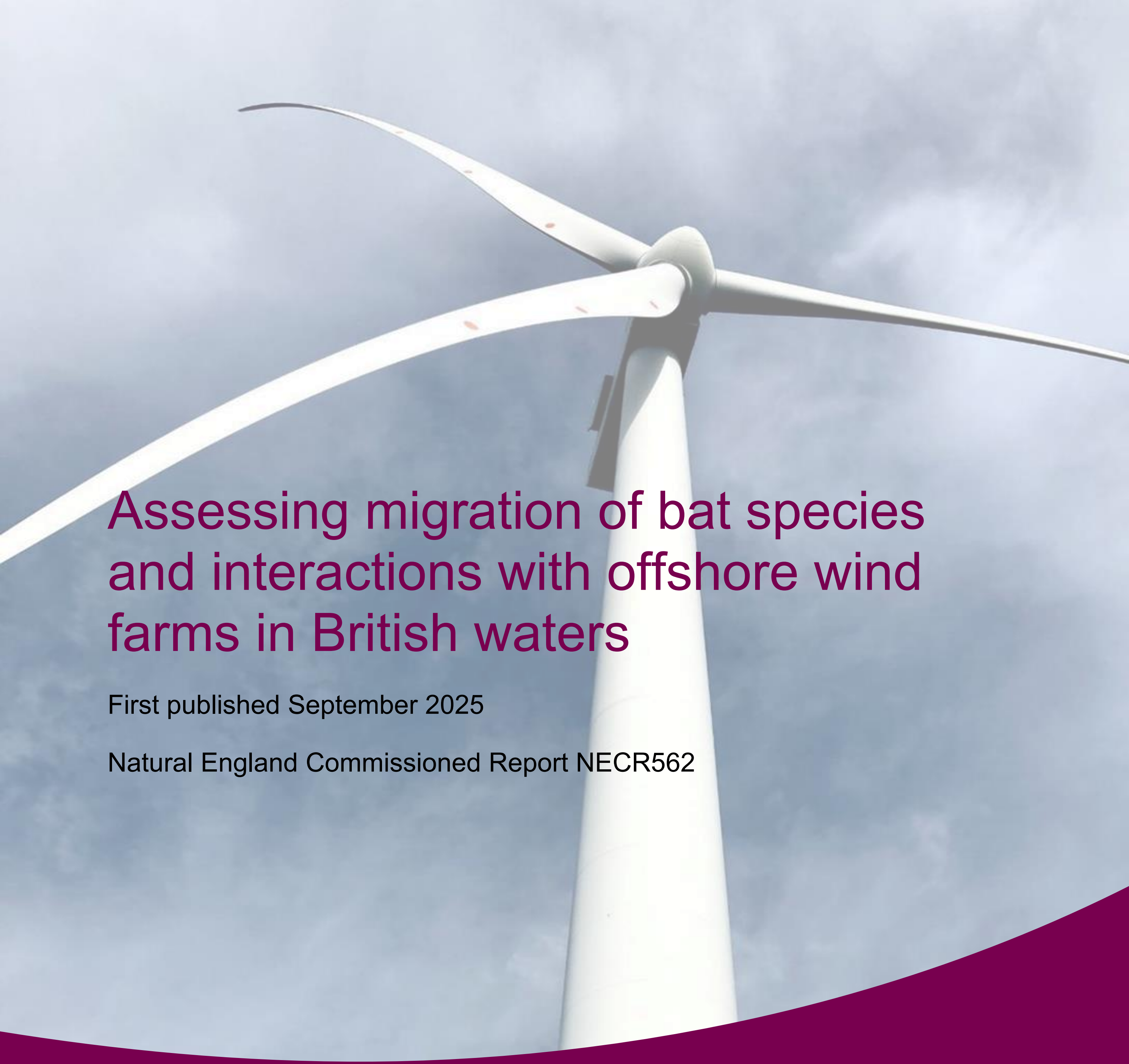

Assessing migration of bat species and interactions with offshore wind farms in British waters

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Assessing migration of bat species and interactions with Offshore Wind Farms in British Waters

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Project details

Offshore wind projects in British waters are developing at pace as we move towards Net Zero Targets and ambitions to deliver 50 GW by 2030. It is Natural England’s duty to provide evidence-based advice as the government's statutory advisers. Potential impacts of offshore wind farms on migrating species are moving up the international agenda.

Understanding the evidence base for the effect of offshore wind development and operation upon different environmental receptors is an integral component which underpins Natural England’s offshore wind work. Common receptors are currently seabirds, marine mammals, benthic receptors (seafloor habitats and species) and designated fish. However, there is a current lack of evidence as to the effects of offshore wind farm development upon bat populations in British waters. This represents an evidence gap which needs to be addressed.

Bats are a relatively poorly understood receptor for marine offshore developments in British waters. Evidence gaps remain on the occurrence of bats in the offshore environment, including migration, and their potential interactions with renewable developments. Little is known about bat migration ecology, the number of individuals migrating over sea, and the risk of mortality from interactions with offshore wind turbines.

Through a desk-based literature review and engagement with international and national projects this study aimed to identify cutting edge international best practice and lessons learnt to inform Natural England's approach, identifying evidence gaps and providing recommendations for next steps.

Improving our understanding of bat ecology, migration and the interaction of bats with offshore wind farms will help to improve the advice Natural England provides to offshore wind developers and regulators regarding environmental impact assessments and monitoring and the development of industry best practice.

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

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Keywords

Wind energy; wind turbines; collision mortality; bat migration; bat mitigation; offshore; renewable energy; barriers; avoidance

Further information

This report can be downloaded from the Natural England Access to Evidence Catalogue: **http://publications.naturalengland.org.uk/**. For information on Natural England publications contact the Natural England Enquiry Service on 0300 060 3900 or e-mail **enquiries@naturalengland.org.uk**.

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Cover image

Turbine at Rampion Windfarm Curtesy of Tamara Rowson

Executive summary

Offshore wind projects are developing at pace with ambitious Net Zero targets in place across Europe. Understanding the evidence base for the effect of offshore wind development and operation upon different environmental receptors is essential and underpins policy. In the UK the current focus is on seabirds, marine mammals and benthic (seafloor) habitats as ecological receptors; however, impacts on bats from offshore wind remain relatively poorly understood. The evidence base for bats moving across the seas surrounding the UK is now growing. In addition, there are legal obligations relating to the protection of bats, including migratory species, making it essential for the UK to better understand the impact of offshore wind on bats and to act where impacts are identified.

Natural England commissioned the Bat Conservation Trust (BCT), partnering with the University of the West of England and University of Stirling, to carry out a study '*Assessing migration of bat species and interactions with offshore windfarms in British waters*'.

A literature review was undertaken including studies that examined bat migration within the British Isles and between the British Isles and Europe, the use of monitoring technologies, and the interaction of bats with wind energy infrastructure. 54 studies were found that directly related to bat migration over marine areas in northwest Europe and 37 were found that indirectly related to offshore bat migration. A further 56 studies were found that related directly to bat interactions with offshore wind turbines.

Based on the data available, Nathusius' pipistrelle (*P. nathusii*) are the most commonly recorded species offshore and are considered a regular migrant to the British Isles therefore putting them at the highest risk for interactions with offshore wind turbines. Analysis of data from BCT's *National Nathusius' Pipistrelle Project* confirms the presence of a both a resident and migratory population of *P. nathusii* in Great Britain (GB).

Surveys undertaken in the English Channel have also recorded both common pipistrelle (*P. Pipistrellus*) and soprano pipistrelle (*P. pygmaeus*), including individuals being 'rescued' from offshore wind turbines, however the extent of their activity or behaviour at sea is not currently known.

There is some limited evidence to suggest that long distance migratory *Nyctalus* spp. such as *N. noctula* and *N. leisleri* may migrate between the British Isles and Europe or Scandinavia. Due to the scarcity of knowledge surrounding the movement and behaviour of these species, no definitive conclusions can be made on the status of their behaviour or activity. The findings presented within this report represent the tip of the iceberg in our understanding of offshore bat movements around the British Isles.

Tagging, radiotracking and acoustic surveys indicate that *P. nathusii* movement across the Southern-North Sea generally peaks during the autumn migration window (Mid-August to late October) as well as a peak in migratory activity in spring (Mid-April to Mid-May). Whilst

it is known that bats move between the east/southeast of England and the European mainland, exact routes taken are not known. Furthermore, due to the scarcity of knowledge surrounding the movement of *P. nathusii* across the Northern-North sea, Celtic and Irish Sea and English Channel, only rudimentary conclusions can be made based on a small sample of recordings or occurrences.

Based on current data available, several environmental factors have been found to influence the offshore occurrence of *P. nathusii* with peaks occurring during easterly tailwinds <5 m/s and air temperatures >15°C in addition to relatively high atmospheric pressure. However, whilst certain environmental factors are often shown to be strong predictors of bat activity, the influence of these factors can be variable, bats will also migrate across open sea with low to moderate headwind or crosswind. During migration over sea, bats have been observed to primarily fly at low altitudes with most activity concentrated at the base of offshore turbines however, this can quickly change when they encounter offshore structures with records of bats investigating offshore structures up to 100 m above sea level placing them at greater risk from moving turbine blades.

There is currently a lack of studies specifically reporting how bats interact with offshore wind turbines however, it is widely assumed that bat behaviour around offshore wind turbines is likely to be similar to around onshore wind turbines and therefore offshore wind induced mortality is likely to occur at sea. Several hypotheses have been proposed to explain why bats are killed by wind turbines, including accidental encounters, the use of the tall structures as a display site during the breeding season, roosting opportunities mid-migration and the accumulation of insects creating increased foraging opportunities. A likely negative consequence of wind turbine-related collision/mortality is the cumulative impact on bat populations across Europe, particularly for migratory species. However, there are currently a lack of studies quantifying a direct link between wind turbine-related collision/mortality and population level impacts either onshore or offshore primarily due to limited baseline data, e.g. of population sizes, recruitment and dispersal rates in the absence and presence of wind turbines.

There are currently no ecological impact assessment or post-construction monitoring guidelines for bats and offshore developments in the UK. However, due to the mounting evidence documenting bats in the offshore environment either during migration or foraging at sea, current EUROBATS guidance indicates that offshore wind farms should be surveyed with the same robustness as onshore wind farms. Collecting baseline data prior to offshore wind development is important to understand the normal behaviour, distribution, and movement patterns of bats, not only to inform strategic planning of offshore development but also for comparison with post-construction monitoring to determine whether changes occur and how to address these in the future. Post-construction monitoring is an essential step for comparative analysis with pre-construction activity levels, to establish whether mitigation methods are successful, and to increase our understanding of the potential impacts of turbines on different bat species. A number of methods are available for monitoring bats in the offshore environment with their usage being highly context dependant. The best available guidance suggests that comprehensive monitoring schemes be put in place that focus on activity levels and mortality rates utilising both manual and long-term acoustic monitoring from the ground and at height complemented with videography and, if possible, radar and radio tracking.

A number of mitigation options are currently available that seek to limit the negative impacts of windfarm developments on bats. Whilst there is limited literature available on mitigating the impact of offshore wind farms specifically, there are a number of options that have been described in guidance relating to onshore windfarms and bats or have direct evidence supporting their efficacy at reducing impacts. Mitigation options should be considered at several stages of development: in the initial site assessment, pre-application (embedded mitigation including in the design of the turbines themselves), pre-construction and then, if necessary, at the post-construction stage.

The best strategy to avoid the risk to bats is preventative planning at the initial site assessment and pre-application stages of any development. Taking into account bat activity and behaviour during the screening and scoping phases of a wind farm development will contribute to evidence-based spatial and strategic planning that may avoid further mitigation requirements and associated financial implications during later stages of offshore wind development. This includes adjusting the proposed layout or location of the turbines within a development zone, to avoid areas that have been shown to have high bat activity or important migratory pathways. Post-construction wind turbine curtailment, including feathering turbine blades (pitching the blades out of the wind to reduce rotation speeds) and/or raising the cut-in speed (the wind speed at which blades start to turn), has been readily adopted both onshore and offshore in several European countries as an effective strategy to minimize bat fatalities.

Engagement with relevant projects was facilitated through the literature review and two structured, online workshop sessions in February 2024. The aims of these sessions were to consult, via guided discussion, a panel of experts and stakeholders on the potential impact of offshore wind farms on migrating bats and bat populations in British waters. This included the methods available for survey and monitoring in the offshore environment and mitigation solutions available to minimise impacts, drawing on knowledge from onshore, offshore, national and international where appropriate. Furthermore, these sessions aimed to identify existing industry guidance and opportunities to develop further research, guidance and policy in this area. As the work on the impact of offshore wind development on bats is still in its infancy, the workshops were designed to enable in-depth discussions and knowledge exchange among a panel of cross-sector experts in the fields of bat migration and/or wind energy as opposed to building consensus through established methodologies.

Main Recommendations

1. The profile of bats as an ecological impact receptor for offshore wind should be raised among decision makers and the offshore wind industry.

2. Government funding should be made available to build capacity for bats and offshore wind projects within Natural England, other Statutory Nature Conservation Bodies, non-governmental organisations, and academic institutions, to meet the UK's legal obligations.

3. Plans (including a timeline for implementation) should be developed to facilitate strategic, national monitoring of bat movements on and offshore to inform future offshore wind leasing rounds. High priority bat monitoring locations should be identified along with the most appropriate types of equipment for monitoring.

4. Consideration of a formal obligation, through Development Consent Orders or marine licence conditions, for developers to carry out pre- and post-construction site-level surveys and share data.

5. The potential to collate and share bat data, collected through strategic monitoring and site-specific surveys, via the Poseidon Project or the Marine Data Exchange should be investigated, along with how international data sharing could be facilitated through suitable community commons licence to allow use of the data.

6. The UK needs guidance on the survey and monitoring of bats in the offshore environment, which should be aligned with guidance in preparation by the EUROBATS Intersessional Working Group (Bats and Wind Turbines) and incorporated into Natural England's best practice advice and Defra's Offshore Wind Environmental Standards.

7. UK and international collaboration opportunities should be taken up for bat ecologists to work together but also to learn from ornithologists and work together on monitoring, as some equipment (e.g. MOTUS, videography, radar) will work for both bats and birds.

8. There are many evidence gaps that should be progressed in the UK through the funding of academic, NGO and industry-led projects. It is important to establish if bats are killed at offshore wind turbines, the number of casualties, which species and what conditions influence collisions as well as collision mitigation methods.

9. Finally, we recommend modelling of capture data from the National Nathusius Pipistrelle Project (NNPP) to investigate seasonal changes in the distribution and abundance of bats and whether these are affected by species, sex, age, reproductive status and weather conditions.

Contents

1. Introduction

At present most work on wind turbines and bats is focused on onshore impacts. However, as offshore wind projects are developing at pace with ambitious Net Zero targets in place across Europe (HM Government, 2021; European Commission, 2019), the potential for offshore wind farms to impact migrating bat species is moving up the international agenda (CMS, COP 14, 2024; UNEP-WCMC, 2024). Understanding the evidence base for the effect of offshore wind development and operation upon different environmental receptors is an integral component that underpins the statutory approach and subsequent policy for offshore wind development. However, in the UK, offshore wind project assessments for Environmental Impact (EIA), Habitats Regulations (HRA) and Marine Conservation Zones (MCZ) have identified a likely significant effect/impact pathway for seabirds, marine mammals, benthic (i.e. seafloor habitats and species) and designated fish species, and therefore these tend to be the focus. Bats remain a relatively poorly understood receptor for marine offshore developments in seas surrounding the British Isles, with a limited evidence base for interactions.

Aims and Objectives

In this review, we aim to evaluate the current understanding of bat migration throughout the British Isles and between the British Isles and continental Europe, as well as bat interactions with offshore (and onshore) wind turbines, highlighting any evidence gaps or areas of uncertainty. Furthermore, we review the current knowledge on species-specific bat migration routes, spatial patterns of migrations and environmental drivers of movement, including potential collision risk from offshore turbines, population and barrier effects and any effective examples of best practice gathered globally or from other disciplines.

Background

The world is facing an unprecedented biodiversity crisis with impacts being witnessed in every habitat on earth (Pimm et al., 2014; Ceballos et al., 2015; Cowie et al., 2022). Despite the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the International Union for Conservation of Nature (IUCN) and the Convention on Biological Diversity highlighting habitat loss and associated mortality as the primary cause of biodiversity decline, targets to reduce or halt biodiversity declines have not been achieved by governments (Mace et al., 2018; Bellard et al., 2022; Convention on Biological Diversity, 2023).

Furthermore, whilst climate change and biodiversity loss have been shown to be interdependent, requiring a holistic global strategy to address these crises, they are primarily tackled in siloes (Pettorelli et al., 2021). This can cause problems when objectives underlying each crisis may be conflicting and the resulting 'green-green' dilemmas can be particularly challenging as they involve two or more necessary goals, yet with detrimental counter-effects (Straka et al., 2020). The threat of climate change requires immediate action to mitigate the worst outcomes in the coming decades (IPCC, 2021), yet at the same time the global biodiversity crisis is driving species to extinction at alarming rates (IPBES, 2019). Stakeholders working in either camp may justify their solutions based on specific knowledge and expertise, but solutions may have no consideration for outcomes of other sustainability objectives. Moreover, finding consensus about the scale and speed of potential climate or biodiversity impacts, including how to handle regional versus global conservation problems, is often challenging. Such issues become even more complex if the solution to one problem is prioritised over, and in detriment to, the solution to another (Young et al., 2007, 2010; Dickman, 2010).

Figure 1. Rampion Offshore Wind farm © Jon Lavis 2018.

Overview of Wind Energy Development

One such green-green dilemma is the worldwide promotion and development of wind energy infrastructure (Straka et al., 2020). While transitioning from fossil to renewable energy sources is identified as one of the most important actions to combat the global climate crisis (Shukla et al., 2022), the ongoing negative impact on biodiversity is an urgent conservation issue (Voigt et al., 2015; Thaker et al., 2018). Wind power is a valuable asset for the UK's Net Zero Strategy (HM Government, 2021), with offshore wind continuing to be the leading renewable technology in 2022, accounting for 56% of all wind generation and a third of all renewable generation in the UK (Fig. 1; DUKES, 2023). At 45.0 TWh, offshore wind generation in 2022 alone exceeded total renewable generation of ten years ago (41.2 TWh; DUKES, 2023). Not only is wind power an efficient way of producing energy, but it also generates negligible greenhouse gas emissions when compared to fossil fuels (Lueken et al., 2012; Zhou et al., 2012) and the approximate greenhouse-gas payback time (i.e. the time in which the system must operate to offset the emissions embedded in its production) for wind turbines in Europe is now only a few months (Dammeier et al., 2019). However, despite their many benefits and their integral part in climate change mitigation, wind farms, like most renewable technologies, can have negative impacts on biodiversity (Gibson et al., 2017; Pörtner et al., 2021). During the construction phase of development, all energy production infrastructure will inevitably impact the environments where they are installed through the functional loss or fragmentation of habitats. However, wind energy also has the potential to impact the surrounding aerosphere and cause direct mortality in associated flying taxa during the operational phase (Leroux et al., 2023).

