred at a slight delay of circa 10 minutes (nine in total all within 10 minutes of each other). A05 also recorded at least one foraging Nathusius' pipistrelle on 12/5, as evidenced by multiple feeding buzzes on the total of 12 recordings clustered within 10 minutes. In addition, A06 was passed by a single Nathusius' pipistrelle (one recording) on 2/6.

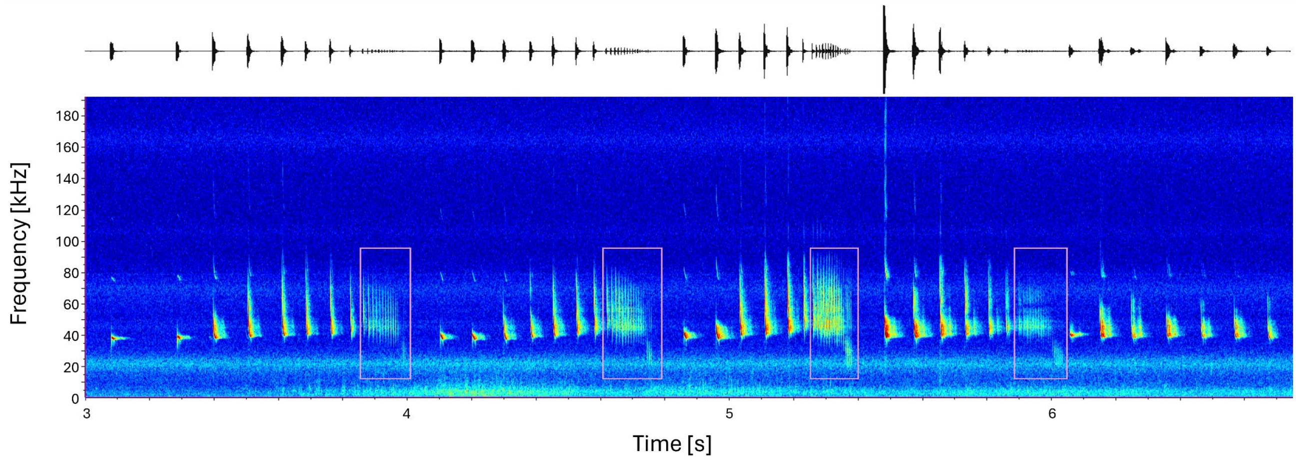

Figure 4.4. Example recording from HR3 wind turbine A05 documenting foraging activity of a Nathusius' pipistrelle (from wav-file HR-A-A05_20230520_203051). A total of 137 feeding buzzes were recorded in 20 minutes, this example visualizes four of them (outlined in pink). The black waveform in the top panel shows the relative amplitude of the recorded echolocation calls as a function of time, the bottom panel displays the relative power of the call frequency content of those same calls across the same time axis in a spectrogram (window size 1024 samples, Hann window, 50% overlap).

In autumn 2023, the wind turbine station C03 made three bat recordings, one of an ENV species and two of a Nathusius' pipistrelle that were within 15 minutes of each other. A02 detected Nathusius' pipistrelle on three separate nights. Bats were present in up to 8% of the total number of nights surveyed per wind turbine station over the course of the entire year.

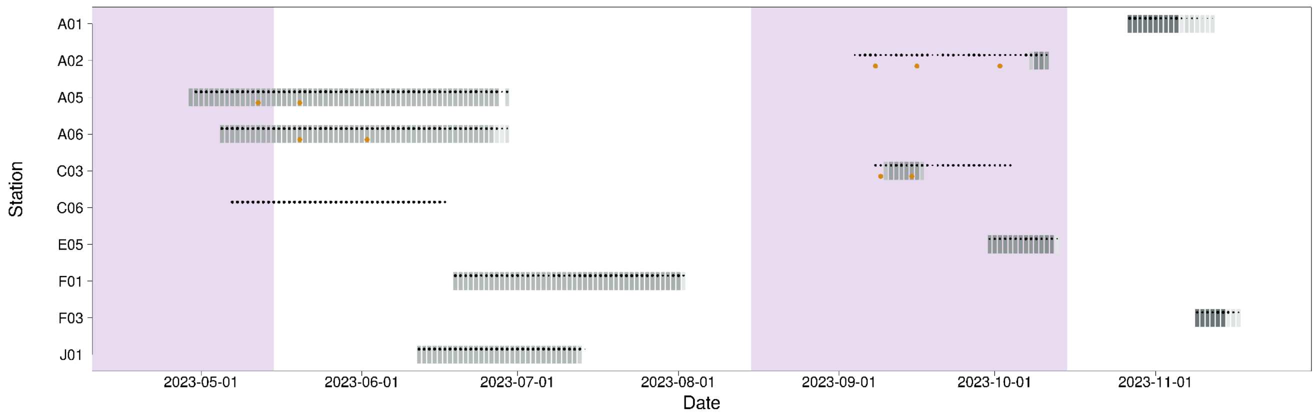

Figure 4.5. Deployment overview for the 10 bat PAM stations deployed on wind turbines in Horns Rev 3 during the first year (April 10, 2023, to April 10, 2024) of the baseline surveys. The x-axis stops on Dec 1, 2023, as no deployments were included between this date and the end of the first survey year. Orange dots represent nights where bats were recorded and are of same size regardless of the number of detections that occurred on any given night. Grey bars and black dots are both indicators of recorder functionality. Grey bars indicate that the recorders were active throughout the night, fading into lighter shades of grey as the recorders ran out of power and recorded partially through the night. Black dots indicate that a recorder was triggered during that night and made recordings, but these only included bats if an orange dot is also present for that same night. The black dots are scaled by the number of trigger events (larger dots: more recordings triggered, smaller dots: fewer recordings triggered). Black dots are present without grey bars for deployments where recorder log files could not be recovered, but the fact that recordings were still triggered during this period indicates that the recorder functionality was intact. No black dot means that no recording was triggered. Purple shading: expected migration periods based on literature.

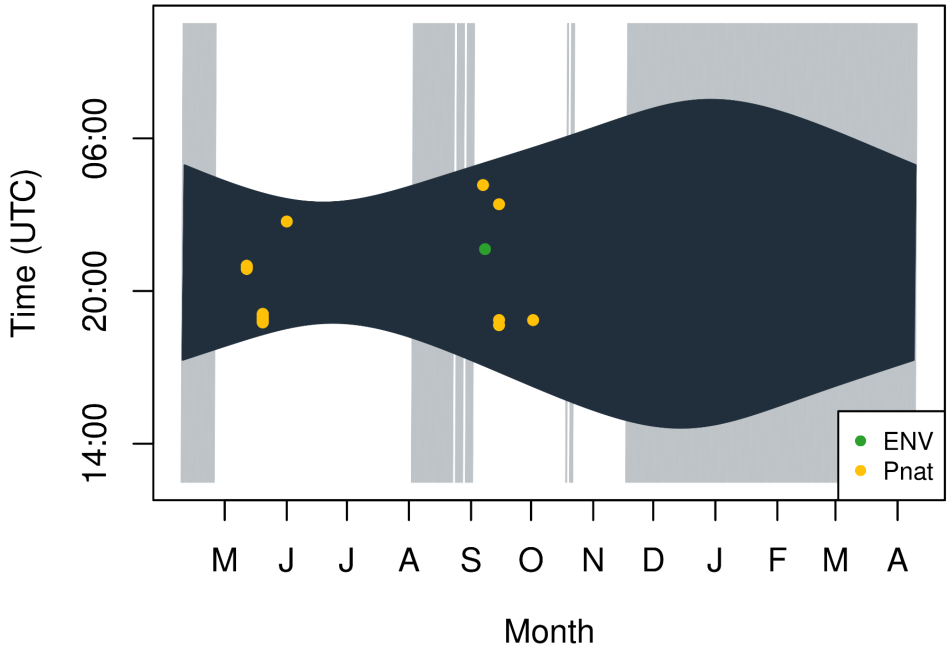

Figure 4.6. Nightly bat activity recorded on the offshore wind turbine stations in Horns Rev 3 over one year, from April 10, 2023, to April 10, 2024. Out of the 10 total bat PAM deployments on wind turbines, four recorded bats. Data points are activity minutes. Each point represents a minute with at least five call detections within a 3-5 second window (see section 3.3.2). Black background: nighttime from solar sunset to solar sunrise. Grey background: days without active deployments. The species (or species complex in cases where a positive species identification was not made) recorded are colour-coded: ENV (green): Eptesicus/Nyctalus/Vespertilio species, Pnat (yellow): Nathusius' pipistrelle.

4.1.3 Passive acoustic monitoring on bird surveys

The bird baseline surveys included a total of eight ship-based surveys in the project area and a single SM4Bat FS recorder was deployed on each of those surveys. Each bird survey lasted 4-7 days and the surveys were conducted according to the overview in Table 4.2.

Table 4.2. Overview of bird surveys with onboard passive acoustic monitoring of bats.

Bird survey	Starting date	Duration (days)
April 2023	26/4	5
May 2023	17/5	6
June 2023	12/6	7
August 2023	10/8	6
September 2023	15/9	6
October 2023	7/10	4
December 2023	2/12	7
February 2024	7/2	4

The bat passes recorded on this device were all from a single night in autumn at a single location (SW observation point, at coordinates 55° 53.420, 7° 2.538, see orange point furthest west in Figure 1.1) where the vessel remained stationary to conduct bird observations. On 18/9 2023, 27 bat recordings were triggered, each including a single individual of an ENV species. Several of them had approach phase calls but no feeding buzzes were present. All the recordings occurred early in the morning and within less than 15 minutes of each other, indicating that they were likely all from the same individual. It was not possible to determine if this bat was stowed somewhere on the vessel during transit and became active at sea or if it arrived at the vessel during an offshore flight. However, the vessel was stationary at this observation point for two days before the activity was observed.

4.1.4 Offshore bat data correlated with weather conditions

The buoy stations did not hold weather loggers, so to correlate offshore bat registrations with weather conditions, we used weather parameters based on re-analysed satellite data from the EU space program (ERA5) and information service *Copernicus* (https://cds.climate.copernicus.eu). The timing and occurrence of bats was correlated with the three parameters found by Lagerveld et al. (2021) to be the most significant predictors, including temperature, wind speed, and wind direction. Most bats were recorded offshore at mean temperatures above 15°C (15-20°C), but all records from spring (2023 and 2024) occurred at lower mean temperatures, including the single spring buoy record (April 2023), recorded at 8°C, and the 67 records from wind turbine A05 and A06 (20/5), recorded at 12°C (Figs. 4.7-4.9). All offshore bat records occurred at mean wind speeds below 11 m/s estimated at 10 m above mean sea level, and 98% of the offshore records occurred at mean wind speeds below 8 m/s. Most of the total offshore activity was clustered around mean wind directions between E and SE. As the sample size from spring 2023 was so low, it was not possible to infer any clear differences in wind directions related to the bat records compared between the spring and autumn periods.

The re-analysed ERA5 weather data was compared to measured weather parameters supplied by Vattenfall A/S from three of the wind turbines that were included in the bat PAM deployments on Horns Rev 3. There was generally good agreement between the measured and re-analysed weather parameters with correlations > 0.8 for wind speed and temperature and > 0.9 for wind direction.