Due to its geographic location, the UK has some of the most favourable conditions for wind power generation in the world and as a result wind energy is seeing consistent growth year on year (Asif and Muneer, 2007; RenewableUK, 2023). In addition to being popular with the public (YouGov, 2018, 2021), wind energy offers the most cost-effective choice for new electricity in the UK and as of 2022 domestic wind energy generation totalled 28,493MW, making the UK the third largest wind energy producer in Europe (WindEurope, 2023). At the end of 2023, installed onshore wind turbines totalled 8,985 across 2,629 projects and creating an operational capacity of 14,972MW (RenewableUK, 2023; DUKES, 2023). A similar operational capacity of 14,735MW has also been achieved for offshore wind albeit from only 2,766 turbines spread across 44 projects (RenewableUK, 2023; DUKES, 2023; Fig. 2).

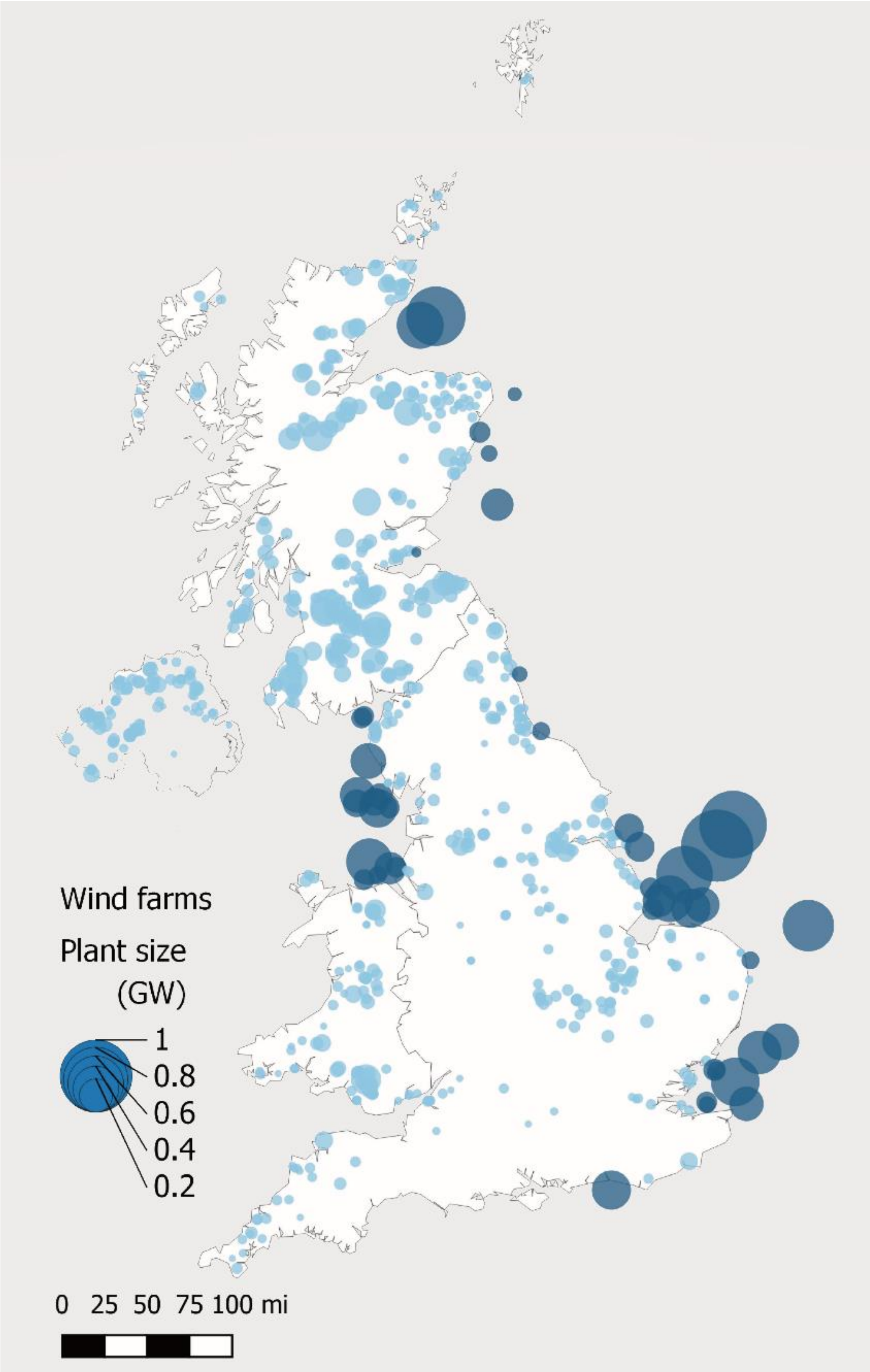


Figure 2. Operational onshore and offshore wind farms in the UK as of 2022 with a capacity of 0.5 GW or more. There are approx. 9000 sites below this threshold as well as other sites that are excluded due to the lack of location data. The locations in this graphic are representative and not exact. Reproduced from DUKES map data by permission of the Department of Energy Security and Net Zero © Crown copyright 2023.

The rapid increase in offshore turbines has resulted in the UK becoming a world leader in offshore wind energy, representing 46% of the total operational capacity of European offshore wind energy. Indeed, the UK commissioned the world's largest wind farm, Hornsea Two, which has an operational capacity of 1,386 MW and in 2022 the last of its 110 turbines (924 MW) were connected to the energy grid (WindEurope, 2023; Fig. 3). Furthermore, as of December 2023, Ørsted are progressing with the world's single largest offshore wind farm, Hornsea Three, which will have a capacity of 2.9 GW and is expected to be completed around the end of 2027 (Ørsted, 2023). Looking to future offshore wind development in British waters, Round 4 sites (8GW) have been leased and are going through examination process currently and Round 5 areas in the Celtic Sea, which will produce 4.5 GW, have been identified by Crown Estate with the leasing process completing next year.

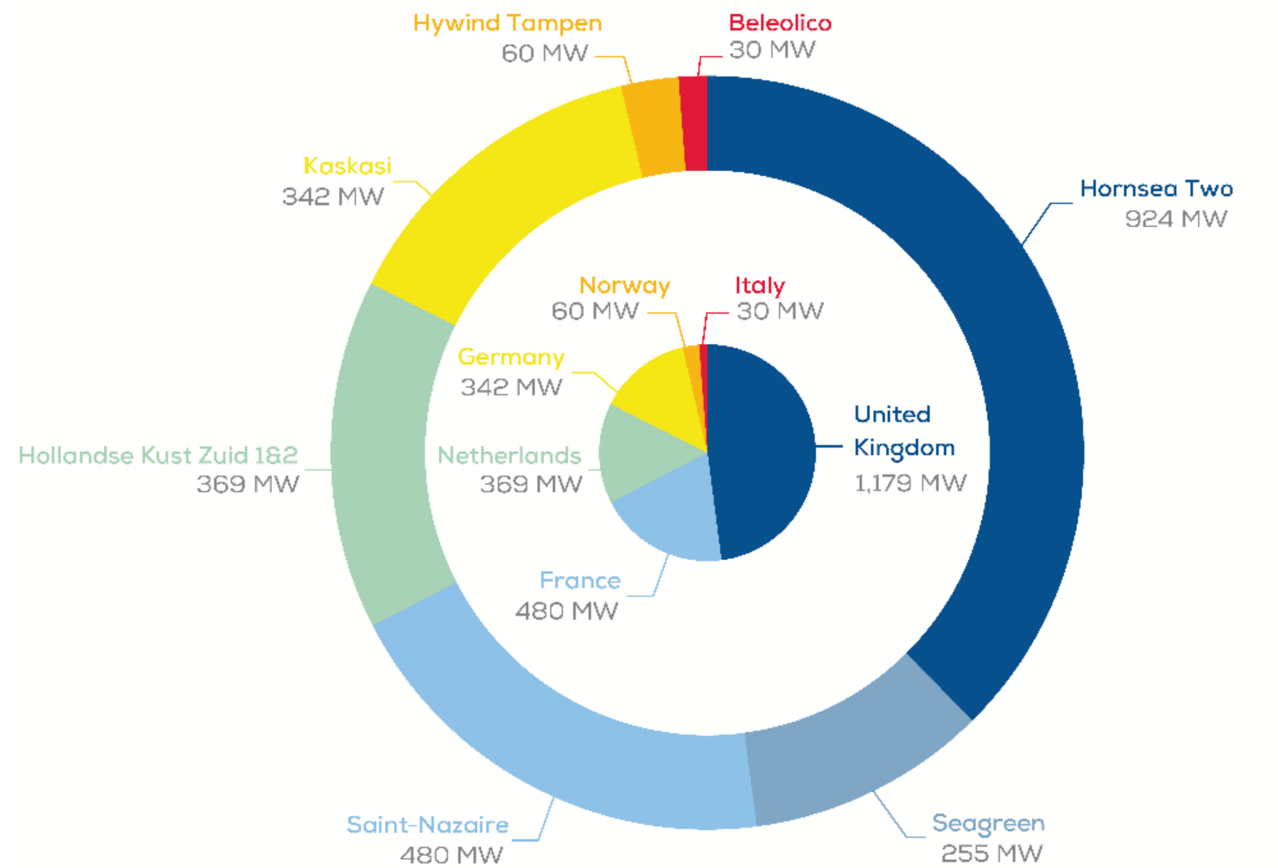


Figure 3. Operational capacities (MW) of new offshore wind infrastructure in Europe in 2022. Capacities are displayed by project and country (WindEurope, 2023).

Potential for Impacts between Wildlife and Wind Energy Infrastructure (Onshore and Offshore)

During their operation, wind turbines create significant airflow disturbances in a so-called "wake effect" that are generated by increased turbulences and decreased wind speed up to a few kilometres on the downwind side of the turbine (Porte-Agel et al., 2020). The disturbances caused by rotor movement, coupled with increased noise, vibration, lights, and increased human presence may decrease habitat suitability and resource availability near turbines (e.g., Campedelli et al., 2014) as well as creating antagonist behavioural responses within and between species (Dai et al., 2015; Gibson et al., 2017). Specifically, turbines can alter habitat use by flying taxa by generating attraction (Richardson et al., 2021; Guest et al., 2022) or avoidance responses (Barŕe et al., 2018; Gómez-Catasús et al., 2018) at different spatial scales. Attraction may increase fatality risk in the immediate vicinity of wind turbines (micro-scale, Cryan and Barclay, 2009; Marques et al., 2021; Tolvanen et al., 2023) while avoidance can include disturbance at the level of the entire wind farm (macroscale) or within the wind farm (meso-scale) and include displacement of migrating and commuting routes as well as functional barriers to foraging habitats and roosting opportunities (Roscioni et al., 2014; Tolvanen et al., 2023).

Bat-Wind Turbine Impact Pathways

The first observations that onshore wind turbines may be causing bat mortalities were made in the 1970s (Hall and Richards, 1972), however serious questioning of their impacts only emerged at the end of the twentieth century, with increasing observations of dead bats at onshore wind farms (Ahlén, 2003; Johnson et al., 2003). Whilst there are no reported records of bat casualties at offshore wind farms, bat casualties have been identified at European onshore wind farms for two decades (Table 1; Rydell et al., 2010; EUROBATS, 2023) during this time 29 species have been identified, with the majority consisting of common pipistrelle (*Pipistrellus pipistrellus*, 22%), Nathusius' pipistrelle (*P. nathusii*, 16%), noctule (*Nyctalus noctula*, 15%) and Leisler's bat (*Nyctalus leisleri*, 7%) (Table 1; EUROBATS, 2023).

Relative to the reported bat casualties, the real extent of bat mortality at onshore wind turbines is likely to be much higher since only the fatalities reported to EUROBATS Intersessional Working Group (IWG) members are included and no account is taken of biases such as survey effort, removal of carcasses by predators/scavengers, searcher efficiency, the proportions of turbines that have been surveyed, and the proportion of available search area that has been covered (EUROBATS, 2023). Nonetheless, the reported casualties suggest *Pipistrellus* spp. (57% of casualties) and *Nyctalus* spp. (23% of casualties) are likely to be most at risk from wind turbines whereas relatively few casualties have been recovered of other common and widespread species such as brown long-eared bats (*Plecotus auritus* 0.08%) or *Myotis* spp. (0.5%) (EUROBATS, 2023).

Whilst this could suggest that these species are at lower risk than species in the *Nyctalus* and *Pipistrellus* genera, it may also be a consequence of the open environments from which most of the data is derived, as there is a general paucity of research on wind turbines 'key-holed' into woodlands. What studies do exist of forest-dwelling bats such as *Myotis* and *Plecotus* spp. have found lower bat activity or general avoidance in forested areas with wind turbines, suggesting that bats could be excluded from important foraging or commuting areas as a consequence of wind energy development (Ellerbrok et al., 2022; Gaultier et al., 2023; Reusch et al. 2023).

Legal Context of Bats in relation to Offshore Wind

All species of bats are protected throughout the UK through a series of domestic and international treaties and legislation, with slight differences in approach to the protection of bats taken by the different devolved administrations. The UK is a contracting party to the 1979 Convention on the Conservation of European Wildlife and Natural Habitats (commonly referred to as the Bern Convention) and the 1983 Convention on the Conservation of Migratory Species of Wild Animals (commonly referred to as the Bonn Convention). Under the framework of the Convention on Migratory Species the UK has also ratified the legally binding Agreement on the Conservation of Populations of European Bats (EUROBATS). In addition, the Habitats Directive (Council Directive 92/43/EEC) was adopted in 1992, requiring Member States to establish a strict protection regime for listed species, including bats. At the time, the UK was a Member State and implemented domestic legislation accordingly, which still stands at the time of writing despite the UK having left the European Union in January 2020.

The provisions of these conventions and the Habitats Directive with regards to bats and their transposition into law are discussed in full in the latest *UK Bat Mitigation Guidelines* (Reason & Wray, 2023) and can be found at legislation.gov.uk. In addition to protecting individual bats, their breeding sites and resting places, specific legal protections make it an offence to deliberately disturb bats so as to significantly affect the local distribution or abundance of the local population and includes impair their ability to survive, breed, hibernate or migrate.

Whilst these regulations do indicate that it is an offence to disrupt a bat's ability to migrate across the landscape, bat casualties at wind farms may be considered an example of incidental killing as described in guidance to the Habitats Directive (p. 40 para. 75; European Commission, 2021) and may not therefore be considered an offence in isolation. However, at a certain level of impact such killing may cease to be incidental and become deliberate or reckless (according to domestic law). The level of impact and meaning of offences under the above legislation is not straightforward, whether or not an offence has occurred would be a matter for the police, court and lawyers, but they will rely on advice by experts informed by the best available scientific evidence.

Despite the legal protection afforded to bats and the first commercial onshore wind farm opening in the UK in 1991, little attention was paid to the potential wind energy impacts on bats until 2008, when concerns about bat fatalities onshore were reported in the USA, Germany and elsewhere. Parties to the EUROBATS Agreement were therefore urged to draw up national monitoring strategies to fulfil statutory obligations for onshore wind (Rodrigues et al., 2008).

Table 1. Reported bat fatalities in Europe by species and country from 2003-2019. Data comprises records submitted to EUROBATS Intersessional Working Group members of bat fatalities found either accidentally or during post-construction monitoring. Table reproduced from data from EUROBATS, 2023. (Note: Some cells are deliberately left blank)

Key: AT = Austria, BE = Belgium, CH = Switzerland, CR = Croatia, CZ = Czech Rep., DE = Germany, DK= Denmark, ES= Spain, EE = Estonia, FI = Finland, FR = France, GR = Greece, IL = Israel, IT = Italy, LV = Latvia, NL = Netherlands, NO = Norway, PT = Portugal, PL = Poland, RO = Romania, SE = Sweden, UK = United Kingdom

Species Name	AT	BE	CH	CR	CZ	DE	DK	ES	EE	FI	FR	GR	IL	IT	LV	NL	NO	PT	PL	RO	SE	UK	Total
Nyctalus noctula	46	1		2	31	1200		1			131	10						2	16	85	14	11	**1550**
N. lasiopterus								21			7	1						9					**38**
N. leislerii		2	1	21	3	180		15			174	58		2				273	5	19			**753**
Nyctalus spp. & Nlei/Vmur				1				2			5							17		8			**33**
Eptesicus serotinus	1	2			11	63		2			29	1				2			3	1			**115**
E. isabellinus								117										2					**119**
E. serotinus/isabellinus								98										17					**115**
E. nilssonii	1				1	6			2	6					13		1		1	1	13		**45**
Vespertilio murinus	2	1		15	6	145					12	1			1				8	15	2		**208**
Myotis myotis						2		2			4												**8**
M. blythii				1				6			1												**8**
M. dasycneme						3																	**3**
M. daubentonii						7												2					**9**
M. bechsteinii											1												**1**
M. emarginatus								1			2							1					**4**
M. brandtii						2																	**2**
M. mystacinus						3					3	1											**7**
M. nattereri						1																1	**2**

Species Name	AT	BE	CH	CR	CZ	DE	DK	ES	EE	FI	FR	GR	IL	IT	LV	NL	NO	PT	PL	RO	SE	UK	Total
Myotis spp.						2		3			1									4			**10**
Pipistrellus pipistrellus	2	36	7	7	16	702		211			930			1		15		323	3	11	1	46	**2311**
P. nathusii	13	6	6	50	7	1066	2				285	35		1	23	8			16	111	5	1	**1635**
P. pygmaeus	4			6	2	134					172				1			42	1	5	18	52	**437**
P. pipistrellus/pygmaeus	1		3					271			39	55						38	1	3			**411**
P. kuhlii				126				44			199		22					51		15			**457**
P. pipistrellus/ kuhlii				12								1						19					**32**
Pipistrellus spp.	8	4		60	9	91		25			211	1			2			109	2	48		12	**582**
Hypsugo savii	1			206		1		50			54	28		12				56		2			**410**
Barbastella barbastellus						1		1			4												**6**
Plecotus austriacus	1					8																	**9**
P. auritus						7																1	**8**
Tadarida teniotis				10				23			2							39					**74**
Minopterus schreibersii								2			5							4					**11**
Rhinolophus ferrumequinum								1					1										**2**
R. mehelyi								1															**1**
Rhinolophus spp.								1															**1**
Rhinopoma microphylum													5										**5**
Taphozus nudiventris													3										**3**
Unidentified bat spp.	1	1		48	1	77		320	1		317	8	2	1				120	3	7	30	9	**946**
Total	**81**	**53**	**17**	**565**	**87**	**3701**	**2**	**1218**	**3**	**6**	**2588**	**200**	**33**	**17**	**40**	**25**	**1**	**1124**	**29**	**335**	**83**	**133**	**10371**

History of Bat-Wind Turbine Guidance in the UK

Following on from interim guidance published by the Statutory Nature Conservation Bodies (SNCBs) in 2009, with minor updates being published in 2012 and 2014 (Natural England 2009, 2012, 2014) EUROBATS reviewed the current research surrounding the impacts from wind energy infrastructure and developed guidelines (see Rodrigues et al., 2014) for assessing the potential impacts on bats.

The EU have subsequently published broader guidance on wind energy developments and nature legislation (Directorate-General for Environment, European Commission, 2020) which supersedes 2011 EU guidance that focused on Natura 2000 sites and the species for which they were designated. The more recent guidance builds on Rodrigues et al. (2014) and summarises recent research from across Europe, covering both onshore and offshore development. In 2022, a new EUROBATS resolution was adopted which places a broader range of requirements on member states (including assessing impacts in offshore developments and conducting pre- and post-construction monitoring).

The EUROBATS guidelines have been adapted and interpreted in a UK context by the SNCBs who have jointly published comprehensive guidance relating to bats and onshore wind turbines and the risk to European protected species (Mathews et al., 2016: NatureScot et al., 2021). These supersede guidance published by Natural England (Natural England, 2014) and Bat Conservation Trust (BCT; Hundt, 2012). The new guidance categorises likely risks to different bat species as ‘high’, ‘medium’ or ‘low’ according to habitat preference, migratory movements and flight/foraging characteristics (Table 2).

Table 2. Assessment of collision risk of wind turbines for UK bat species based on physical and behavioural characteristics including evidence of casualty rates in the UK and rest of Europe. Table reproduced from Appendix 3 in *Bats and onshore wind turbines – survey, assessment and mitigation*, NatureScot et al., 2021.

	Risk of turbine impact		
Factor	**Low Risk**	**Medium Risk**	**High Risk**
Habitat preference	Bats preferring cluttered habitat	Bats able to exploit background cluttered space	Bats preferring to use open habitat
Echolocation characteristics	■ Short range ■ High frequency ■ Low intensity ■ Detection distance ~15m	Intermediate – more plastic in their echolocation (excl. *B. barbastellus*)	■ Long range ■ Low frequency ■ High intensity ■ Detection distance ~80m (excl. *Pipistrellus* spp.)
Wing shape	■ Low wing loading ■ Low aspect ratio ■ Broadest wings	Intermediate	■ High wing loading ■ High aspect ratio ■ Narrow wings
Flight speed	■ Slow	■ Intermediate	■ Fast
Flight behaviour and use of landscape	■ Manoeuvre well ■ Will travel in cluttered habitat ■ Keeps close to vegetation ■ Gaps may be avoided	■ Some flexibility	■ Less able to manoeuvre ■ May avoid cluttered habitat ■ Can get away from unsuitable habitat quickly ■ Commutes across open landscape
Hunting Techniques	■ Hunt close to vegetation ■ Exploit richer food sources in cluttered habitat ■ Gleaners	■ Hunt in edge and gap habitat ■ Aeriel hawkers	■ Less able to exploit insect abundance in cluttered habitat ■ Aerial hawker ■ Feeds in open

	Risk of turbine impact		
Factor	**Low Risk**	**Medium Risk**	**High Risk**
Migration	■ Local or regional movement	■ Regional migrant in some parts of range	■ Long-range migrant in some parts of range
Conclusion	**Low Risk** ■ Myotis spp. ■ *Plecotus* spp. ■ *Rhinolophus* spp.	**Medium Risk** ■ Eptesicus serotinus ■ *Barbastella barbastellus*	**High Risk** ■ Pipistrellus spp. ■ *Nyctalus* spp.

Additional guidance relating to mitigating wind turbine-related mortality on bats has been summarised in the latest UK Bat Mitigation Guidelines (Reason and Wray, 2023) and outlines good practice based on the information and evidence available at the time of publication. This guidance focuses on onshore wind infrastructure and specifies that mitigation protocols begin with an assessment of risk that considers the likelihood of high-risk species and site-based risk factors, taking local bat activity records into account. It places a greater emphasis on avoidance as the primary means of reducing impacts and includes siting turbines away from bat migration/commuting routes and important foraging/roosting areas; creating buffer zones around nationally and regionally important roosts; establishing a buffer to other habitats specifically important for bats (tree lines, hedgerow networks, wetlands, waterbodies, and watercourses); and adjusting the layout of turbines in line with the avoid, reduce, mitigate hierarchy.

Wind Turbine Induced Mortality in Bats

Bats are killed at onshore wind turbines either by direct collision (blunt-force trauma) with the moving blades or by barotrauma i.e. tissue damage, particularly in the lungs and ears provoked by rapid changes in air pressure near the turbine blades (Baerwald et al., 2008; Grodsky et al., 2011). The relative importance of these two mechanisms is unclear as research suggests that most bats with barotrauma also have evidence of direct collision (Rollins et al., 2012). It is likely that the number of bat fatalities attributed to barotrauma is under-recorded as successful identification of barotrauma requires postmortem examination immediately after death, which is rarely feasible. Furthermore, barotrauma does not always instantly kill injured bats thus allowing for the possibility that the individuals might fly outside the radius of subsequent carcass searches at onshore turbine locations (Rollins et al., 2012).

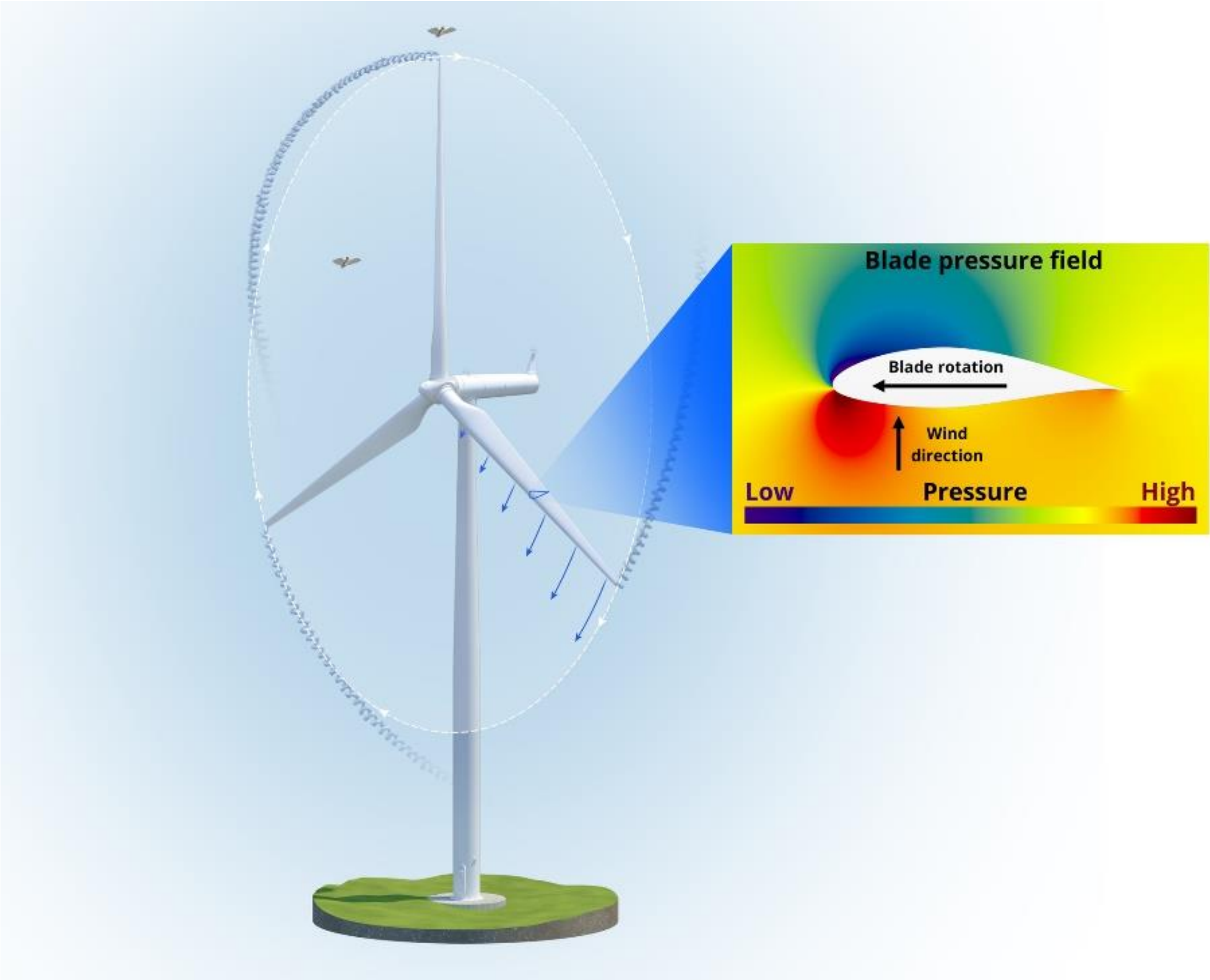


Figure 4. The pressure change caused by operating wind-turbine blades. Local flow accelerations cause high-pressure fields (displayed as red) to form over the upwind side of the blade with low pressure fields (displayed as blue) forming over the downwind side of the blade, as well as a region of low pressure created by the vortex at the blade tip. The tip-vortex propagates downstream in the direction of the wind as shown. Graphic from Lawson et al., 2010. *An Investigation Into the Potential for Wind Turbines To Cause Barotrauma in Bats*. PLoS ONE 15(12): e0242485.

The extent to which turbine-induced mortality in bats can be attributed to barotrauma is the subject of much debate as empirical evidence documenting the impacts of pressure changes on bats is not feasible due to ethical considerations (i.e. subjecting live bats to lethal pressure changes). An analysis by Lawson et al. (2020) used computational fluid dynamics simulations of a wind turbine and analytical calculations of blade-tip vortices to estimate the characteristics of the sudden pressure changes bats may experience when flying near a utility-scale wind turbine. This study used mammals of a similar size e.g. rats and mice, as surrogates and found that the low-pressure field experienced by bats on the downwind side of the moving blade (Fig. 4) is nearly eight times smaller than the pressure that causes mortality in rats. In addition, the high-pressure field on the upwind side of the moving blade (Fig. 4) is approximately 80 times less than the exposure level that causes 50% mortality in mice.

Whilst physiological difference between bats and rodents can make direct comparisons difficult (Baerwald et al., 2008), the study concluded that the pressure changes required to cause barotrauma are so close to the turbine blade (i.e. bats would have to skim the surface of the blade) that it is highly unlikely that a bat could experience barotrauma without also being struck by the moving blade. It is important to note that the study by Lawson et al. (2020) was based on a 5MW reference turbine with a rotor diameter of 126m whereas the next generation of offshore wind turbines will have a rotor diameter of 200m or more. The authors conclude that future research is required to ascertain how turbine size may impact bat interactions with turbines which will likely to be a product of their behaviour.

To maintain optimal ratio of blade-tip speed to wind speed (i.e., tip-speed ratio; Manwell et al., 2010), rotor revolutions per minute (RPM) must decrease linearly with turbine radius. If bats fly mostly near the nacelle, where the blades of large turbines move relatively slowly, the number of fatalities per MW of installed capacity may be reduced for large offshore turbines. However, if bats interact with the turbine blades away from the hub where blade speed is high the opposite may be true. Evidence from studies onshore have identified that mortality not only depends on the dimensions and the location of the wind turbine within the wind farm (Baerwald & Barclay, 2009) but bat mortality can increase with both the tower height and the rotor diameter, which could potentially make offshore turbines more dangerous due to their increased size (Rydell et al., 2010; Mathews et al., 2016; Thaxter et al., 2017).

Whilst it may be unlikely that barotrauma forms a significant component of turbine-related fatalities worldwide, the exact mechanisms behind bat fatalities at wind farms is dependent on how bats interact with turbines in the landscape, where and when they encounter them and the current environmental conditions at the time of these interactions (e.g. inclement weather may initiate roosting behaviour, whilst warm still weather may increase insect prey availability).

Current knowledge on fatality risk in bats suggest that the species most prone to collisions with onshore wind turbines are aerial hawkers such as *Pipistrellus* spp. and *Nyctalus* spp. that have echolocation characteristics, wing shape and flight speeds adapted for movement in open space and for hunting flying prey further from the ground or landscape features. In contrast, the lower-risk species such as *Myotis* spp. or *Rhinolophus* spp. hunt close to surfaces or directly in the vegetation, which decreases the time that they spend in the turbine rotor sweep zone, reducing the probability of collision (Table 1; Table 2; Rydell et al., 2010).

The characteristics of bat collisions with operating onshore turbines in Europe have been extensively studied, with fatalities occurring primarily during autumn migration, roughly from August to mid-September, with a smaller peak also noted during spring for certain migration pathways across Europe (Rydell et al., 2010; Schuster et al., 2015; O'shea et al., 2016; Roemer et al., 2019; Gaultier et al., 2020). Migratory activity, an established risk factor for wind turbine collisions in Europe and North America, was until recently thought to be absent among bats in the British Isles. However, the evidence gathered through a suite of methods (e.g. acoustic surveys, ring recaptures, stable isotope analysis and radio telemetry) used to investigate bats migrating between the UK and mainland Europe, as well as between distinct areas of the British Isles, is highlighting the extent of migration habits of Britain's bats, particularly the *P. nathusii* population (National Nathusius' Pipistrelle Project, 2024). Whilst not considered a form of migratory movement, infrequent immigration of bats into the UK from mainland Europe have also been demonstrated through disease transmission studies whereby passive surveillance of *Eptesicus serotinus* recorded a previously absent strain of European bat lyssavirus 1 (EBLV-1) into the UK (Folly et al., 2021).

The exact timings of fatalities can vary geographically across Europe with southern latitudes generally experiencing a longer collision risk window (Georgiakakis et al., 2012; Sánchez-Navarro et al., 2019). Collision risk has been found to be correlated with favourable weather conditions for foraging and commuting with nights of low wind speed, warmer temperatures and no precipitation associated with the highest collision risk (Rydell et al., 2010; Arnett and Baerwald, 2013; Cryan et al., 2014). However, in North America it has been observed that large-scale weather phenomena, such as high-pressure areas and low humidity, can be a more accurate indicator for predicting bat-turbine collisions than local weather conditions (Arnett et al., 2008).

2. Literature Review

Methodology

Literature Search

We conducted a literature review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocols (Page et al., 2021). PRISMA is a standard protocol for conducting objective and reproducible reviews to improve scientific transparency. We searched for studies that examined bat migration within the British Isles and between the British Isles and Europe, including the use of monitoring technologies or approaches to investigate migration pathways. We also searched for studies on the interaction of bats with wind energy infrastructure including established or novel technologies to monitor and mitigate interactions of bats with wind turbines.

We searched the Web of Science Core Collection, Scopus, and Google Scholar for English language peer-reviewed publications published on all continents. The search fields varied by options available in respective databases, for Google scholar we conducted a full article search (default parameters for keyword searches), whilst for Web of Science-indexed databases and Scopus, we searched using the title-abstract-keyword search. For all databases we included an index search of citation records to include publications that may not be available on the respective databases. We used the following search terms to find studies on the migration of bats within and between the British Isles and Europe: ('bat*' OR 'Chiroptera') AND (migration* OR movement* OR dispersal* OR migratory OR dispersion). An additional search was also completed using the same protocol using the following search terms to find studies on the interactions between bats and wind farm developments: ('bat*' OR 'Chiroptera') AND 'wind' AND (farm* OR energy* OR windfarm* OR industry* OR wind-farm* OR park* OR development*). In order to comprehensively address our research questions, we also searched for relevant grey literature, conference proceedings, personal communications, technical reports and unpublished data. The final search was carried out in February 2024.

Article Screening and Classification

For the review process, all articles that appeared in each search string were exported into the Rayyan intelligent systematic review tool (Ouzzani et al., 2016) which was used to deduplicate repeated references across databases. Reviewers then used an inclusion/exclusion protocol to make final decisions for each article in Rayyan after screening the title, abstract and full-text levels. The articles retrieved from indexed databases were first screened by title and abstract and documents were excluded that did not study either the migration of bats, the impacts of wind energy infrastructure on bats, or techniques and technologies used to monitor and mitigate impacts to bats. More specifically, we interpreted interactions as any measured effect whether positive, negative or neutral, in response to the construction or operation of wind energy infrastructure. We included impacts that were either explicitly measured through observational or experimental studies or predicted based on modelling, molecular or genetic approaches.

As the aim of this review is to establish a baseline on the overall current state of knowledge of bat migration within and between the British Isles and Europe including current knowledge on the potential impacts of offshore wind, we excluded studies focused only on onshore wind development from the literature search section of this review. Furthermore, whilst we included studies on the interactions between bats and offshore wind turbines internationally, we only included studies on bat migration in North-west Europe and on species relevant to a British context.

Literature Review

Whilst the main review focused on bat migration around the British Isles and bat interactions with offshore wind turbines, the purpose of the literature review was to use knowledge gained from theoretical and empirical studies in other landscapes or with other taxa to inform our understanding of potential impacts. This includes a review of technological advances in the area of wildlife monitoring that may have potential future applications.

Due to the high volume of literature available studying the interactions of bats with onshore wind infrastructure, a targeted literature review was undertaken to inform our current knowledge on this topic. This non-systematic review of the evidence focused on the most up to date studies and reviews, taking an in-depth but not systematic approach to the research question. The literature identified has been used and cited throughout this report to establish the current knowledge base surrounding bat physiology and behaviour, turbine collision risk (by species) and technical information relating to offshore wind turbine location, construction and operation.

Where applicable and transferable, specific literature on the interaction of bats and onshore wind has been used to inform our understanding of the impacts of offshore wind on bats, particularly where evidence gaps have been identified during the literature review. These topics include, but are not limited to:

- Bat behaviour at wind turbines
- Potential barrier and population effects
- Pre-construction ecological impact assessments
- Monitoring methods
- Mitigation methods

Non-English literature

Whilst our literature review only included English language search terms, the inclusion of non-English literature identified during the index search of citation records was facilitated through the utilization of Google Translate, a widely accessible machine translation tool. Non-English texts relevant to our research objectives were identified, downloaded as a PDF and inputted into the Google Translate interface (Google, n.d). This platform automatically translated the text into the desired language, enabling comprehension for analysis. It is important to note that while Google Translate provides a convenient means of accessing non-English resources, potential limitations such as translation inaccuracies and the loss of linguistic nuances were considered. To mitigate these issues, efforts were made to validate key findings through consultation during workshop sessions. The use of Google Translate supplemented by human validation ensured a comprehensive and accurate interpretation of non-English literature in our study.