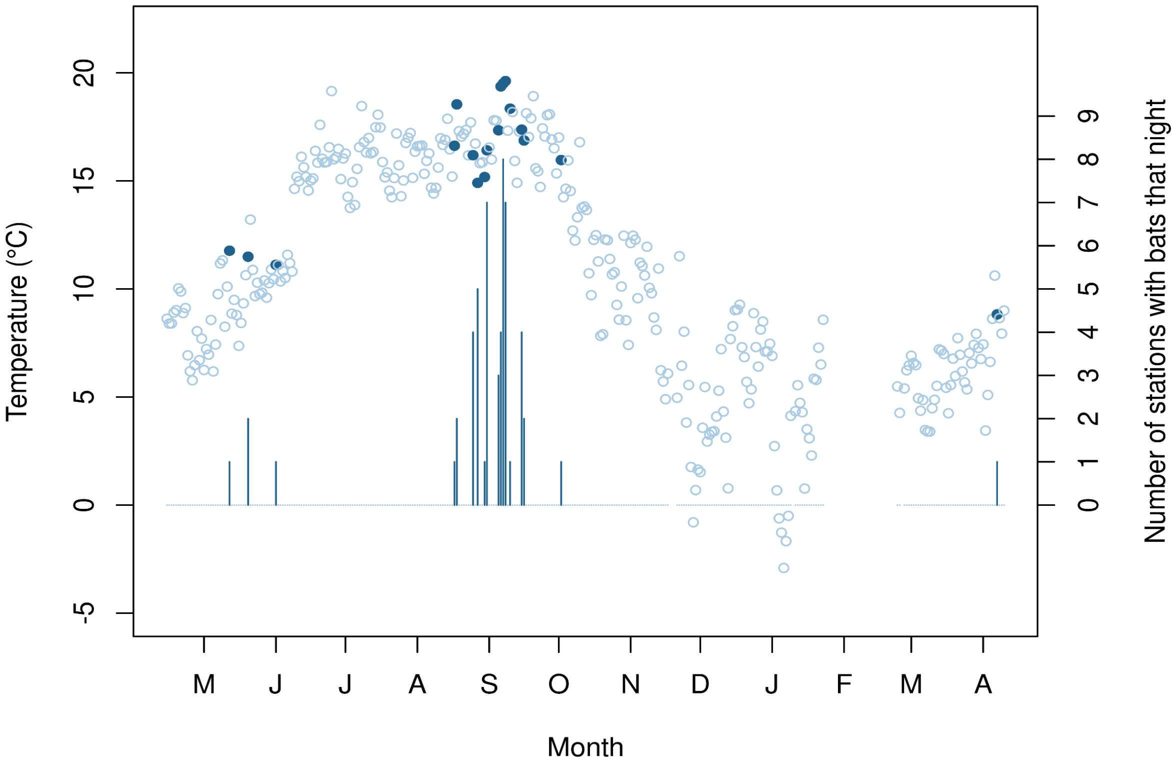

Figure 4.7. Timeline showing the number of offshore stations (buoys and wind turbines) with bat recordings per night with nightly temperature (based on estimates from satellite data at 2 m above sea level at 23:00 UTC and averaged across all offshore stations). The length of each bar indicates how many stations recorded bat activity on a given night, zeros represent nights without recorded bat activity. Open circles show mean temperatures estimated on nights without recorded bat activity, filled circles show mean estimated temperatures on nights where bats were recorded.

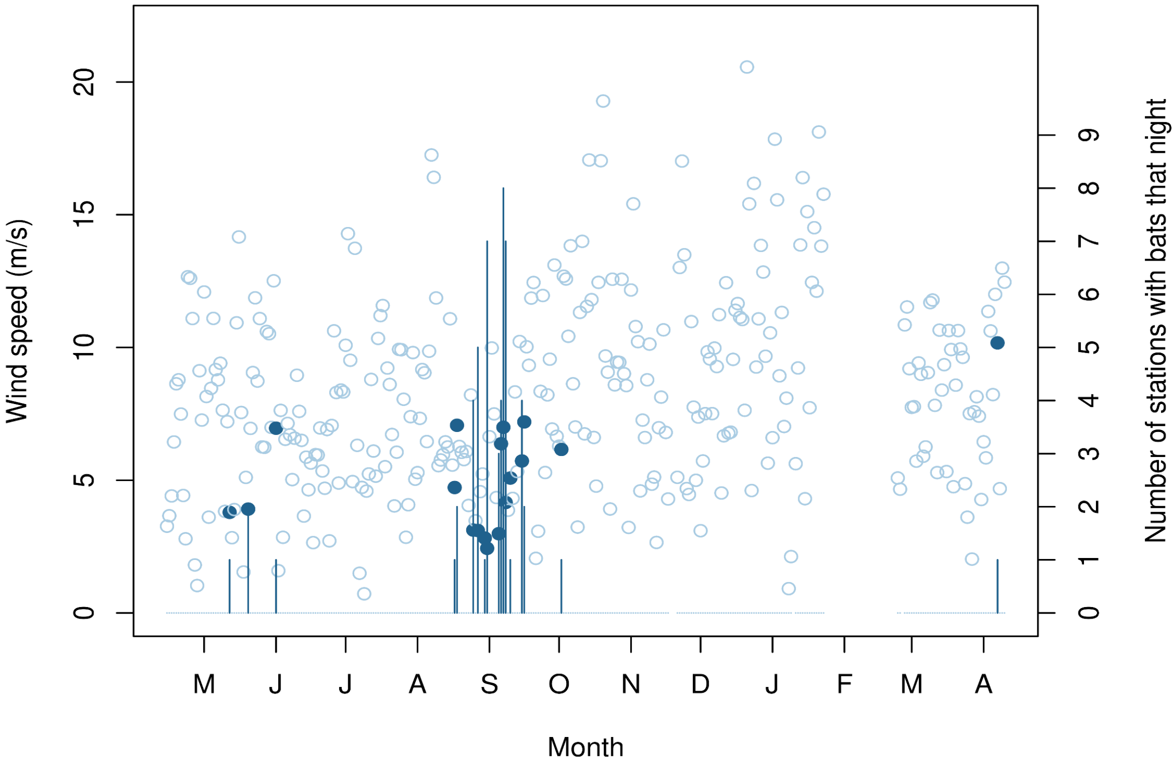

Figure 4.8. Timeline of the number of offshore stations (buoys and wind turbines) with bat recordings per night shown with nightly wind speeds (based on estimates from satellite data at 10 m above sea level at 23:00 UTC and averaged across all offshore stations). The length of each bar indicates how many stations recorded bat activity on a given night, zeros represent nights without recorded bat activity. Open circles show mean wind speeds estimated on nights without recorded bat activity, filled circles show mean estimated wind speeds on nights where bats were recorded.

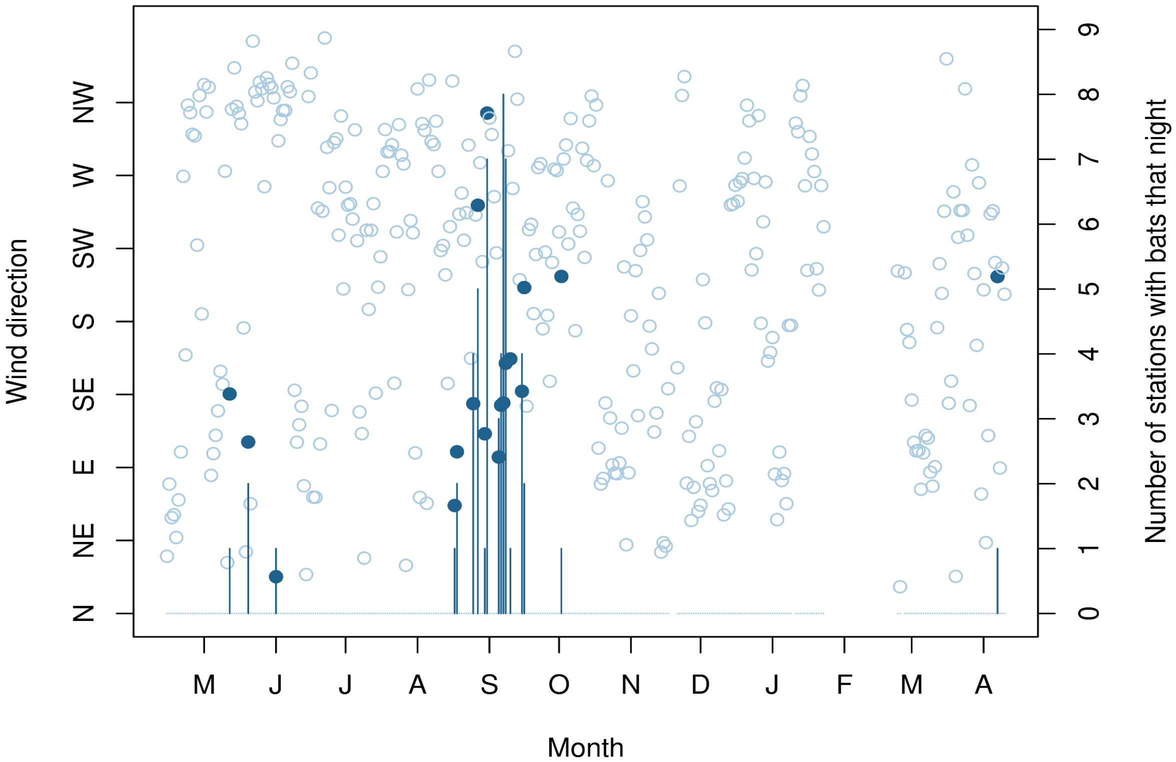

Figure 4.9. Timeline of the number of offshore stations (buoys and wind turbines) with bat recordings per night shown with nightly wind directions (based on estimates from satellite data at 10 m above sea level at 23:00 UTC and averaged across all offshore stations). The length of each bar indicates how many stations recorded bat activity on a given night, zeros represent nights without recorded bat activity. Open circles show mean wind directions estimated on nights without recorded bat activity, filled circles show mean estimated wind directions on nights where bats were recorded.

4.2 Onshore passive acoustic monitoring

Contrary to the activity recorded overall offshore by the PAM stations on buoys, on wind turbines in Horns Rev 3, and on bird survey vessels, respectively, the 11 PAM stations on land recorded bats on most nights where the stations were active, including activity during winter (Figure 4.10 and 4.11).

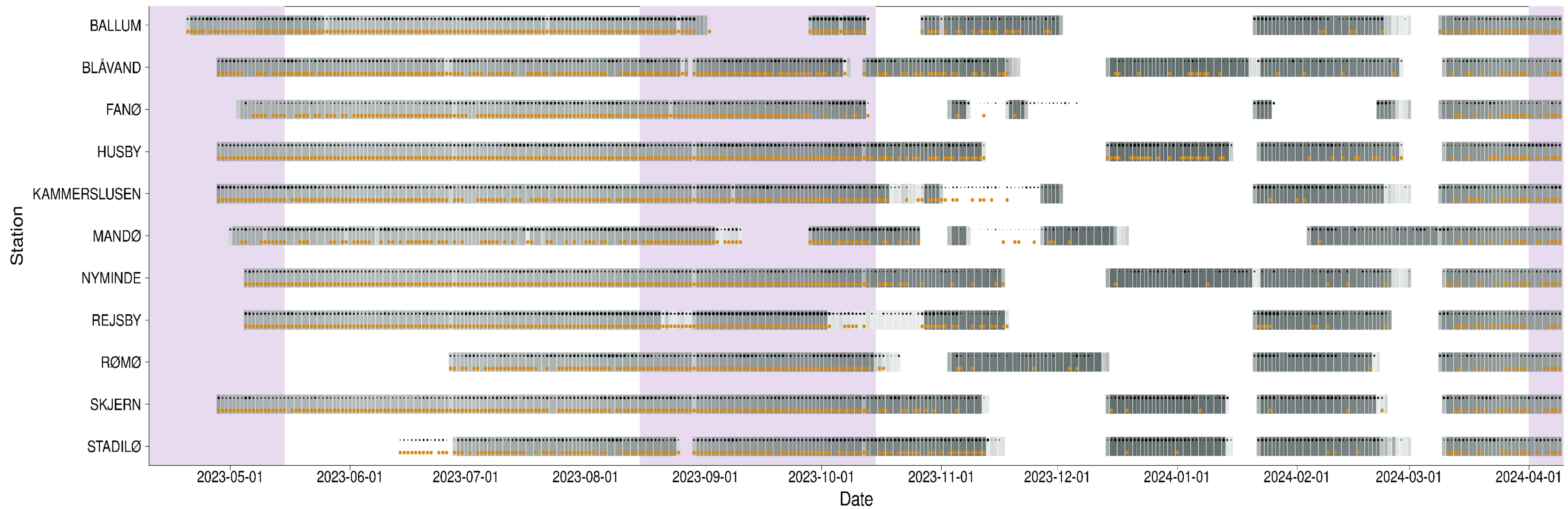

Figure 4.10. Deployment overview for the 11 bat PAM stations on land over one year, from April 10, 2023, to April 10, 2024 (x-axis). Orange dots represent nights where bats were recorded and are of same size regardless of the number of detections that occurred on any given night. Grey bars and black dots are both indicators of recorder functionality. Grey bars indicate that the recorders were active throughout the night, fading into lighter shades of grey as the recorders ran out of power and recorded partially through the night. Black dots indicate that a recorder was triggered during that night and made recordings, but these only included bats if an orange dot is also present for that same night. The black dots are scaled by the number of trigger events (larger dots: more recordings triggered, smaller dots: fewer recordings triggered). Black dots are present without grey bars for deployments where recorder log files could not be recovered, but the fact that recordings were still triggered during this period indicates that the recorder functionality was intact. No black dot means that no recording was triggered. Purple shading: expected migration periods based on literature.