Workshop Sessions

Expert international opinion was solicited through two structured, online workshop sessions conducted for the purpose of this study. The workshops were organised to facilitate in-depth discussions and knowledge exchange among a panel of experts in the relevant field of bat migration and interactions with offshore wind energy. Delegates were selected based on their expertise and experience in the subject matter and included academics, professional and voluntary ecologists, renewables industry professionals, environmental consulting firms, NGOs and representatives from national and international SNCBs and Government departments. A full list workshop attendees as well as their affiliations has been included at Appendix A.

Each of the workshops started with a series of short presentations from delegates working in the field of bat migration and/or wind energy, followed by questions. After the presentations, specific questions or topics related to the research objectives were shared with the delegates. They were invited to contribute information and ideas by adding virtual sticky notes to topic-specific frames on an online white board (Miro). The Miro boards were kept open for five days after each of the two workshops to allow delegates to further contribute. The populated Miro boards were used to inform discussions both in plenary and in smaller groups in breakout rooms. All of the discussions were moderated to ensure comprehensive exploration of the issues at hand. Expert opinions were recorded through detailed notes on the Miro boards (allowing delegates to observe what was being recorded live) and audio/visual recordings for subsequent analysis and incorporation into the study findings. Agendas for the two workshops, including the objectives and proposed outputs, are included in Appendix B and C. More details on the two sessions are provided in Section 3, Workshops.

Confidence levels

The confidence levels in the evidence (type, amount, quality and consistency) have been discussed throughout the text where this is possible but have not been formally assigned (i.e. limited, medium or robust). The degree of agreement across the literature review, data from tagging and MOTUS, and workshop participant discussion groups and mural boards has been discussed qualitatively within the text where possible but has not been formally assigned (low, medium, high). The list of recommendations represents the full range of views gathered throughout the report, these have not been weighted but rather grouped by thematical area.

The robustness of the evidence and level of agreement has not been weighted in this report as it very much represents a start of discussions in this emerging field. We suggest that further workstreams in this field, as evidence and discussions develop, should assign a level of confidence expressed using five qualifiers: “very low,” “low,” “medium,” “high,” and “very high.” (IPCC,2010, PPCC, 2021) based on the evidence and agreement.

Results

We determined 54 studies were directly related to bat migration over marine areas in northwest Europe. In addition, 37 studies were indirectly related to offshore bat migration (e.g. migration behaviour over land, population dynamics, genetic/molecular studies and general modelling approaches) but relevant to the migratory species or geographic areas important for this review. We assessed the combined direct and indirect studies by geographical area and hypothesis, with 36 relating to the North Sea, five to the English Channel, four to the Celtic and Irish Sea, and nine to the Baltic Sea. In addition, 24 studies looked at the behaviour of migrating bats, 10 studies considered migration through either molecular or genetic techniques and three were based on modelling techniques. Several studies include results related to more than one geographical area. An overview of research that pertains to bat migration within the British Isles and between the British Isles and Europe is in Appendix E.

We determined 53 studies were directly related to bat interactions with offshore wind turbines. We assessed the studies by topic, with 21 relating to bat activity around offshore wind turbines, seven relating to the impacts of offshore turbines on bats, two relating to mitigation of impacts and 10 to monitoring of bat activity at offshore turbine locations. In addition, 10 reviews were included that had direct relevance to the interactions of bats with offshore infrastructure. An overview of research that pertains to bat interactions with offshore wind turbines is in Appendix F.

Bat Migration within the UK and between the UK and Europe

Migratory movement is a prominent life history trait and adaptive strategy that sees many of the world's fauna travelling long distances to exploit seasonal resources and improve their chances of reproductive success. Animals in temperate zones face substantial seasonal fluctuations in climatic and environmental conditions that require both physiological and behavioural changes that align with or precede seasonal changes (Baker, 1978; Dingle, 2014). Bat migration between summer and winter areas is a widespread phenomenon in temperate climates (Fleming & Eby, 2003; Popa-Lisseanu & Voigt, 2009; Krauel & McKracken, 2013; Ciechanowski et al., 2016; Lehnert et al., 2018), with bats exhibiting three broad spatial patterns of behaviour including regional (typically 100–500 km) or long-distance (> 1000 km) seasonal movements and partial migration. Partial migration may occur in which some populations of a migratory bat species perform seasonal movements while other populations remain sedentary. This is known to occur in a number of European bat taxa including *Nyctalus* spp. and *Pipistrellus* spp. (Krauel & McKracken, 2013; Rydell et al., 2014).

Whilst the migratory movements of bats have been described for over a century (Miller, 1897), evidence of seasonal migration in to and out of the UK has historically been largely anecdotal. However, with the increased interest in migration of bats across Europe as well as the increased availability and deployment of emerging remote sensing technology, studies are starting to uncover migratory pathways across the British Isles. So far, most information pertaining to the migratory ecology of bats has been gathered through studies in terrestrial habitats, with scientific knowledge on bats migrating over open sea being scarce. In this review, we discuss the evidence on species-specific bat migration to and from the UK, summarise the current state of knowledge, including potential migratory pathways and outline remaining questions and future research priorities.

Bat Migration across the North Sea

The North Sea is the shallow continental shelf sea covering an area of 570,000 square kilometres constituting the northeastern arm of the Atlantic Ocean. The sea is bordered by the island of Great Britian to the southwest and west, the Orkney and Shetland islands to the northwest, Norway to the northeast, Denmark to the east, Germany and the Netherlands to the southeast, and Belgium and France to the south (Talley et al., 2011; Alexander, 2024).

Since the mid-1980s, reports from offshore platforms have indicated the regular movement of bat species across the North Sea (Russ et al., 2001; Boshamer and Bekker, 2008). Since this time, the southern North Sea has become an epicentre of bat migration research between the UK and Europe, an effort led in part by several European countries (Belgium, Netherlands and Germany) and the development of offshore wind farms in this area.

In the North Sea, bats have been recorded over the past few decades either through occurrence on offshore structures or through a concerted effort to document their movements or migratory patterns (e.g. Walter et al., 2007; Boshamer and Bekker, 2008; Hüppop & Hill, 2016; Brabant et al., 2021; Lagerveld et al., 2023). *P. nathusii* is the most frequently observed bat species offshore (Boshamer & Bekker, 2008; Brabant et al., 2021; Hüppop & Hill, 2016; Lagerveld et al., 2014, 2021) and as a result the majority of studies are focused on this species. *P. nathusii* is found from western Europe to Asia Minor (Corbet & Harris, 1991; Strelkov, 1997a,b; Mitchell-Jones et al., 1999) and their main breeding areas are found in central and eastern Europe and potentially further east in Russia (Hargreaves, 2024, pers. comm.). *P. nathusii* is an example of a partial migrant whereby populations in central Europe are sedentary or migrate over short distances (Sachanowicz et al., 2019), whereas eastern populations are known to perform long-distance seasonal movements with the longest known migration distances in autumn recorded from Latvia to Spain (2224 km; Alcalde et al., 2021) and from Russia to France (2486 km; Vasenkov et al., 2022).

P. nathusii was first recorded in the British Isles in 1940, with a female museum specimen having been collected on Whalsay, one of the Shetland Islands (Herman, 1992). Due to the infrequency of historic records, it was initially regarded as a vagrant species (Stebbings, 1988) however, it was later afforded 'migrant winter visitor' status due to the presence of hibernating continental populations (Speakman, Racey, Hutson et al., 1991; Hutson, 1997). The status of *P. nathusii* in the British Isles was further updated in the late 1990s after a number of maternity colonies were documented, indicating that at least part of the UK *P. nathusii* population is resident and breeds successfully (Russ et al., 2001).

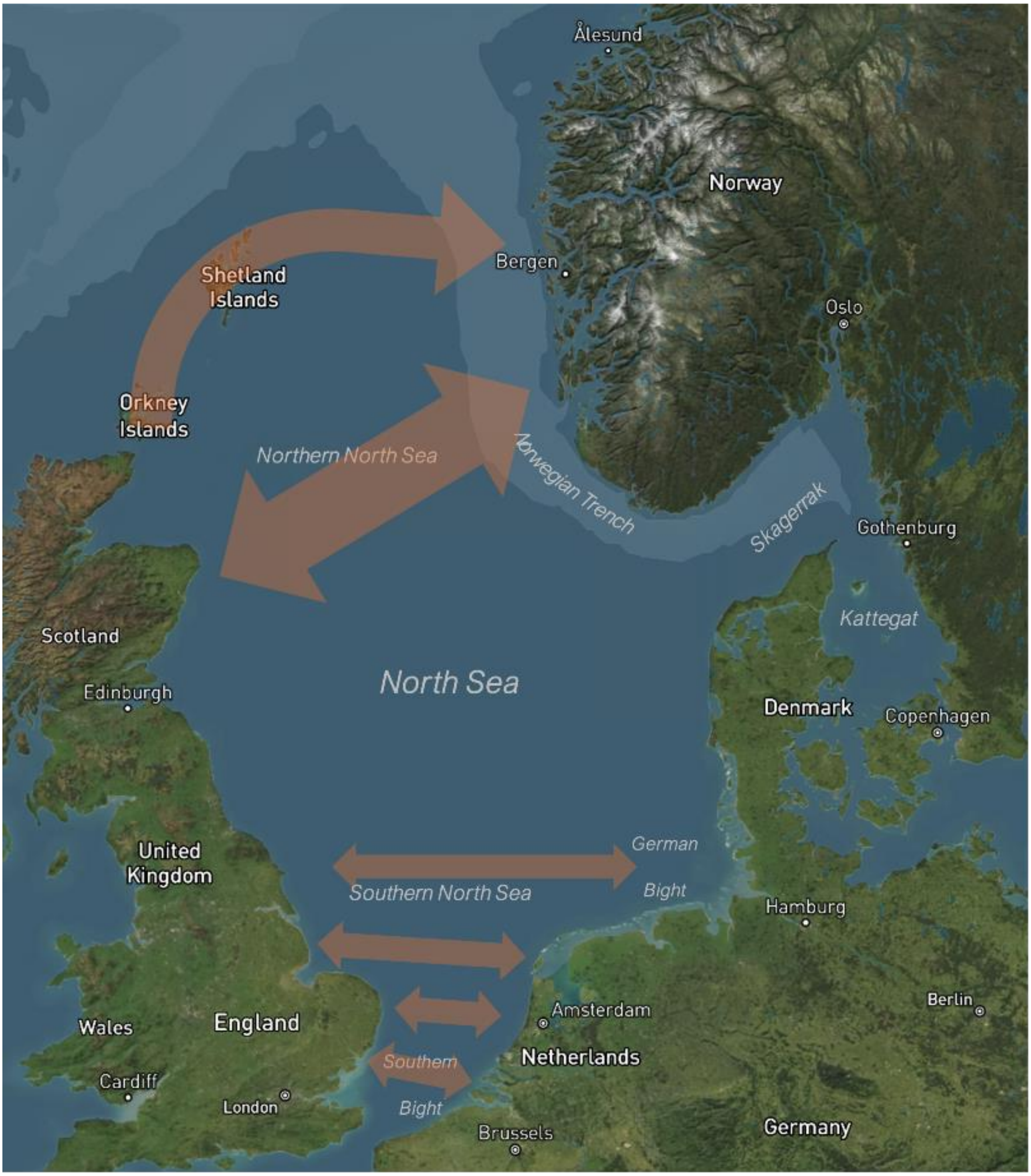


Figure 5. Potential bi-directional migration corridors across the North Sea between the British Isles, Europe and Scandinavia. Orange arrows indicate possible migration corridors as identified during the literature review. The evidence for migration across these broad fronts varies geographically and should only be taken as an indication (arrows are indicative and their size is not significant). Detailed discussion of the evidence base surrounding each of these corridors is discussed further within this review. © Mapbox © OpenStreetMap.

However, the status of *P. nathusii* populations in the British Isles are likely to change annually, with distinct geographical differences in distribution and demography.

National Nathusius' Pipistrelle Project

In 2014, The National Nathusius' Pipistrelle Project (NNPP) was established by BCT with the aims of determining the resident and breeding status of *P. nathusii* in Britain. This included gathering further information on distribution of *P. nathusii* in Great Britain and the Channel Islands as well as determining their migratory origins.

Surveys conducted as part of the NNPP found that capture rates of *P. nathusii* were highest in early April and late October, corresponding to periods during which migratory individuals are anticipated to be present in Great Britain, having arrived in late summer and early autumn, and departed again in the spring. The seasonal differences in capture rates suggest that the majority of the population of *P. nathusii* in Great Britain is migratory, with a smaller population remaining during the summer breeding season. A detailed summary report from the NNPP can be found can be found in Appendix G.

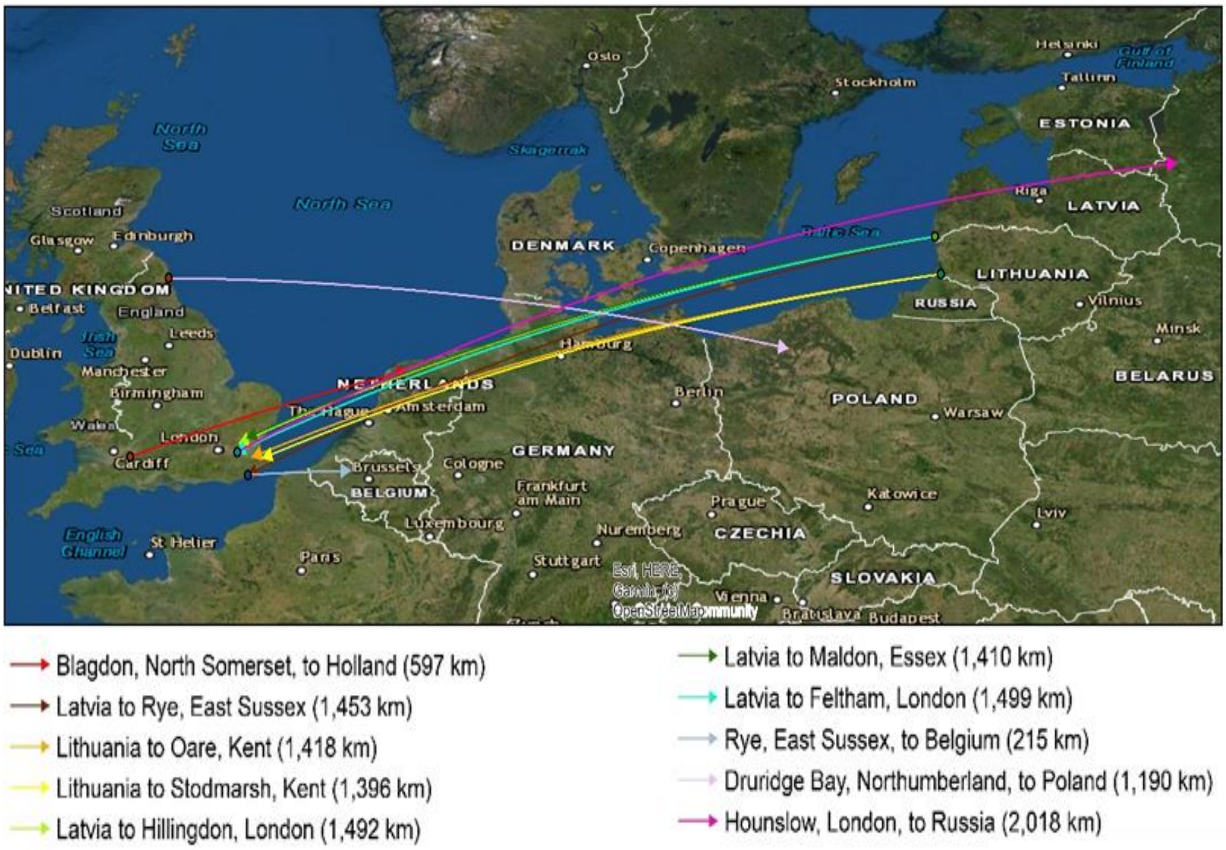


Figure 6. Ring recaptures of ten long distant migratory bats have been recorded as part of the National Nathusius' Pipistrelle Project. The minimum distances travelled, recapture dates and indicative flight paths are shown above.

After the breeding season, females and their offspring begin to migrate from their breeding areas in north-eastern Europe to their wintering areas in southern and western Europe (Russ et al., 2001). Along this route, males who may have been holding territories since spring, advertise to attract and mate with passing females (Strelkov, 1969a,b; Brosset, 1990; Jahelkova & Horacek, 2011). In late autumn/early winter, after the mating season, individuals from both sexes begin to migrate to lower latitudes further south-west to overwinter in western Europe, while others may hibernate in the same areas (Bastian, 1988; Brosset, 1990; Lina, 1990; Roer, 1995; Pētersons, 2004; Sachanowicz et al., 2019). During late spring, migratory populations of *P. nathusii* return to their traditional breeding areas in north-eastern Europe and Russia (Hutterer et al., 2005; Alcarde et al., 2020; Pētersons et al., 2014).

Bat Migration across the Southern North Sea

Bat migration across the open sea is an established phenomenon and bats are regularly found on offshore structures in the southern North Sea (e.g. Walter 2007; Boshamer & Bekker, 2008; Skiba, 2007; Brabant et al., 2016). However, in recent decades the use of technology combined with a concerted effort to ring migratory bats has allowed for more detailed research into the phenology and behaviour of bat migration over open sea. Ringing recoveries reported as part of the NNPP have confirmed long distance migrations of individuals following an east-northeast (ENE) west-southwest (WSW) route to and from the breeding areas in north-eastern Europe (Fig. 6; National Nathusius' Pipistrelle Project, 2024).

Similar migratory pathways across the southern North Sea have also been demonstrated using the MOTUS wildlife tracking system which utilises radio telemetry to track animal movement. This network of receivers has been specifically designed to track the movements of smaller animals such as bats and uses coded VHF radio tags attached to individual animals. The movement of tagged bats can be picked up by any receiving station on the network (Fig. 7) and the approximate flight path can be roughly assessed by connecting the locations of the receiving stations where the animal has been successively detected. Using this system, Harris and Parsons (2020), Briggs et al. (2023) and Lagerveld et al. (in prep.) have been able to construct probable flight corridors of *P. nathusii* as they cross the southern North Sea and eastern extent of the English Channel, as well as the pre-migratory activity of bats up and down the coastline (see Figure 5). Data of direct crossings can be combined with both biometric data from tagged bats and weather variables to gain a better understanding of the timings and demography of migration in this area. It should be noted that the data gathered from this method must be assessed in relation to the extent of the receiver network along the coastline. After registration at a MOTUS receiver, bats may continue to move further up or down the coast before crossing or after reaching the other coast, but these movements would not be detected. Furthermore, as there are no current MOTUS receivers stationed offshore, we do not know the behaviour or the exact flight paths of bats once they are out at sea. This is anticipated to change in the near future with organisations such as the RSPB looking to install MOTUS receivers in the North Sea[1].

Whilst radio telemetry has captured greater details of the migratory pathways of bats crossing the southern North Sea, acoustic monitoring through the deployment of ultrasonic detectors has yielded additional insights into the migratory activity and behaviour as well as environmental factors that determine the species offshore occurrence.

[1] psg-meeting-website-powerpoint-sept-2023.pdf (ctfassets.net)

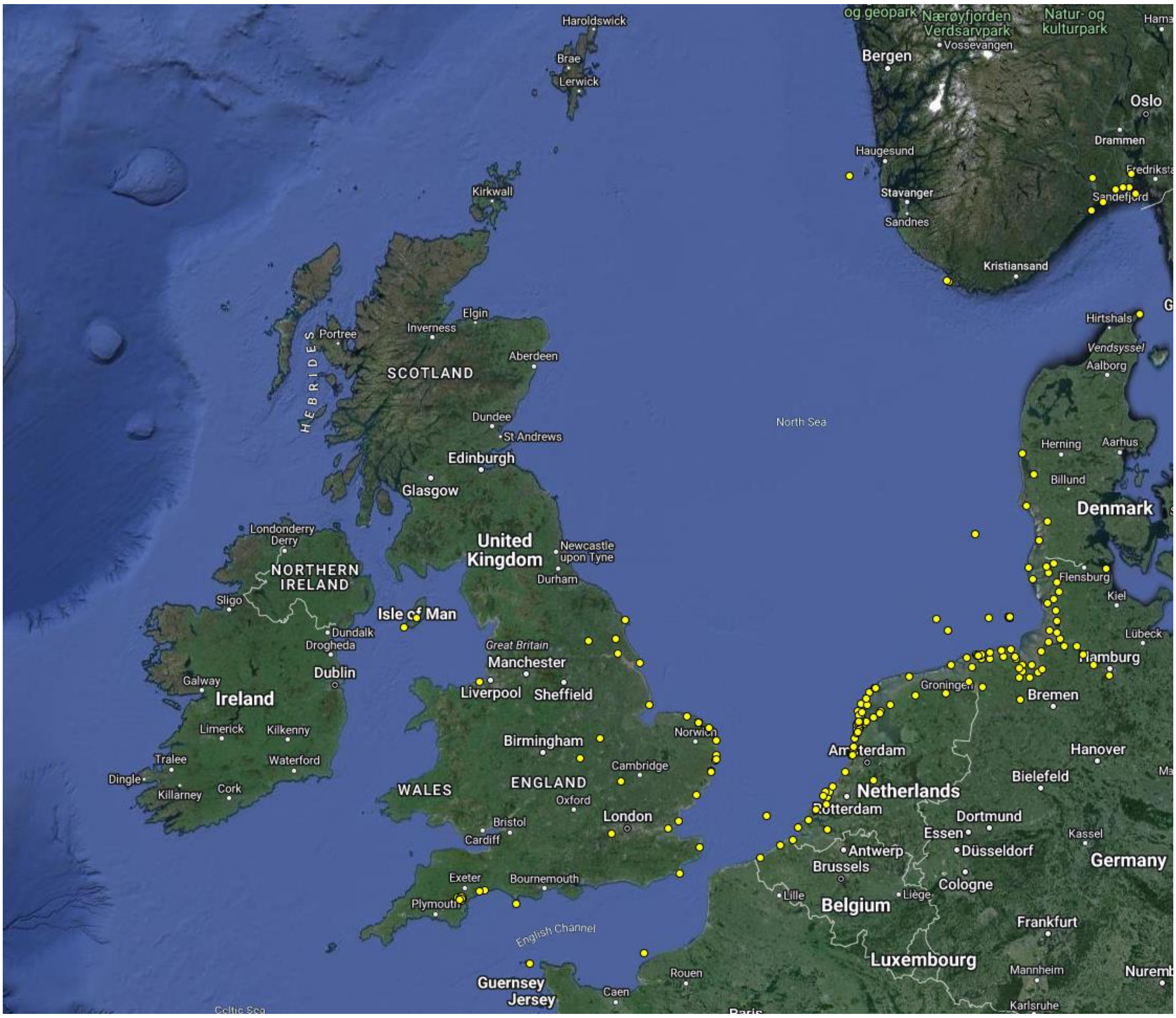


Figure 7. Distribution of MOTUS wildlife tracking stations across northwest Europe, 2024. An interactive map of all MOTUS stations worldwide along with detailed metrics on individual receivers can be found at https://motus.org/. Map data © 2024 GeoBasis-DE/BKG © 2009 Google Imagery 2024 TerraMetrics.

Seasonal patterns of migration

Acoustic monitoring across offshore wind farms in the southern North Sea indicates that the spatiotemporal occurrence of *P. nathusii* aligns with the main autumn migration window from mid-August to late October (Case Study 1; Case Study 2). During this period, bat activity peaks from early to late September followed by a subsequent decrease in activity to the middle and end of October (Rydell et al., 2014; Brabant et al, 2019, 2021; Lagerveld, 2021, 2023). This peak coincides with departure from breeding areas and is likely to consist of predominantly females and juveniles (Strelkov, 1969a,b; Hüppop & Hill, 2016). A second smaller peak may also occur at the end of October and is likely to reflect sex and/or age-specific differences in migratory movements as males are likely to remain longer on the migration pathway to attract and mate with passing females before moving to hibernation areas (Jahelkova & Horacek, 2011; Lagerveld et al., 2021). Records from two ferries transiting the southern North Sea (Hull to Belgium and Felixstowe to the Netherlands) equipped with bat detectors have also recorded *P. nathusii* in May,

Case Study 1 – Offshore Wind and Bats: Knowledge from Germany

Since 2016, bat migration in the German North Sea and the Baltic Sea has been studied by the Nature Conservation Union (NABU). The focus lies on an acoustic survey of 12 study sites (five in the North Sea and seven in the Baltic Sea). Ultrasound detectors were fixed to available offshore structures like buoys, platforms, an island, and a lighthouse.

Bat activity is clearly limited to the migration periods (mid-April to end of May and august to end of October). The activity during autumn migration is higher than during spring migration. At all study sites *P. nathusii* is by far the most frequent species with its proportion being higher in the North Sea than in the Baltic Sea. In the North Sea there is an activity gradient present with decreasing activity with distance from the shore whereas in the Baltic Sea, where activity is mostly higher than in the North Sea, the

September and October and *Nyctalus spp.* in September up to 66 miles offshore (Hobbs et al., 2014).

activity is more homogeneous. We found that 90% of the activity occurs at windspeeds below 6 m/s.

Exploration behaviour
We noticed that the bat activity is higher at structures than at buoys and presumed that this is a result of the extent of exploration behaviour. As offshore study sites are extremely remote and bat activities are low compared to onshore, we used the following measures of exploration behaviour; we define a bat event as an activity or activity cluster dissociated from another activity or activity cluster by at least 20 minutes silence. The ratio between bat activity and bat events can be used as a measure for exploration behaviour. The higher this ratio is, the longer the duration of stay of a bat, meaning more exploration behaviour. We found that there is much more exploration behaviour at the lighthouse and in general more exploration behaviour at the platform than at the buoy.

Bat activity and height
Since 2021 we have installed bat detectors at different heights on a 100 m platform pole and can clearly see that the activity and the number of bat events decreases with height with about 20 % of the bat events at 33 m, 10 % at 66 m and 2 % at 100m. It is important to consider that at offshore wind turbines the blades and therefore the risk zone start at a height of about 20 m above sea surface.

Bat activity in OWF Baltic 1
Swimming bat boxes i.e. acoustic detectors floating on the sea surface, were positioned at the turbines and beside the wind farm and found that activity varies a lot between the sites on different nights. There are turbines without any activity and turbines with quite high activity and in general, we found there were much more noctules and soprano pipistrelles recorded by swimming bat boxes compared to the acoustic survey. On some nights these were the most the most common species and may be exhibiting attractant or exploration behaviour.

Migration of individual bats
To get an idea of migration of individual bats, we tagged *P. nathusii* on the island of Helgoland, a remote island about 50 km off the German coast. We used MOTUS stations at the German Coast from the Birdmove project, stations at the Dutch coast mainly from the Wageningen University, Sander Lagerveld and stations at the Belgian coast from the Lifewatch Belgium project, Elisabeth Debusshiere to detect tags. Both bats tagged were tracked about more than 500 to 600 km from Helgoland along the German, Dutch and – in case of the female – also the Belgian coast. They did so in 4 to 5 migration nights and both had lots of resting days in between. The male stopped at the German coast for more than ten nights and the female on Helgoland. There are hints that departure from Helgoland and also departure from stopover was linked to favourable weather, especially low winds and tail wind.

Project
The research of the NABU is supported by the Federal Agency for Nature Conservation (BfN) with funds from the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV). Involved researchers are (in alphabetical order) Lothar Bach, Petra Bach, Reinhold Hill, Matthias Göttsche, Michael Göttsche, Hinrich Matthes, Henrik Pommeranz, Sandra Vardeh, Christian Voigt, Antje Seebens-Hoyer.

In addition to the autumn migration window, studies have also identified a distinct spring migration window and whilst bat activity is not as high as during autumn, it does represent a substantial increase in activity compared to the summer months and correlates with increased capture rates of *P. nathusii* in April across Great Britain (Hüppop and Hill, 2016; Lagerveld et al., 2017; Seebens-Hoyer et al., 2021; National Nathusius' Pipistrelle Project, 2024). During this period, bat activity peaks from mid-April to mid-May, although this is variable across geographic locations, e.g. in Finland the timing of the migration is on average 20 days later than in Northern Germany (Rydell et al., 2014). The lower intensity of spring migration is also a widespread but poorly documented onshore phenomenon that has been reported in Ireland (Russ et al., 2003), the Dutch coastal provinces (Lagerveld et al., 2017) and continental Europe (Perks and Goodenough, 2020). Several hypotheses have been proposed for this lower recorded bat activity in spring and include reduced availability of insect prey and faster migratory movements at higher altitudes. If migratory bat behaviour resembles that of migrant birds, spring migration may be more rapid, occurring at higher altitudes particularly with wind assistance of the prevailing south-westerly tail winds (Lack 1963, Eastwood 1967). Therefore, they may use fewer stopovers and fly above the detection range of acoustic detectors leading to an under-recording of their activity. Additionally in a radar study on bird and insect migration by Shi et al. (2021), the authors found insect movements were almost non-existent in spring but had a strong peak in summer and early autumn. The absence of insects offshore in spring might be an additional driver for migrating bats to minimize their time spent foraging above the North Sea, thereby reducing the chance of being detected.

Limpens et al. (2017) describe a modelling and expert-led approach to estimating migratory populations in the southern North Sea, with their model producing a preliminary estimate for bats crossing the Southern North Sea of roughly 40,000 individuals (with a bandwidth between 100 and 1,000,000 individuals). The approach in this study aimed to model the migration flux based on either quantitative or estimated parameters defining the population dynamics for the different regions in the relevant geographical population/migration area for the species. Regional bat specialists provided iterative feedback on the structure of the flow model and as a source of information, to help estimate and/or give their expert judgement regarding chosen values.

Environmental patterns of migration

In addition to seasonal considerations, several environmental factors have been found to influence the offshore occurrence of *P. nathusii*. Peaks in migratory activity over sea occur when there are tailwinds from the east, wind speeds <5 m/s and air temperatures >15°C in addition to relatively high atmospheric pressure (Brabant et al., 2019, 2021; Lagerveld et al., 2021, 2023). Low to moderate wind speeds and wind direction are one of the strongest predictors of bat activity and favourable tailwinds from the east northeast are of particular importance for autumn migration (Ahlén et al., 2009; Pettit and O'Keefe, 2017; Brabant et al., 2021; Lagerveld et al., 2023). However, bats will also migrate across open sea with low to moderate headwind or crosswind. Offshore crosswinds are a significant factor driving bat activity in some areas of the southern North Sea, (Hüppop and Hill, 2016). However, it should be noted that whilst certain environmental factors are often shown to be strong predictors of bat activity, the influence of these factors can be variable, with bats showing plasticity in their migratory behaviour in response to environmental conditions. For example, whilst higher temperatures are usually a strong predictor of bat activity, during autumn in the UK, warmer weather is often caused by low pressure fronts with higher wind speeds and stormier conditions offsetting any potential advantage of higher temperatures. Therefore, higher bat activity can often be recorded on colder nights that arise from high pressure systems with lower wind speeds (Bicker, pers. Comm.; Met Office, 2024).

Altitudes of migration

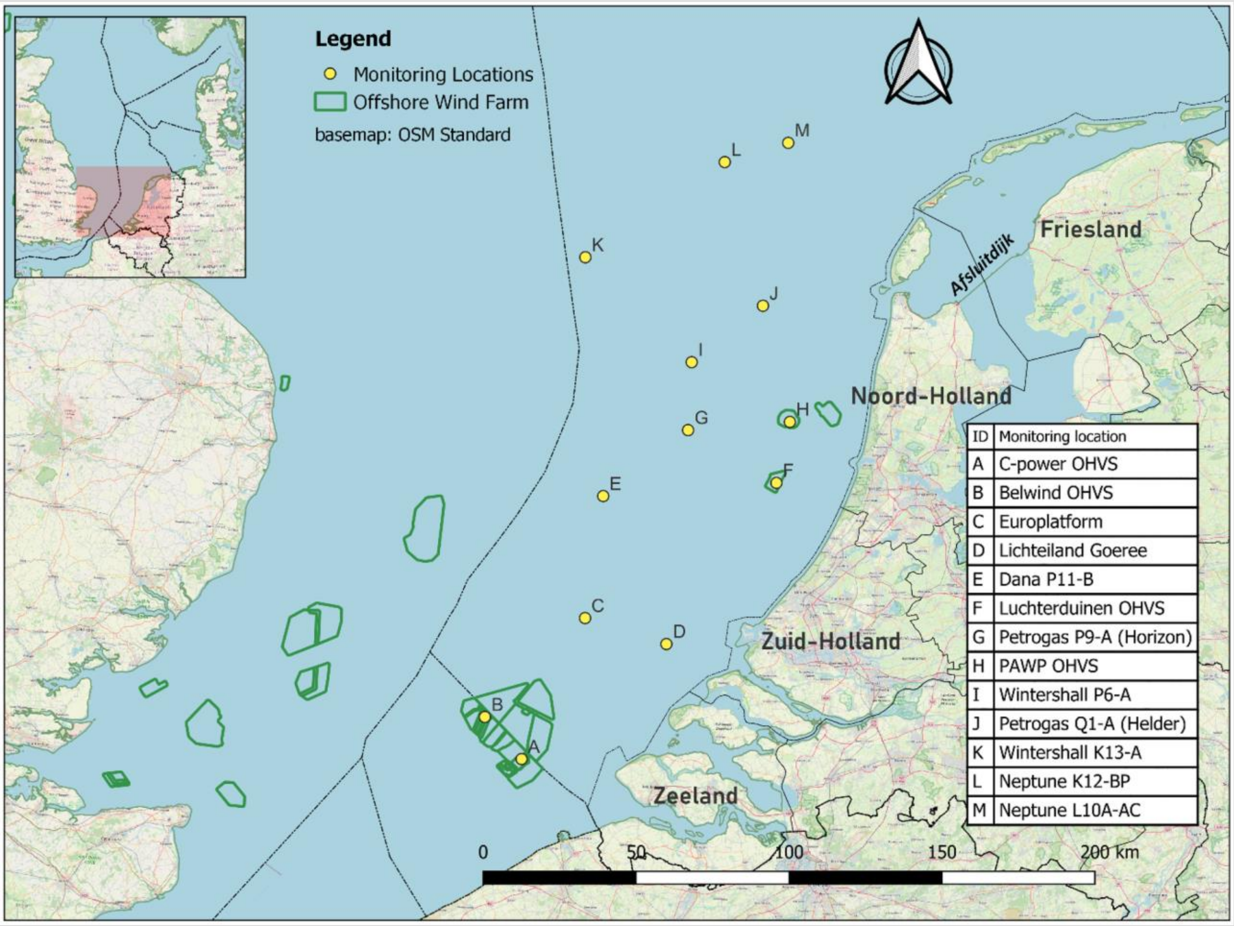
During migration over sea, bats have been observed to primarily fly at low altitudes with most activity found in the proximity of offshore wind turbines concentrated around the service platform at the base of the structure (Ahlèn et al., 2009; Brabant et al., 2019). However, this can quickly change when they encounter offshore structures, ships, or in response to the distribution of insect prey at different altitudes as foraging behaviour is often correlated with migratory movements with bats making use of available prey to fuel their onward movements (Ahlèn et al., 2009). Furthermore, there are records of bats migrating at high altitude (>100 m) at sea and whilst the majority of bats detected by Ahlén et al. (2009) flew at relatively low altitudes (<10 m) there were a few observations of bats flying >40 m and some bats investigating offshore structures up to 100 m above sea level. It has been suggested that low flight altitudes may be restricted to coastal waters, whilst migration further offshore may include a significant high-altitude component, where bats can take advantage of increased wind speeds at height, as is shown for migratory birds and insects (Alerstam, 1993; Chapman et al., 2004; Hüppop and Hill, 2016). Research by Seebens-Hoyer et al. (2021) found that activity recorded at varying heights on a platform pole decreased with height with about 20% of the bat activity recorded at 33 m, 10% at 66 m and 2% at 100 m (See Case Study 1). This behaviour has been documented during aerial surveys off the eastern coast of the United States, where eastern red bats were photographed offshore during tailwind conditions (9–10 m/s) at altitudes of more than 100 m above sea level (Hatch et al., 2013).

Nyctalus noctula, a species known to migrate at higher altitude over land (Kronwitter, 1988; O'Mara et al., 2019), have also been recorded to fly at low altitudes (<10 m) over sea, although radar observations also detected them at >40 m changing their altitude quickly near turbines (Ahlèn et al., 2009). This behaviour by *N. noctula* when foraging is consistent with GPS tracking studies, for example O'Mara et al., (2019) found that individuals used a wide range of airspace including altitudes that put them at increased risk from human-made structures.