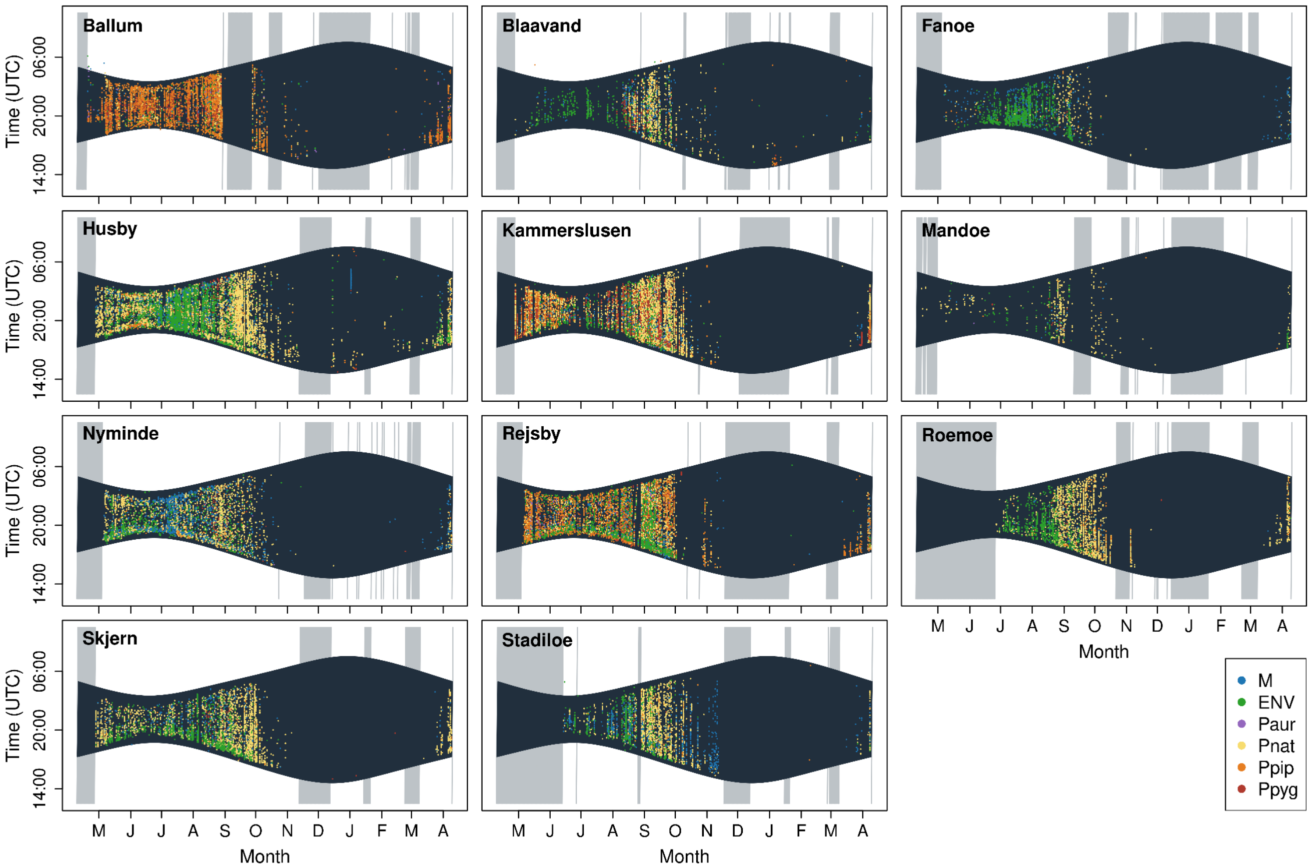

Figure 4.11. Nightly activity overview for all species across all onshore locations. Dates (x-axis) range over one year, from April 10, 2023, to April 10, 2024. Time (y-axis) ranges from noon on a given day until noon the next day. Data points are activity minutes. Each point represents a minute with at least five call detections within a 3-5 second window (see section 3.3.2). Black background: nighttime from solar sunset to solar sunrise. Grey background: days without active deployments. The species (or species complexes) are colour-coded: M (blue): Myotis species, ENV (green): Eptesicus/Nyctalus/Vespertilio species, Paur (purple): brown long-eared bat, Pnat (yellow): Nathusius' pipistrelle, Ppip (orange): common pipistrelle, Ppyg (red): soprano pipistrelle. The station at Rømø was added to the survey programme in late June 2023.

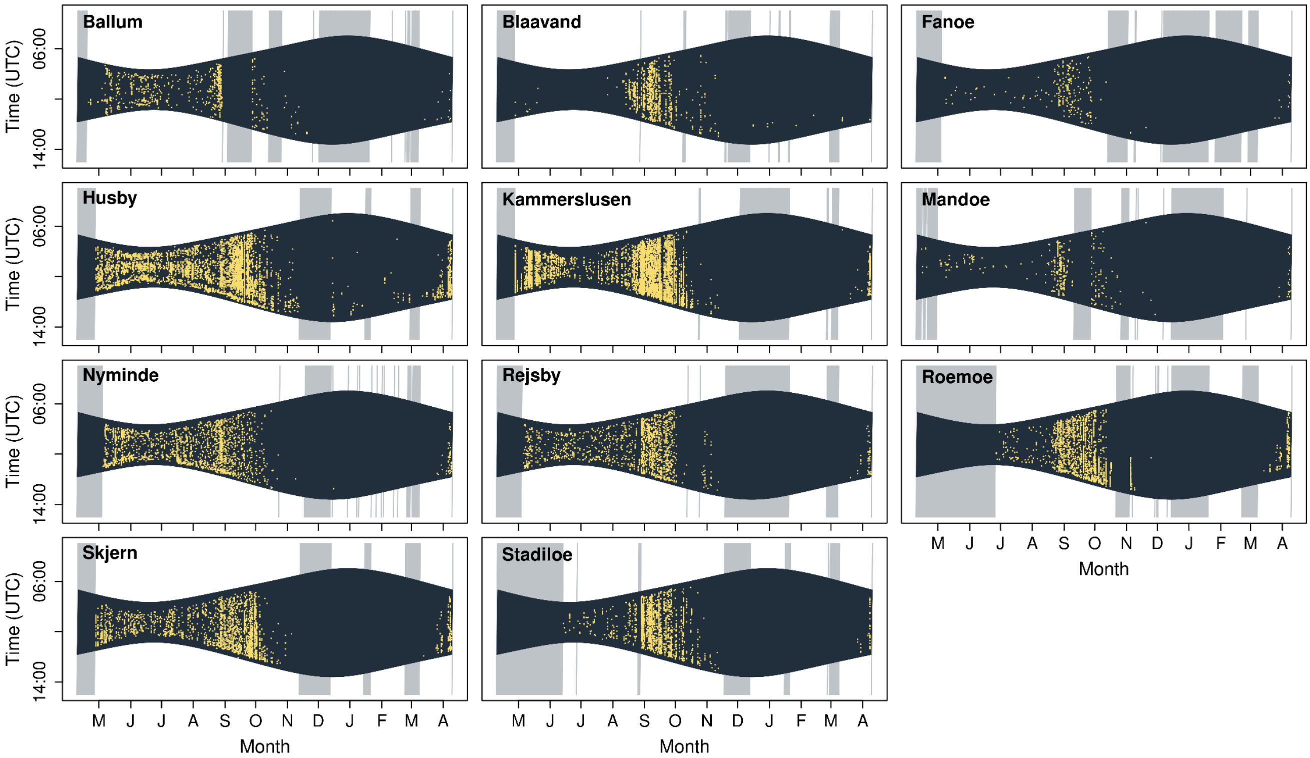

Figure 4.12. Nightly activity overview for Nathusis' pipistrelle across all onshore locations. Dates (x-axis) range over one year, from April 10, 2023, to April 10, 2024. Time (y-axis) ranges from noon on a given day until noon the next day. Data points are activity minutes. Each point represents a minute with at least five call detections within a 3-5 second window (see section 3.3.2). Black background: nighttime from solar sunset to solar sunrise. Grey background: days without active deployments.

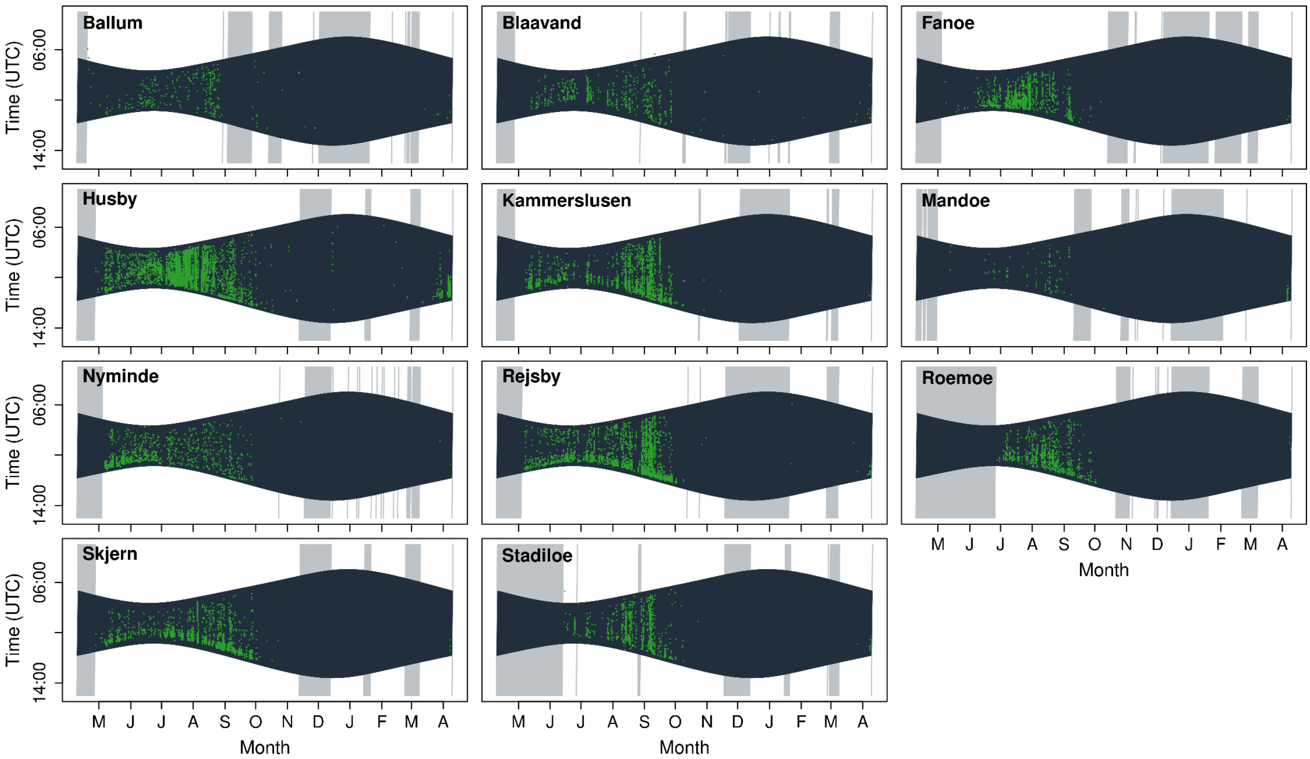

Figure 4.13. Nightly activity overview for the Eptesicus/Nyctalus/Vespertilio species complex across all onshore locations. Dates (x-axis) range over one year, from April 10, 2023, to April 10, 2024. Time (y-axis) ranges from noon on a given day until noon the next day. Data points are activity minutes. Each point represents a minute with at least five call detections within a 3-5 second window (see section 3.3.2). Black background: nighttime from solar sunset to solar sunrise. Grey background: days without active deployments.

The activity levels recorded at the land-based passive acoustic monitoring stations were generally not reflected in the offshore bat activity levels.

Activity of the common and soprano pipistrelle was highest at Ballum, Kammerslusen, and Rejsby. For Rejsby and Ballum activity persisted throughout the summer from May to September, while at Kammerslusen, two more narrow activity peaks were present, in May and September, respectively (Figure 4.11).

For both Nathusius' pipistrelle, and species identified either to the ENV complex or the *myotis* species complex, the stations at Husby and Kammerslusen had most activity. For the latter two, the activity at Husby occurred throughout the summer, whereas an increase in activity occurred at Kammerslusen towards September (Figure 4.12 and 4.13).

The ramp-up in activity at the end of August and into September was especially pronounced for Nathusius' pipistrelle, where it was present across all stations and persisted until the beginning of October. The pattern was most pronounced at Husby, Kammerslusen, and Rømø (Figure 4.12).

4.3 Radio-tracking of bats

Four of the five Motus radio receiver stations were installed in August 2023 and the last one in early September 2023. Thirteen bats, all Nathusius' pipistrelle, were caught in mist nets or from bat boxes in coastal areas north of the five receiver stations in September and October. Following capture, each bat was tagged and re-released at the site of capture (see section 3.2.2). Two of the 13 tagged individuals, both adult females captured and tagged on Sept. 29, 2023, at bat boxes in Østerild, Thy, in the northern part of Jutland, were registered at receiver stations in Germany (tag ID 78814 and tag ID 78818, respectively). One at station 19_Petershörn (ID# 7242) on Oct. 21, 2023, between 18:04 and

18:09 UTC and the other on station 03_Sönke-Nissen-Koog (ID# 10138) on Oct. 8, 2023, between 17:39 and 19:27 UTC (Figure 4.14). Both these receiver stations are part of the collective Motus station network but were installed by the University of Oldenburg for another project and registrations of the two tags were not publicly available until at least six months after the tags were deployed. To verify the tag registrations, the number of registrations that occurred at each of the two respective stations with an interval of 2.9 seconds was counted. This corresponds to the emission interval of the tag radio signal and multiple registrations at this interval indicate that a tagged bat is within range of the receiver, whereas any noise that could be confused with the tag signal should be received with intervals that only accidentally match this value. The Petershörn station had 67 registrations of tag ID 78814 with 2.9 seconds interval and the Sönke-Nissen-Koog station had 197 registrations with this non-random interval for the tag with ID 78818, indicating that the registrations were reliable rather than incidental noise activation of the receivers.