Case Study 2 – WOZEP

Dutch Governmental Offshore Wind Ecological Program (WOZEP) is a research program aimed at filling the knowledge gaps around the effects of offshore wind farms on the North Sea ecosystem. WOZEP investigate the ecological impacts of sea-based wind farms on legally protected species and the potential effects on the ecosystem of large offshore wind farms. The program focuses mainly on protected species and habitats, in line with the Nature Conservation Act, but also on the underlying food web. For this purpose, WOZEP also does research on bats, particularly focusing on collision victims. This knowledge is also shared for environmental impact assessments.

The bat research within WOZEP primarily aims to gather more insights into the specific circumstances of when and why bats are present at sea and their behaviour within offshore wind farms (do they fly past or over them, linger around a turbine, is there a specific attraction to a turbine, etc.). To map the movement of bats along the coast and over the sea, WOZEP conducts research using telemetry stations (receivers of radio signals) and tagged pipistrelle bats. These tags emit a radio signal captured by the telemetry stations. Additionally, research is conducted using acoustic observations (bat detectors), recording the echo signal bats use to navigate and forage.



A four-year study installed acoustic monitoring equipment on thirteen platforms in the North Sea. Findings highlight significant patterns in bat migration behaviour. Pipistrelle bats primarily undertake their autumn migration from mid-August to late October, with peak activity in September and October, decreasing towards mid-November.

Bats are more frequently observed off the coast of North Holland, with fewer registrations within the research area towards the north and south. Notably, there is higher activity on offshore structures farther out at sea, especially at the beginning of the night, suggesting bats rest there before resuming their nocturnal migration, contributing to their longer presence at sea, particularly farther from the coast.

Based on our research indicating that the peak bat migration occurs at night during a specific period, with factors such as wind speed, direction, and temperature playing a role, we have tightened mitigation measures at wind farms accordingly.

It has been determined that for wind farms, under specific weather conditions indicating (increased) bat migration in the area, the number of rotations per minute of the wind turbines must be reduced to less than one. This approach leads to a loss of energy yield but hopefully reduces ecological impacts. The findings of this work have been published in Lagerveld et al. (2023) 'Acoustic monitoring reveals spatiotemporal occurrence of Nathusius' pipistrelle at the southern North Sea during autumn migration', *Environmental Monitoring and Assessment*, 195(9). Available at: https://doi.org/10.1007/s10661-023-11590-2.

Future Directions
Over the coming years, WOZEP aims to gain better insight into flight altitude and migration patterns through telemetry and in conjunction with research on bird migration. They will also establish a Bat Detector Network North of the Wadden to gather sufficient data as the conditions for occurrences that seem different than off the west coast of the Netherlands.

WOZEP are currently in discussions with the market regarding camera detection in order to investigate whether (combinations of) radar imagery, thermal imaging techniques, and acoustic information (bat detector data), alone or in combination with foreign research, can provide more insights into bat behaviour in offshore wind farms.

Bat Migration across the Northern North Sea

Unlike the southern portion of the North Sea, there is a paucity of studies into the activity and behaviour of migratory bats and their pathways in the northern North Sea. Information regarding the status of migratory bats in this area primarily comes from occurrence records at offshore islands and oil platforms in the North Sea with seasonal peaks during the main migratory windows (Russ et al., 2001; Petersen et al., 2014; National Nathusius' Pipistrelle Project, 2024).

P. nathusii is the most commonly recorded species from North Sea installations and the Shetland Islands (Peterssen et al., 2014; Harvey, 2014; National Nathusius' Pipistrelle Project, 2024). Occurrence peaks of individuals recorded at these locations coincide with the main autumn migration period and is consistent with a suggestion by Gerell (1987) and Ahlén (1997) that *P. nathusii* migrates in a south-westerly direction from Scandinavia, where it has been found in Norway and Sweden (Syvertsen et al., 1995; Swenson et al., 2010; Ahlén, 2011) to avoid the harsh winter. The Shetland Islands is one of the windiest locations in the UK with a mean wind speed throughout the year of 7.6 m/s (Met Office, 2024). As a result of this extreme climate and lack of native tree cover the Shetland Islands do not support a resident summer population of bats. However, these northerly islands can support overwintering or migratory populations and roosting bats have been found throughout the winter months (Harvey, 2014; National Nathusius' Pipistrelle Project, 2024). As with migratory movements seen further south in the North Sea, the occurrence of migrant bats on the Shetland Islands is associated with strong tailwinds from Scandinavia which also sees large influxes of migrant bird species arriving on their southward migration (Pennington et al., 2004; Harvey, 2014). The spatiotemporal distribution of these occurrences suggest that *P. nathusii* migrates from Scandinavia to overwinter in the British Isles where they mix with sedentary resident populations. However, a more concerted surveying effort is required in this area to establish the phenology and activity patterns of bats using this migratory pathway (Russ et al., 2011; Barr, 2020; National Nathusius' Pipistrelle Project, 2024).

Occurrences of other migratory bats have also been reported to a lesser extent from offshore islands and North Sea oil installations and include *Nyctalus leisleri, N. noctula* and *Vespertilio murinus* (Petersen et al., 2014; Harvey, 2014). *N. leisleri* is considered to be a long-distance migrant and across Europe displays regular seasonal NE to SW movements between summer and winter habitats (Hutterer et al., 2005; Sheil et al., 2008). Whilst it is unlikely that migration was a factor in most of the records across the northern North Sea due to the occurrence of summer records, a number of records were reported during the spring and autumn migration season (Peterson et al., 2014; Harvey, 2014). Therefore, it cannot be ruled out that the corridor between Scandinavia and the northeast of the British Isles represents a migratory pathway for this species.

N. noctula has shown both sedentary and migratory behaviour with some individuals covering distances of up to 1600 km during migration, whilst other populations include partial and differential migrants (i.e. those who do not migrate at all or migrate variable distances; Strelkov, 1969a,b; Hutterer et al., 2005; Dietz et al., 2009; Lehnert et al., 2014). The variability in *N. noctula* migratory behaviour is likely to reflect a strong selection for migratory in populations at higher latitudes where seasonality in climatic conditions and food availability is most pronounced (Strelkov, 1969a,b; Fleming and Eby, 2003). As such, *N. noctula* is considered to be migratory in northern and eastern Europe but in central and western Europe populations of *N. noctula* do not exhibit the pronounced migration behaviour exhibited by other long-distance migrants such as *N. leisleri* or *P. nathusii* (Strelkov, 1969a,b; Steffans et al., 2004; Hutterer et al., 2005). Despite migratory activity of *N. noctula* being documented in Scandinavia (Ahlén, 1997; Baagøe 2007; Ahlén et al., 2009) populations are not known to migrate to the British Isles for the winter and records from the Orkneys, Shetlands and North Sea installations are currently regarded as vagrants from Europe and Scandinavia (Mackie and Racey, 2008).

Lastly*, V. murinus* is also considered to be a long-distance migrant that spends the summer in northern, central and eastern Europe, migrating to southern Europe to overwinter (Hutterer et al., 2005; Stebbings et al., 2007). There has been an increase in records of *V. murinus* in the British Isles since 1980, including from Shetland and North Sea installations (Petersen et al., 2014; Harvey, 2014). These records tend to peak in the autumn and spring suggesting that migrants are sometimes deflected from continental Europe (Racey et al., 2008). In southern Sweden a few individuals were recorded in the autumn leaving land and flying out over the sea (Ahlén, 1997). However, the intended destination of these bats is unknown and due to the infrequent records of *V. murinus,* it is currently regarded as a rare vagrant species, with no breeding colonies in the British Isles (Bat Conservation Trust, 2024).

Bat Migration across the English Channel

The English Channel offers potential for bi-directional migration corridors (Fig. 8). Due to the distinct lack of survey effort conducted over the English Channel, there are few documented offshore occurrences of bats in this area. It is known that migratory species such as *P. nathusii, N. noctula* and *N. leisleri* are present across the south coast including the Isle of Wight and Channel Islands (Russ et al., 2001; NBN Atlas, 2024; National Nathusius' Pipistrelle Project, 2024; Bicker, in prep.). However, these are largely restricted to terrestrial records, with direct evidence for bats crossing the English Channel limited to an individual male *P. nathusii* landing on a fishing vessel halfway between Cherbourg and Start Point in Devon in September 1998 (Russ et al., 2001). Furthermore, a ringing recovery reported as part of the National Nathusius' Pipistrelle Project (2024) confirmed a long-distance migration of an individual *P. nathusii* ringed in East Sussex flying to Belgium in September 2018. Whilst the exact route of the bat cannot be determined, it is likely that the bat crossed the eastern English Channel.

Acoustic surveys undertaken along the south coast in the UK have recorded *P. nathusii* activity along the coastline with peaks of activity coinciding with the established autumn migration period. Furthermore, registrations were primarily recorded between 1-3 hours after sunset suggesting that bats may have flown a substantial distance from their roosts before arriving at the survey location along the coast (Lang et al., 2014; Bicker, 2023). A similar pattern of behaviour has been found along the Northern Baltic Sea where *P. nathusii* aggregate along coastlines during migration windows (Ahlén, 2009; Ijäs et al., 2017). In addition, further acoustic surveys undertaken in spring 2019 hinted at migration from France and the Channel Islands during April with a strong surge of activity through the Solent at the end of May, coinciding with a similar pattern of migratory activity along the Brittany coast (Bicker, pers. comm.).

Monitoring from April to October in 2012 and 2013 on the Kent coast at the eastern end of the English Channel also revealed peaks in passes of *P. nathusii* in autumn (September and October) and spring (May). The diurnal timing of detections was indicative of migratory movements from adjacent mainland Europe, and the majority occurred in wind speeds of <4.2 m/s of a westerly or southerly direction (Jennings et al., 2013a,b).

Figure 8. Potential bi-directional migration corridors across the English Channel between England, the Channel Islands and France and potential corridors between the UK and Ireland including the Isle of Man. Orange arrows indicate possible migration corridors as identified during the literature (arrow size is not significant). The evidence for migration across these broad fronts varies geographically and

should only be taken as an indication. Detailed discussion of the evidence base surrounding each of these corridors is discussed further within this review. © Mapbox © OpenStreetMap.

Further evidence of potential migratory movement of bats comes from a large-scale acoustic survey conducted across the Bailiwick of Guernsey since 2021 which provided the first baseline data for bats on the Channel Islands of Guernsey, Alderney, Hern and Sark. Due to the extensive coverage of ultrasonic detectors deployed between April and the end of October, Newson et al. (2021, 2023, 2024) were able to determine the spatiotemporal occurrence of a number of species and provide evidence as to whether populations of these species were migrating across the English Channel.

P. nathusii was recorded in relatively low numbers on every island but peaked in September, coinciding with the known autumn migration period for this species, before dropping again in October to below the mid-summer number. In addition, social calls for *P. nathusii* started in September and mainly comprised of male advertisement calls with a small number of other social calls. Due to the restricted distribution of social calls both spatially (only 12 locations) and temporally (September to October), Newson et al. (2024) suggest that *P. nathusii* is a winter visitor or a resident with a substantial migratory component. However, as all previous records found and reported on in the *Transactions of La Société Guernesiaise* and Russ et al. (2001) have been from September to April, it is likely that this species constitutes a winter visitor and migrant.

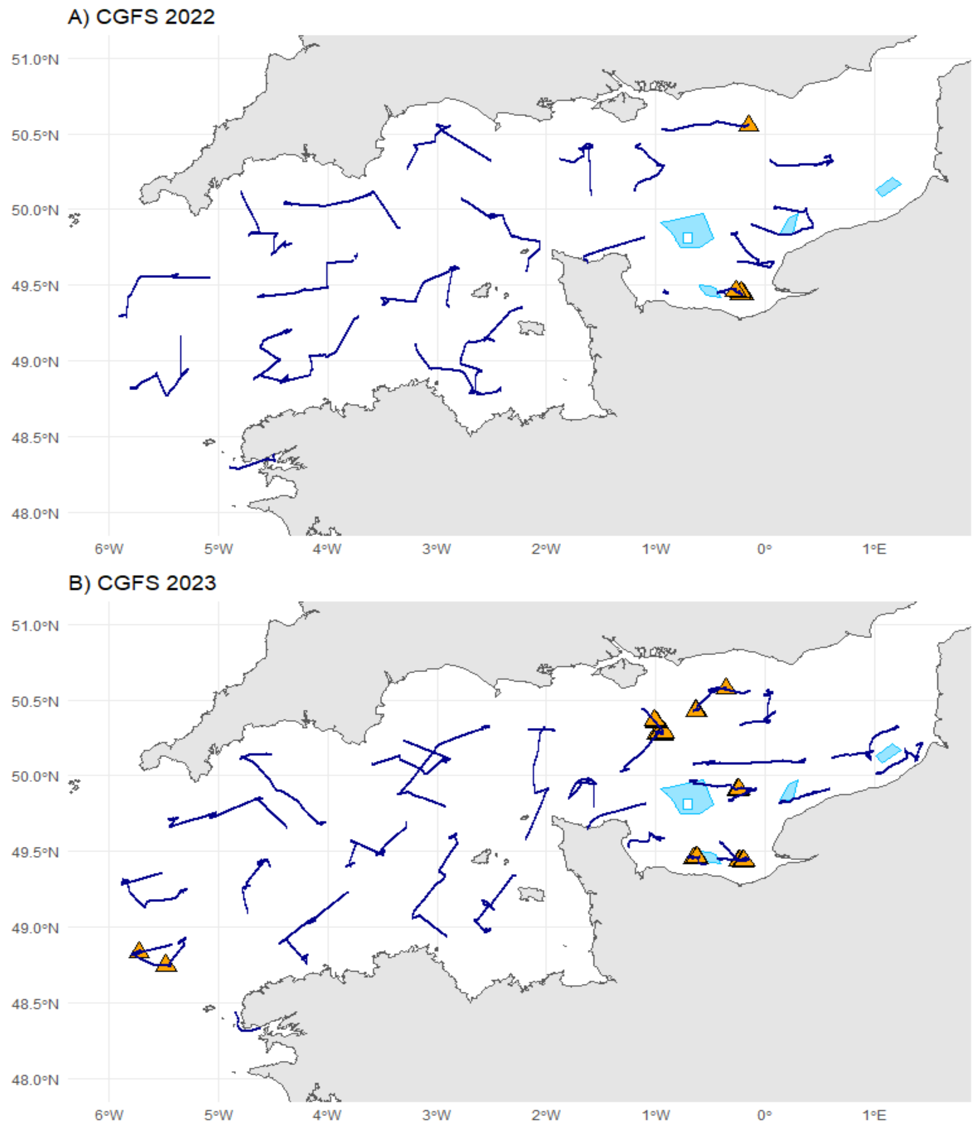
Other records of migratory bats during this survey were very rare. In 2023 *N. leisleri* was recorded on 14 nights, from 17 locations during September and early October with similar numbers being recorded in previous years (2022 - nine nights from 11 locations, 2021 – seven nights from five locations). The spatiotemporal distribution of these recordings (i.e. three open grassland/garden locations that consisted of one, or two recordings a few seconds apart) indicates that the bat was passing through the area, which along with the pattern of records (all in autumn), suggests that it may be a rare but regular migrant to the islands.

In order to fill the evidence gaps surrounding the use of the north-east Atlantic by bats, a large-scale multi-source data acquisition and modelling project is currently underway by the French Biodiversity agency (MIGRATLANE, 2024). This project will conduct acoustic monitoring along the English Channel and offshore structures over three years to determine which species occur at sea as well as the spatiotemporal occurrence of these species. Preliminary results have shown that both *Pipistrellus* spp. and *Eptesicus/Nyctalus* spp. are recorded in the English Channel and seem to highlight the presence of a migration corridor between the UK and France during autumn (Pessato, pers. Comm; Case Study 3).

Case Study 3 – MIGRATLANE

MIGRATLANE is a French project that aims to characterise the migration of birds and bats at sea and determine the functional areas for seabirds, from the Bay of Biscay to the English Channel. This project includes 4 methods of monitoring: unit 2: telemetry, unit 3: acoustic and visual survey, unit 4: radar and unit 5: aerial survey. However, only unit 3 aims to monitor bats.

This project was started in 2023, and the first acoustic campaign acquisition was started from august 2023. Acoustic recorders (SM4-FS) were set up at several sites along the coast, on islands and on structure at seas (mast, wind turbine, etc), on the Atlantic and English Channel coasts. In addition, recorders were set up on some vessels of the French Oceanographic Fleet in partnership with IFREMER and PELAGIS (CNRS, Université de la Rochelle) and on the Brittany Ferries in collaboration with BIOTOPE. CGFS is a survey at sea, led on the vessel of the French Oceanographic Fleet (IFREMER, PELAGIS) in the English Channel, between September and October. Acoustic recorders were set up in 2022 and 2023.



In 2022, only one bat species was detected: the Nathusius' pipistrelle. However, in 2023, several species of bat were identified and on a wider geographical range than in 2022. Indeed, from the 16th of September to the 8th of October, the Nathusius' pipistrelle, the common pipistrelle, the soprano pipistrelle, and the Leisler noctule and/or serotine were all found in the English Channel.

Bats (yellow triangles) found at sea during the CGFS campaign (IFREMER, PELAGIS) in A) 2022 and B) 2023*. Blue lines correspond to the transects sampled and blue areas correspond to the French offshore Wind Farms. *2023 map represents preliminary data with further analysis still being undertaken.

Figure taken from Treyvaud, c., Pessato, A., Baron, J., Peyret, P., Linossier, J., Chabrolle, A., Kerbirou, C. 2024 MIGRATLANE - Caractérisation de l'utilisation de l'arc atlantique nord-est par les migrateurs terrestres et l'avifaune marine a l'aide de méthodes complémentaires.

Bat Migration across the Celtic and Irish Sea

In concurrence with other seas surrounding the British Isles, there is a lack of documented occurrences of bats offshore in the Celtic and Irish Seas, but they also offer potential for bi-directional migration corridors (Fig. 8). It is known that migratory species such as *P. nathusii, N. noctula* and *N. leisleri* occur across the west coast of England and Wales including the Isle of Man and Welsh offshore islands, Skomer, Ramsey and Skokholm (Russ et al., 2001; Taylor et al., 2014; Dyer et al., 2019; Pinder, 2020; NBN Atlas, 2024; National Nathusius' Pipistrelle Project, 2024). Both *P. nathusii* and *N. leisleri* are resident breeding species in Ireland (Aughney et al., 2022; Bat Conservation Ireland, 2024) and whilst climatic differences between Great Britain and Ireland are less distinct, movement across the Celtic and Irish seas may still be categorised as regional migration whereby roost temperatures rather than seasonal climatic differences are the main driver for movement (Krauel et al., 2018).