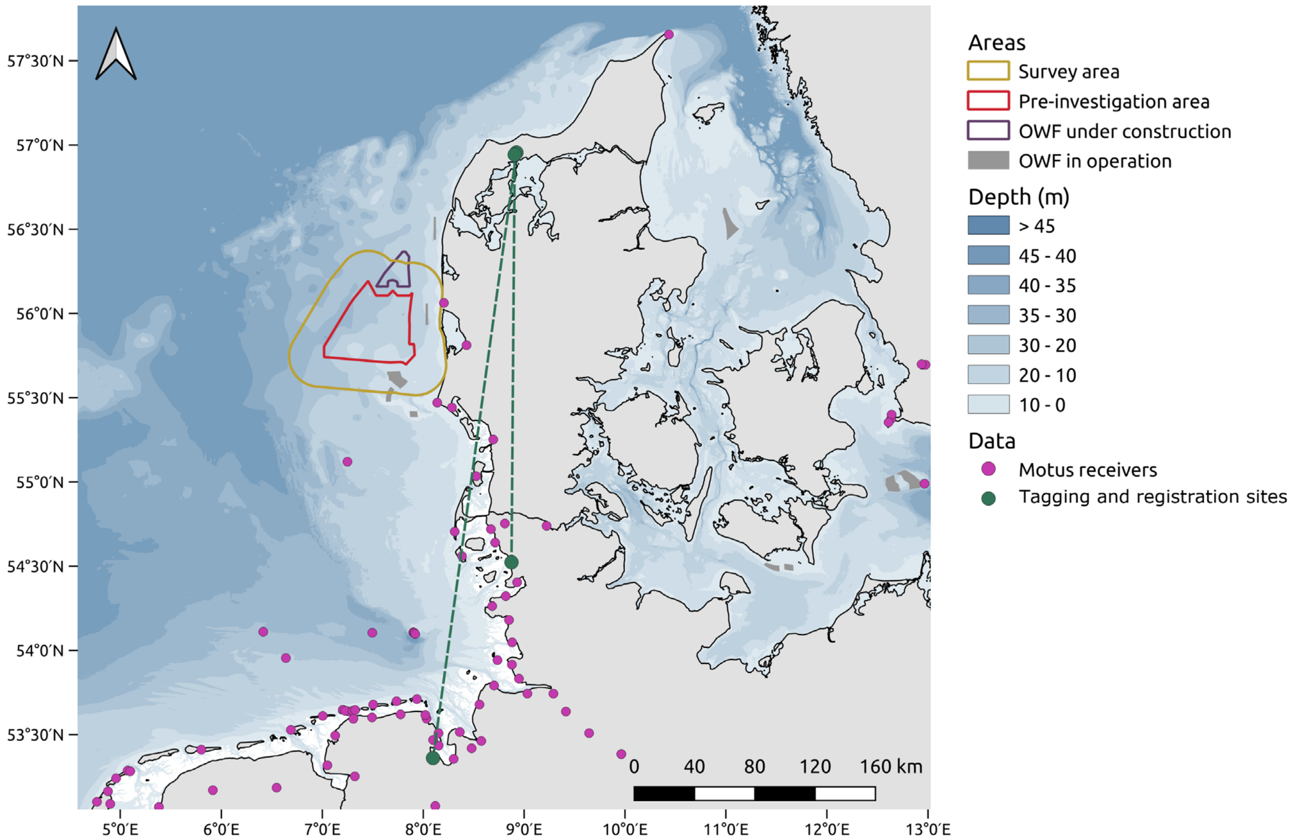

Figure 4.14. Map of the locations where the two female Nathusius' pipistrelles were captured and tagged (both in Østerild, Thy, in the northern part of Jutland) and the locations of active Motus receivers during the autumn of 2023 along the North Sea coastline. The map also displays the German Motus receiver stations 19_Petershörn (southernmost filled green circle) and 03_Sönke-Nissen-Koog that each registered one of the tagged bats 22 and 9 days, respectively, after they were tagged. The dashed lines connecting the tagging sites and receiver stations are not representative of the actual flight paths in detail. Coordinates and activity periods of Motus receivers are accessible through the Motus website: https://motus.org/explore.

None of the 13 tagged bats and no bats tagged from other Motus projects were registered on any of five Motus receivers included in the bat baseline surveys. System functionality was successfully tested within line of sight on one of the receivers with an activated tag at 500 m range, indicating that no tagged bats passed within this range of the receivers while wearing an active tag. The Motus component was foregone from the survey programme in winter 2023 before the two tag registrations became available.

5. Discussion and Conclusion

A limited number of bat passes occurred offshore during the first year of the bat baseline surveys, relative to the observed much higher activity at the land-based PAM stations along the western coastline of Jutland. Most passes recorded at sea were of Nathusius' pipistrelle, as expected from existing information (Lagerveld et al. 2021, Petersen et al. 2014, Seebens-Hoyer et al. 2021). The second-most frequent offshore records was of species identified to *Eptesicus/Nyctalus/Vespertilio* and pooled in an ENV species complex due to the significant overlap between call types, call variation and call frequencies used by these species. The bat baseline surveys also found a single offshore record of a *Myotis* species, presumably a Daubenton's bat, and a single record of a soprano pipistrelle. Most of the offshore activity was recorded on stations within the survey area buffer zone between the project area and the coastline and correlated with weather parameters, i.e., bats mostly occurred offshore at temperatures > 15 °C estimated at 2 m above mean sea level and wind speeds below 8 m/s estimated at 10 m above mean sea level and when the wind direction was from E-SE.

While the eastern component equals tailwind for potential migration due west off the western coast of Jutland, the southern component is puzzling in this context. If bats are migrating off the coast to cross the North Sea (assuming a departure point near Ringkøbing), then they face distances of circa 200 km, 350 km and 550 km, respectively, to reach the coast of Southern Norway, Germany/Holland and East Anglia. Discounting northbound migration during the autumn, when nearly all offshore occurrences were recorded, bat migration offshore from the west coast of Jutland in the autumn is predicted to occur in a S-SW flight direction. Accordingly, it would be expected to coincide with N-NE tailwinds. It should be noted, however, that the observations at S-SE winds coincided with higher temperatures and relatively low wind speeds, potentially confounding the effect of wind direction. Also, easterly winds on warm nights may blow more insects out over the North Sea and promote bat activity. When wind directions are favourable for long-distance migration, bats may fly higher up in the stronger winds, but outside of the detection range of acoustic detectors at sea level.

Although travel distances of 500-1,500 km are not uncommon for medium to long distance migratory bats species (Fleming 2019, Hutterer et al. 2005), and distances of 270 km and 400 km were documented for the two Nathusius' pipistrelles tagged as part of the survey effort detailed in this report, they have rarely been documented across open ocean. Since no further registrations were made on additional receiver stations in between the site of tagging and the receiver where each of the two individuals was registered, the tagging results did not provide detailed information about the migratory flight paths but based on the most direct line of flight, the two individuals appear to have stayed mostly land, potentially following the coastline. More data is needed to support this observation. Further knowledge about the offshore presence of insects would also be useful in this context, as migrating bats are likely to apply a fly-and-forage strategy (Šuba et al. 2012).

The offshore activity that was documented from buoy PAM stations primarily occurred during one month in autumn 2023, from mid-August to mid-September, with 69% of the records occurring on just four specific nights. Offshore activity was only found during expected migration periods. All recordings, except one remote outlier, were from stations located within 40 km of the coastline. The part of the project area within 40 km of the coastline and the survey area buffer between the project area and the coast should therefore be of special attention in further bat investigations as monitoring of these areas is most likely to reflect where most bat activity occurs and whether bat offshore activity in the project area can be predicted from nearby coastal or nearshore features, e.g. estuaries or existing offshore wind turbines (Vesterhav Syd). The outlier included two Nathiusius' pipistrelles passing on the same recording at one of the western-most buoy PAM stations, nearly 80 km from the coast.

Most (93%) of the activity recorded by the PAM stations deployed on wind turbines in Horns Rev 3 occurred on two dates (12/5 and 20/5) in the spring of 2023 and included intense foraging activity. Overall, however, most offshore activity was recorded in the autumn. This could reflect observations from inner Danish waters that indicate more diffuse migration activity in spring (Ahlén et al. 2009) that may occur through different and more variable routes, e.g. entirely over land if food availability is more reliable here during spring than in autumn.

The land-based PAM stations recorded substantial activity for an area with relatively sparse documentation from the NOVANA programme (Søgaard et al. 2018). The pronounced activity of Nathusius' pipistrelle during autumn could indicate migration activity along a north-south vector in the western part of Jutland. However, the results did not suggest specific hotspots or departure points for offshore migration routes over the North Sea I area. The activity of Nathusius' pipistrelle did show a later peak than for the other bat species recorded, from end of August to mid-October at most of the land stations, but this pattern was consistent across land stations and could reflect increased foraging, rather than migratory, activity. However, the two bats tracked as part of the survey efforts support that bats are migration along the western coast of Jutland. At Kammerslusen and Husby, where this late activity peak was most pronounced, further monitoring and tagging studies could help verify if migration occurs into and across the project area but based on the results of the first year of bat baseline surveys, offshore migration activity in the project area is likely sporadic.

The Motus tagging programme was an additional component of the first year of bat baseline surveys and an attempt to gain movement data of individual bat migration patterns potentially crossing the North Sea, through the project area. Apart from the five Motus receiver stations installed under the survey programme, the expanding Motus network includes numerous active receiver stations along the North Sea coastline. The tagging effort resulted in movement vectors for two individual bats. Both migrated from Thy in the northern part of Jutland to the northern part of Germany. It is not known whether the two individuals were only passing through Denmark or spent the summer here. With only two points to describe each of the two long-distance flights, it is not possible to determine the detailed routes followed by the two tagged bats, but the most direct routes were mostly over land or close to the coast over the Wadden Sea south of Esbjerg (Figure 4.14). As proof of concept, there is currently one Nathusius' pipistrelle tagged in a different project under the Motus programme that appears to have travelled offshore from Benacre pump station (East Anglia) to Sylt (northern Germany) in spring 2024 without any registrations on coastal stations in between. The straight-line distance between those two stations is circa 500 km (https://motus.org/dashboard/54550).

6. Data and knowledge gaps

The survey programme for bats realised here as part of the pre-investigations for the North Sea I OWF (offshore wind farm) area contributes significantly to the baseline knowledge of bat activity in the North Sea north of German waters and the inclusion of bat monitoring rather than desktop studies as a general component in environmental surveys (baseline and other) is necessary to improve the data foundation for the North Sea in general. The extension of the North Sea I pre-investigations to include a second year of bat surveys based solely on acoustic monitoring will add further to the robustness of the results for this area.

The lack of systematic data on bat presence/absence, abundance and movement patterns over the North Sea, and of population dynamics of bat species that are part of North Sea flyway populations still, however, represent a significant knowledge gap.

The results from the offshore survey programme included records of feeding buzzes offshore both at buoys and wind turbines. Notably, the bat recordings from two of the wind turbines in Horns Rev 3 included multiple buzzes indicating foraging activity over a prolonged period. As little is known about the behaviour of bats around wind turbines and factors attracting the bats to the turbines, on land and even less so offshore, this points to the importance of post-construction surveys as a vital add-on to pre-investigations and environmental impact assessments to properly evaluate impacts of the rapidly expanding wind energy sector on bats.

Further pre-construction studies of bats on the North Sea and long-term post-construction monitoring programmes are needed to properly assess the potential effects of offshore wind turbines in the North Sea and to adapt effective mitigation measures in the operational phase. Long-term monitoring programmes for a substantial number of offshore wind turbines in the North Sea and other Danish waters would also contribute to knowledge on cumulative effects of wind turbines, as this is not possible based on short-term single project studies with different study designs and methodology.

Methods to provide detailed data on bat migratory paths for individual bats are challenging. The traditional method akin to bird ringing involves capture and ringing (also often referred to as banding) of individual bats to track their movements but requires successful re-capture or recovery of the ring/band and is extremely inefficient and will only document two locations (trapping and recovery sites, Fleming 2019). Further, ringing bats is ethically problematic, due to a relatively high risk of injuries to the bats. Modern tracking methods rely on the attachment of different types of transmitters to animals, such as radio or GPS tags. Information on individual flight patterns would be highly valuable, as would continuous GPS tracking of bats moving from land to sea, to indicate if migration flights occur along the west coast of Jutland and to and from the coast across the project area. However, methodological challenges mean that GPS tags for tracking bats are currently still either archival, and must be retrieved to recover data, or too large to be used on species such as Nathusius' pipistrelle, of special focus in this context. Radio tags that are small enough for this purpose will only provide data if the tagged bats pass close enough by the receivers that must pick up the signal from the tag.

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