Acoustic surveys undertaken at coastal locations and offshore islands along the Welsh coast have shown limited recordings of *P. nathusii* and *N. leisleri* at survey locations on the western most points of the Welsh coast. Although generally recorded in low numbers, for some survey locations there were small peaks noted in May and September that may give some indication of migratory activities. Detectors placed on ferries sailing between Dublin – Holyhead and Rosslare – Fishguard obtained no records of bats whilst at sea, although a number of registrations of both *P. nathusii* and *N. leisleri* were recorded when ferries were in harbour (Dyer, 2019).

During acoustic surveys on the Pembrokeshire islands by Taylor et al. (2014) a peak of activity was observed during the late summer/autumn for species that are known to be long distance migrants in Europe. While this did not confirm that bats are migrating within GB, or between GB and Ireland, it provided an indication that this may be occurring. Lastly, acoustic results have shown use of Pembrokeshire islands by *Rhinolophus ferrumequinum* and *Barbastella barbastellus*, both of which are not known to regularly cross open sea, although both have been recorded on the Isle of Wight (Altringham, 2003). *R. ferrumequinum* were recorded on all islands studied and recordings from each island suggest that this is regular and predictable behaviour and that bats may be commuting to the islands nightly due to their proximity to the mainland (e.g. Ramsey Island ~1 km; Skomer ~1 km; Skokholm ~4 km).

Studies by both Dyer (2019) and Taylor et al. (2014) concluded that whilst no direct evidence of bat migration across the Celtic and Irish Sea was found, both project methodologies were limited by the reliance on a low number of fixed sampling points along the coastline or offshore islands. Recording locations were based on the logic that bats would make the shortest route possible, however bats may make landfall anywhere on the Welsh coast and may be following other routes such as estuaries to take advantage of riparian corridors inland. Furthermore, without knowing the activity and distribution of resident bats in the local area, attempting any assessment of migratory activity from onshore locations is difficult (Taylor et al., 2014; Dyer et al., 2019).

Table 3. Summary of migrating bat species to and from the British Isles

Species	Extent of Current Understanding
Nathusius' pipistrelle (*P. nathusii*)	Based on the data available, *P. nathusii* are the most commonly recorded species offshore and are considered a regular migrant to the British Isles. Tagging as part of NNPP, MOTUS, and acoustic surveys indicate that movement across the Southern-North Sea generally peaks during the autumn migration window (Mid-August to late October) as well as a peak in migratory activity in spring (Mid-April to Mid-May). Whilst it is known that *P. nathusii* move between the east/southeast of England and the European mainland, exact routes taken are not known. Furthermore, due to the scarcity of knowledge surrounding the movement of *P. nathusii* across the Northern-North sea, Celtic and Irish Sea and English Channel, only rudimentary conclusions can be made based on a small sample of recordings or occurrences.
Common pipistrelle (*P. Pipistrellus*) and soprano pipistrelle (*P. pygmaeus*)	Surveys undertaken by researchers in France have recorded these species in the English Channel, with individuals also being ‘rescued’ from offshore wind turbines. The extent of their activity or behaviour at sea is not currently known.
Nyctalus spp.	There is some limited evidence to suggest that long distance migratory *Nyctalus* spp. such as *N. noctula* and *N. leisleri* may migrate between the British Isles and Europe or Scandinavia. Due to the scarcity of knowledge surrounding the movement and behaviour of these species, only rudimentary conclusions can be made based on a small sample of recordings or occurrences.
Other species	A number of other bat species have been recorded at various locations that may indicate some migratory element to their movement across open seas. However, due to the lack of empirical evidence no conclusions can be made to their status.

Bat Interactions with Offshore Wind Turbines

There is currently a paucity of studies specifically reporting how bats interact with offshore wind turbines in part due to more problematic logistical considerations when surveying offshore, coupled with a lack of suitable or affordable technology that can be widely deployed as in the onshore wind energy environment. However, it is widely assumed that bat behaviour around offshore wind turbines is likely to be similar to around onshore wind turbines and therefore offshore wind induced mortality is likely to occur at sea (Ahlén et al., 2009).

Are Bats Attracted to Wind Farms?

Several hypotheses have been proposed to explain why individual bats are killed by wind turbines, including accidental encounters (particularly by juveniles or along migration pathways), the use of the tall structures as a display site during the breeding season (Kunz et al., 2007; Cryan and Barclay, 2009) or roosting opportunities mid-migration (Fig. 9; Brabant et al., 2020) and the accumulation of insects creating increased foraging opportunities near wind turbines. The latter of these is often assumed to be one of the most important factors determining fatality risk for individual bats (Rydell et al., 2010, 2016; Long et al., 2011; Voigt, 2021).

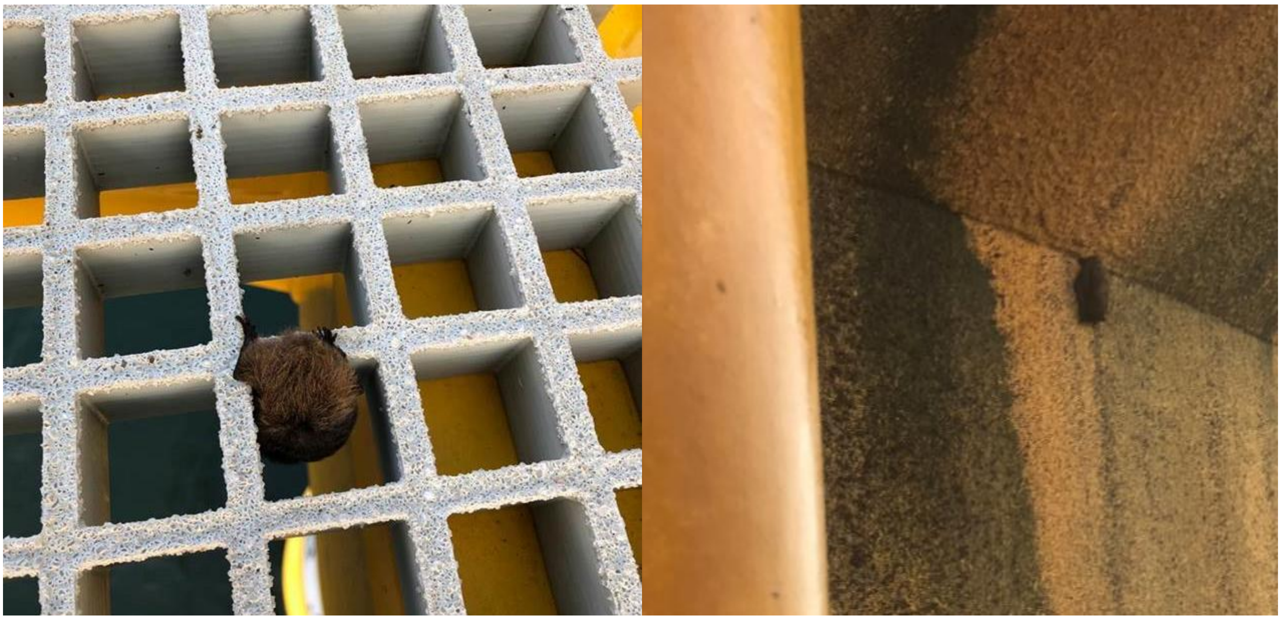


Figure 9. Bat occurrence recorded at offshore windfarms in Spring 2019. Left picture: unidentified bat species roosting in the floor grate of an offshore turbine at the Belgian Nobelwind Wind Farm (8th April 2019). Right picture: Unidentified bat species roosting on an offshore wind turbine foundation in the Belgian C-Power Wind Farm (30th April 2019). © Royal Belgian Institute of Natural Sciences 2024.

Thermal video observations of flight behaviour around onshore wind turbines indicate that some bats may not be randomly colliding with wind turbines, but instead are actively and repeatedly approaching wind turbine components (e.g., tower, nacelle, and blades) around the rotor-swept area, even after being buffeted away by the increased turbulence (Horn et al., 2008; Cryan et al., 2014). Furthermore, recent studies have indicated that bats could be attracted to wind energy infrastructure with echolocation activity increasing for some species after wind turbines are constructed (Solick et al., 2020; Richardson et al., 2021). This is further compounded by a lack of predictive relationships between pre-construction bat activity and bat mortality during the operational phase, providing additional evidence that bats are actively attracted to these areas post-construction (Lintott et al., 2016; Solick et al., 2020).

However, after more than a decade of research and considerable advances in our understanding of bat mortality at wind turbines, we still do not have a definitive mechanism of attraction explaining why rates of bat fatalities at wind turbines can be so high. Recent reviews by Jonasson et al. (2024) and Guest et al. (2022) have attempted to summarise our current knowledge on the mechanisms of attraction, taking into account bats' sensory perception, with both concluding that cause(s) and scale(s) remain largely unknown but are likely to be species-specific and not mutually exclusive.

Sensory stimuli

As bats commute, forage and migrate, they integrate different sensory stimuli that shift in seamless coordination with the current task (Danilovich and Yovel, 2019). As a result, different sensory pollutants (e.g. light, noise, etc.) can contribute to misguidance, obscuring, and diverting of bats as they traverse wind farms, with the mechanisms underlying sensory pollution varying based on proximity and the bats' perceptual faculties (Fig. 10). Notably, the sensory inputs that bats prioritise may differ when detecting distant wind farms compared to their immediate interaction with turbine blades (Jonasson et al., 2024).

As bats move across a landscape or seascape their first perception of a wind farm is most likely facilitated by senses such as vision or somatosensation of the turbine wake, i.e. senses associated with navigation during migration or other long-distance movements including mechanoreception (vibration, touch and pressure discrimination) and thermoception (Romo et al., 2002). Despite common misconceptions, bat vision is often utilised for detecting objects beyond the range of echolocation (Suthers & Wallis 1970; Boonman et al., 2013) and is well suited for detecting distant objects in dim light (Shen et al., 2010), with homing experiments suggesting that some bats may use visual, topographical cues to orient themselves (e.g. Williams et al., 1966).

A leading hypothesis of bat attraction to wind turbines is that the tall stand-alone silhouettes of wind turbines could be mistaken for trees and viewed as potential roost structures that may also serve as potential mating sites (Cryan, 2008; Cryan & Barclay, 2009; Jameson & Willis, 2014). The visual detection range of turbine structures at night is species-specific but will generally be within a few kilometres, however the maximum detection distance will be greater for bats with greater visual acuity, under high contrast conditions and as object height increases (Boonman et al., 2013; Eklöf et al., 2014).

The visual detection range of wind turbines at night will depend on both tower size and placement but also ambient illuminance provided by the moon phase (Jonasson et al., 2024). Bat species most frequently killed by wind turbines in temperate areas generally roost in trees, with tree height being an important characteristic for roost selection (Crampton and Barclay, 1998; Kalcounis-rüppell et al., 2005). Night vision surveys at onshore wind energy facilities have shown bats to use turbines as roosts where they have been observed entering or exiting wind turbine structures at night. Whilst searches at turbine towers, transformers and around turbine doorways have documented the presence of guano from several bat species (Bennett et al., 2017; McAlexander, 2013).

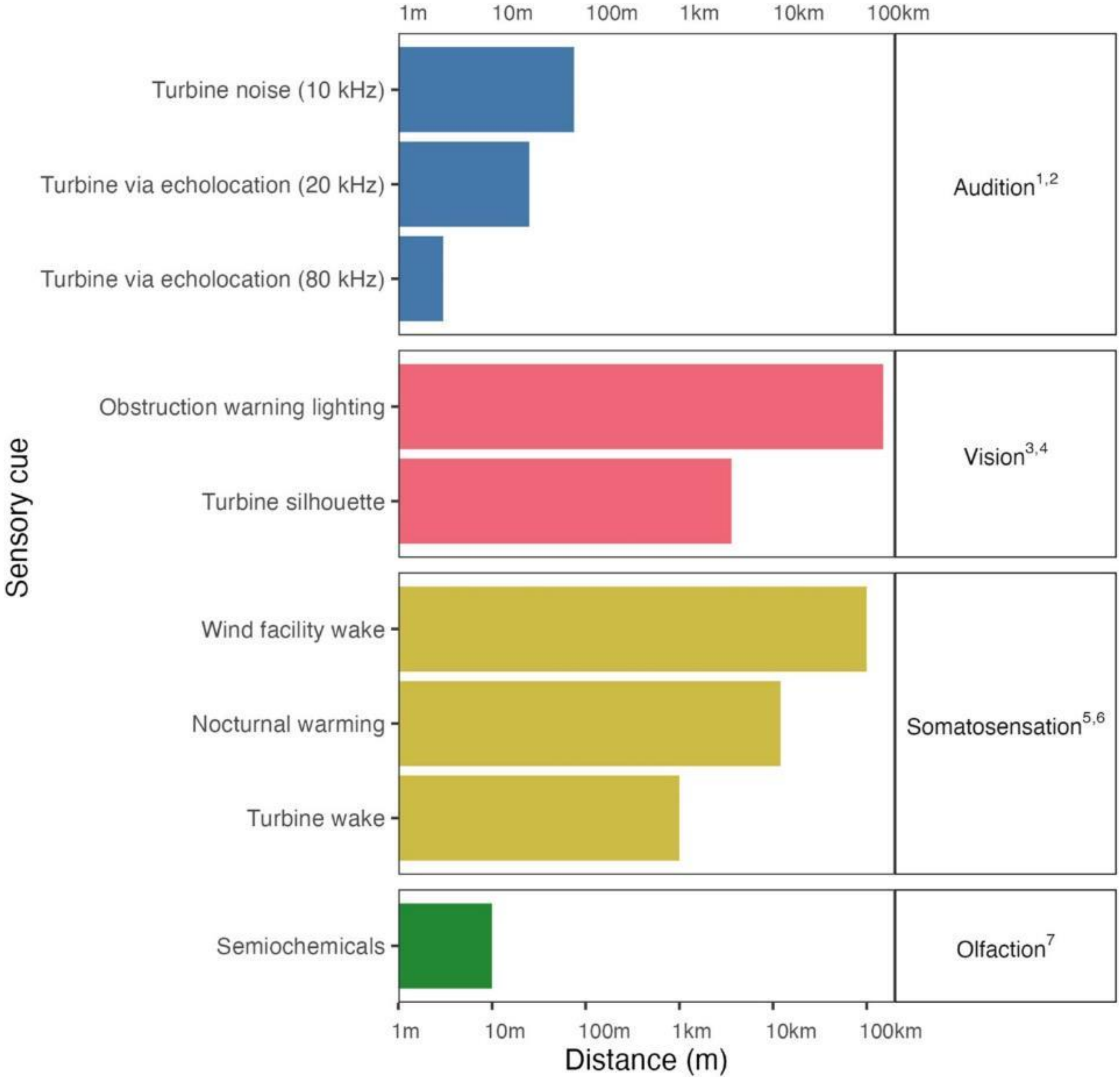


Figure 10. Sensory cues and potential pollutants at wind energy facilities and the distances they are likely perceived by bats. [1]Katinas et al. (2016), [2]Stilz and Schnitzler (2012), [3]Boonman et al. (2013), [4]Eklöf and Jones (2003), [5]Porté-Agel et al. (2020), [6]Lundquist et al. (2019), [7]Reddy et al. (2021). Graphic from Jonasson et al. 2024. *A Multisensory approach to understanding bat responses to wind energy developments*. Mammal Review doi: 10.1111/mam.12340.

A similar pattern of behaviour has also been found during multiple studies at offshore locations where diurnal stopovers have been recorded along flight routes on structures such as wind turbines, ships, and other offshore structures where bats have been recorded to roost for several days, regularly foraging over the surrounding waters and even flying around turbines emitting territorial or mating calls (Ahlén et al., 2009; Lagerveld et al., 2021). The occurrence of bats at offshore wind turbines have been reported through direct observation of roosting bats by maintenance workers in the housing of a utility crane on the turbine service platforms, turbine foundations and nacelles (Boshamer and Bekker, 2008; Ahlén et al., 2009; Brabant et al., 2020; Lagerveld et al., 2021). Using thermal imaging, bats have been observed investigating both stationary and moving turbine blades and towers which suggests that they are attracted to these stand-alone structures for potential roosting or foraging opportunities (Arnett et al., 2005; Horn et al., 2008) but this is likely to be highly species-specific (Guest et al., 2022).

As the maximum flight speed of migrating *P. nathusii* is currently recorded to be 40-47 km/h- (Šuba 2014) and the proximity of monitoring locations where bats have been found are <30 km from shore, it is assumed that bats departed from land the same night. It is suggested that a subsequent deterioration in weather conditions offshore or the arrival of daybreak may force bats to interrupt their flight and find a suitable structure at sea to roost, until weather conditions are suited to continue their journey, the next night or later (Lagerveld et al., 2021).

Studies analysing the temporal distribution of *P. nathusii* calls have recorded bats around offshore wind turbines close to dusk when they are known to leave their roost, as well as close to and even after sunrise, suggesting that these animals are spending the day at the monitoring location (e.g. Fig. 9) at sea, or in its vicinity (Dietz et al 2007; Lagerveld et al., 2014a,b, 2017a,b). However, it is possible that some individuals may continue their migration during the daytime (Lagerveld et al., 2014a,b, 2017a, b).

Feeding stations

Bats have also been suggested to perceive turbine sites as potential food sources. Possible explanations for the accumulation of insects at wind turbines includes hill topping behaviour (i.e. congregation of insects at the highest point in the local landscape to improve the likelihood of mating success; Grof-Tisza et al., 2017), insect attraction to the light or heat emitted from wind turbine structures, and insect attraction to wind turbine colour (Ahlén et al., 2003; Long et al., 2011; Jansson et al., 2020; Guest et al., 2022).

Studies suggest that bats adapt their behaviour in the vicinity of offshore structures, often interrupting their migratory flight and changing their altitude for foraging bouts in response to insect prey that may congregate around offshore wind turbines. Evidence of this fly-and-forage strategy is especially common in areas with a high abundance of insects in the air or crustaceans gaffed from the water surface (Ahlén et al.,2007, 2009; Šuba et al., 2012).

Due to their scale and extent, wind farms interact with the atmospheric boundary layer, affecting local meteorology which can subsequently increase nocturnal temperatures for up to 10 km in their wake (Miller & Keith, 2018; Porté-Agel et al., 2020). Whilst the relative importance of these microclimatic patterns in attracting bats is unknown, bats may use temperature as a cue when searching for foraging patches because nocturnal insect activity increases with temperature and insects are known to be attracted to the heat emitted by turbines (Ahlén et al., 2004). Studies have shown that bat activity increases with ambient temperature and prey density (Müller et al., 2012) and ambient temperature is positively correlated with bat mortality at wind farms (Baerwald & Barclay, 2011; Amorim et al., 2012; Grodsky et al., 2012). Studies conducted offshore by Lagerveld et al. (2021, 2023) and Brabant et al. (2021) showed that the majority of bat observations around offshore turbines in the southern North Sea were recorded on nights when average night temperatures were greater than 13-15 ºC which in part could be explained by the same increase in insect availability and activity triggered by higher temperatures seen onshore. When higher temperatures coincide with easterly winds, insects may drift offshore, but in addition insects are known to migrate in large numbers over sea, often at heights of several hundred meters above sea level (Chapman et al., 2004; Drake and Reynolds, 2012). This increased insect availability at higher temperatures enables bats to fly-and-forage during offshore migratory flights (Šuba et al., 2012). However, increased fatalities may also correlate with increased bat migration during weather fronts that increase ambient temperature (Pettit & O'Keefe 2017, Jonasson & Guglielmo 2019).

It is worth noting that, whilst most research is focused on foraging around offshore wind turbines by migratory bats, there is evidence to suggest that resident bat species regularly forage offshore especially for developments situated closer to the coast. Studies by Ahlén et al. (2007, 2009) in the Baltic Sea have shown that at least 10 species, both migratory and resident, regularly forage offshore and even *Myotis daubentonii* and *Myotis dasycneme* have been found foraging up to 10 km from the coast. *P. pipistrellus*, a resident non-migratory species, has been recorded offshore throughout the summer season (Dietz et al., 2007; Ahlén et al., 2007; Lagerveld et al., 2017a, b; Brabant et al., 2016; Seebens-Hoyer et al., 2021). In June 2023 an adult female *P. pipistrellus* was found inside a wind turbine at the Rampion offshore wind farm approximately. 15 miles off the Brighton coast (Hurstpierpoint Bat Hospital, 2024, pers. comm.).

Whilst it is unclear the extent to which sedentary species utilise offshore areas for foraging or the seasonal or climatic conditions required, it is clear that resident bat species take advantage of invertebrate prey found offshore. In some areas at sea, prey availability is extremely high and is easily accessible because of complete lack of clutter (Ahlén et al., 2009) and therefore non-migratory species should be considered when mitigating impacts of wind turbines at sea.

Lighting as an attractant

Other theories relating to increased bat activity at wind turbines include bat attraction to lights on turbines or associated infrastructure. Obstruction lights are a requirement at most wind energy facilities and involve either flashing red or white lights mounted at the top of a turbine monopole in order provide aviators with clear visual cues during poor visibility. These lights are likely the most distant stimuli that bats encounter when flying in the vicinity of wind farms and bats may orient towards certain wavelengths during migration or be attracted by insect concentrations near illuminated areas (Cryan & Brown, 2009; Voigt et al., 2017, 2018). The influence of artificial light on bats is species-specific and often based on the species' morphology, with various wavelengths known to exhibit species-specific effects on bats that is dependent on locality and season (Rowse et al., 2016; Voigt et al., 2021).

Bat attraction to obstruction lighting on turbines has predominately been studied in North America in an onshore setting with no clear effects on bat mortality (Johnson et al., 2003, 2004; Arnett et al., 2008; Bennett & Hale, 2014). Studies by Voigt et al. (2017, 2018) have shown that some migrating bat species seem to exhibit movement towards specific wavelengths of light, such as red and green, but not warm, white light. However, like with most studies on the effects of lighting on bats, this attraction to obstruction lighting appears to be both phylogenetically and geographically complex, and conclusions are hindered by studies with little spatiotemporal control for mortality or consideration of how bats view the landscape. In a review of bat attraction hypotheses by Guest et al. (2022) the authors analysed the research conducted at wind farms and concluded that artificial lights do not appear to be the primary cause of bat attraction to wind turbines. However, it is recognised that currently no studies have tested the effect of lighting at the scale of attraction to entire wind farms rather than single turbines. While bat fatalities do not increase at individual turbines with obstruction lights onshore, these lights could attract bats towards areas with wind farms, which aligns with evidence of bat visual acuity and navigation at the scale of kilometres (Jonasson et al., 2024).

Are Bats Displaced from Wind Farms?

Whilst the potential causes of wind-turbine induced fatalities on bats have been widely investigated on land and to a lesser extent offshore, the impacts on bats through avoidance or displacement, rarely appear in the scientific literature. Consequently, this review did not find any studies covering the avoidance or displacement of bats in the offshore environment.

Most of the research in this area has been conducted in Western Europe at onshore wind energy facilities and have generally found lower bat activity the closer you get to wind turbines at the landscape scale, indicating that turbines are directly avoided, or habitats surrounding turbines appear less attractive. This avoidance effect has also been recorded in Pacific Island habitats (see Millon et al., 2018) and indicates that suitable habitat around the turbine is effectively lost to bats (Reusch et al., 2022).

These findings are in contrast to the attraction towards turbines recorded at a finer scale and the reasons for avoidance are currently unknown, although a number of possible causes have been proposed, including turbine lighting and noise emission (Barré et al., 2018; Leroux et al., 2022). Furthermore, studies indicate that all species, regardless of their sensitivity to wind power related mortality, may be displaced from areas of wind farm development (Barré et al., 2018).

Studies researching GPS tagged bats across agricultural and coastal regions of Germany support the hypothesis that bat responses to wind turbines may be scale-dependent where bats are found to be active around turbines at a small spatial scale but avoid them at a broad spatial scale (Reusch et al., 2022, 2023). This larger scale behavioural response has also been recorded in acoustic studies at onshore wind farms across France where a significant negative effect of wind farm proximity was found for most bat species groups (Millon et al., 2015; Barré et al., 2018). Barré et al. (2018) reported a significant drop in activity in a 1000 m radius around wind turbines for both fast flying species (19.6% reduction; *Barbastella*, *Eptesicus*, *Nyctalus* and *Pipistrellus* genera) and gleaning species (53.8% reduction; *Myotis nattereri*, *Plecotus* and *Rhinolophus* genera). Similar landscape scale avoidance has been reported in studies at small onshore wind turbines (SWTs) by Minderman et al. (2012, 2015) who found bat activity increased with greater distances from the SWTs.

Depending on the location and layout of the wind farm, avoidance or displacement could have ecological consequences for bats (Rybicki and Hanski, 2013) that may lead to the fragmentation of the habitat through virtual barriers that cannot be passed, or areas that are very complex to navigate. For onshore wind farms, the avoidance effect may be considered to form a “no-fly zone” of several square kilometres around each turbine, which bats may avoid depending on context and species (Gaultier et al., 2023).

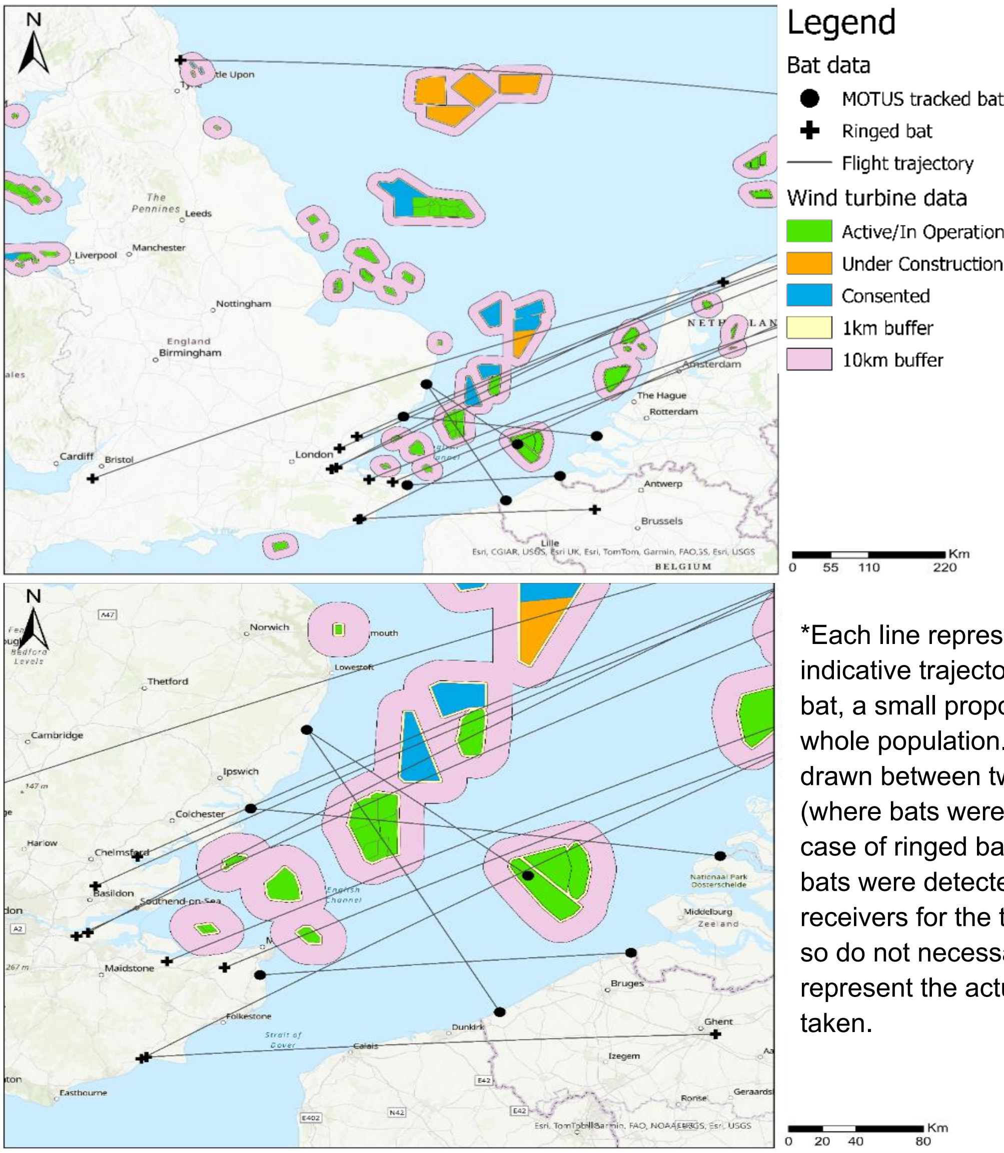
However, it is currently not known to what degree any potential avoidance/displacement impacts translate to offshore wind farms as much of the research on land has focused on particular habitat features that are not present in the offshore environment. Studies into the barrier effect offshore in seabirds have shown strong avoidance behaviour/displacement for a range of species that appears to be strongest when the turbine blades are rotating (Dierschke et al., 2016). A recent study by Garthe et al. (2023) found that the distribution and abundance of seabirds from the family Gaviidae (loons) in the North Sea changed substantially before and after offshore wind farm construction. Densities of loons were significantly reduced at distances of up to 9–12 km from the wind farms corresponding to a decline of 94% within 1 km and 52% within 10 km of the offshore wind farm. Although, like bats, different seabird species respond differently and sometimes inconsistently to the development of offshore wind farms. A recent review of 20 offshore wind farms in European waters found that behavioural responses by different bird species ranged from strong avoidance to strong attraction (Dierschke et al., 2016).

The influence of offshore wind farms on bat movements

It is not currently known to what extent bats are attracted or displaced from wind farm locations in the offshore environment. Evidence from studies conducted onshore indicate that the behaviour of bats at wind farms may be different based on scale, with avoidance/displacement at the landscape scale and attraction at finer scales. However, it is not known whether this translates to an offshore setting due to substantial differences in the scale of wind farm arrays and turbine size as well as the nature of the environment and behaviour of bats offshore. As such, accurate collision risk maps are not currently achievable for bats in the offshore environment and instead inferences can only be drawn based on the ‘zone of influence’ buffers surrounding offshore wind farms (Fig. 11).

These ‘zones of influence’ are based on sensory cues and potential pollutants at wind energy facilities and the distances they are likely perceived by bats.

Figure 11. Straight line ‘flight’ trajectories of single *P. nathusii* bat crossings between England and Europe (based on onshore point data from recapture of ringed bats or MOTUS detections of tagged bats) overlaid on map of operational and projected future



*Each line represents an indicative trajectory of a single bat, a small proportion of the whole population. Lines are drawn between two points (where bats were caught in the case of ringed bats and where bats were detected by MOTUS receivers for the tagged bats) so do not necessarily represent the actual flight path taken.

wind farms. Buffers around wind farms represent a zone of influence for bat species travelling through these areas based on sensory cues of wind energy facilities and the distances they are likely to be perceived by bats as summarised in Figure 10.

Impacts on Bat Populations

It is acknowledged that current population risk assessments for UK bats are restricted by a lack of evidence in our understanding of demography, abundance and behaviour (Natural England, 2014). Whilst population trends for UK bat species have been studied through a variety of national monitoring projects (e.g. National Bat Monitoring programme; Bat Conservation Trust, 2023) overall population estimates are uncertain for many species (Mathews et al., 2018), therefore evaluation of the impacts of turbine collision rates on population viability also remains uncertain. It has been suggested that even calculating population impacts for *P. pipistrellus,* one of the most common and widely studied bats in Europe and one of the primary species killed by onshore wind turbines in northern Europe, is restricted by the lack of appropriate demographic data (Lentini et al., 2015).

A likely negative consequence of wind turbine-related collision/mortality is the cumulative impact on bat populations across Europe, particularly for migratory species, which are thought to normally experience low mortality rates during their seasonal migrations (Giavi et al., 2014). Bats have a long-life expectancy and late maturation which, coupled with a low fecundity rate (1-2 offspring per year; Dietz and Kiefer, 2016), result in populations that are heavily dependent on adult survival (Medinas et al., 2013). These populations are particularly susceptible to increased adult mortality rates due to slow recruitment of juveniles in populations (Jones et al., 2003) and therefore, even minor increases in mortality risks might have large-scale effects on bat populations. This negative impact of increased adult mortality rates has been demonstrated by Erickson et al. (2015) who used models to study effects of different rates of mortality on a long-lived, low fecundity bat and a short-lived, moderate fecundity bat. They showed that long lived species may seem to have stable populations until a threshold mortality rate is passed, after which even small increases raise the risk of (local) extinction. In addition to potential large-scale impacts of turbine-induced mortality on bat populations, there is likely to be intraspecific variation in mortality that reflect gender and/or age-related differences in migratory movements. Studies at wind farms across Germany reported a higher percentage of females and juveniles from distant places were killed at wind turbines, suggesting a potential large negative effect of the so-called German “Energiewende”, (i.e. Germany's policy of increasing the share of renewables and phasing out nuclear power), which could aggravate the negative effects on bat populations in Northeastern Europe (Voigt et al., 2015; Lehnert et al., 2014; Kruszynski et al., 2022).

Reported cases of bat fatalities at onshore wind turbines across Europe show significant variation in both species’ composition and quantity of individuals (Table. 1; Rydell et al. 2010). This variation will likely reflect regional variation in species richness and habitat composition across latitudinal/longitudinal gradients as well as differences in applied search protocols (e.g. survey duration). Furthermore, studies have not always considered carcass removal by scavengers and searcher efficiency in the estimation of annual bat fatalities (Arnett et al., 2008; Voigt et al., 2015). Using standardized protocols to control for these biases (Rodrigues et al., 2014), Voigt et al. (2015) estimated that over 250,000 bats are likely killed annually across Germany by onshore wind turbines, whilst 600,000 have been reported in the USA in a single year (Brinkman et al., 2011; Hayes, 2013). As carcass detection rates in the UK (0-0.18 observed bats per turbine per day; Matthews et al., 2016) are consistent with the range reported across Europe (0 to 0.11 bats per turbine per day; Rydell et al., 2010), and assuming that bats in the UK experience the same mortality risk as those in Germany, it is estimated that more than 80,000 bats may be killed at onshore wind turbines annually in the UK if mitigation measures (e.g. curtailment) are not practiced.

Unlike wind farms on land, the number of bat fatalities at offshore wind farms is very difficult to directly assess through carcass searches. Such searches on offshore wind turbines are only possible at the service platform and whilst theoretically these can be used when detection biases are accounted for, the searched area will be tiny in relation to the area where carcasses potentially may land. In addition, the increased attrition rates of carcasses compared to onshore turbines (e.g. falling into the sea through grates or through wind or wave action) means that carcass monitoring will be logistically and financially impractical as search intervals are typically 2-3 days where practiced onshore, and several wind turbines of multiple offshore wind farms would have to be monitored simultaneously in order to obtain a robust data set.

It has been suggested that the number of bat collisions with offshore turbines is likely to be lower than onshore as the majority of activity is limited to the migration period and in periods of suitable weather conditions. In addition, non-migratory bats, such as *P. pipistrellus*, which makes up the majority of fatalities onshore (Table 1.), are very rare in the offshore environment (Leopold et al., 2014; Lagerveld et al., 2017; Seebens-Hoyer et al., 2021). Based on the knowledge that fatalities at wind farms in large, open, intensively used agricultural areas are typically around one fatality per turbine per year, Leopold et al. (2014) estimated the number of collisions offshore, based on expert opinion, to be somewhere between zero and one fatalities per turbine per year (Rydell et al., 2010; Limpens et al., 2013). However, this was a ‘best guess’ based on the available knowledge at the time, which is very limited in terms of behaviour and knowledge of activity around offshore wind turbines. The real number may be a lot higher as these estimates do not account for other potential attractant factors such as lighting, or bats using offshore wind turbines to roost at in inclement weather. Understanding how bats behave as they cross open sea is crucial in being able to extrapolate any fatality estimates from onshore landscapes to offshore settings.

Despite the potential impact on bat populations across Europe, there are a lack of studies quantifying a direct link between wind turbine-related collision/mortality and population level impacts either onshore or offshore. A primary driver of this paucity in research arises from limited baseline data, e.g. of population sizes, recruitment and dispersal rates in the absence and presence of wind turbines (EUROBATS, 2023). This is particularly difficult when trying to relate individual bats killed at wind turbines (particularly those that migrate), to the likely location of their ‘local’ populations. Studies based on stable hydrogen isotypes in fur by Voigt et al. (2012) and Lehnert et al. (2014) have shown that wind turbines kill bats not only from sedentary local populations but also distant migratory populations. This is of particular importance for migratory species such as *P. nathusii*, whose home range may extend from the UK to the Baltic States or from Russia to Greece, and they are likely to be subject to the cumulative impact of all wind farms in those home ranges. In addition to these geographical considerations, when longitudinal demographic studies have been able to establish population estimates and parameters, it is difficult to disentangle the impacts of wind energy infrastructure from confounding factors, such as changes in the management of local habitats, losses of daytime roosts, annual climatic fluctuations and global climate change impacts. The urgent need for evidence synthesis linking empirical datasets to population scale impacts has been highlighted in several reviews (e.g. Köppel et al., 2014; Tabassum Abbasi et al., 2014; Dai et al., 2015; Schuster et al., 2015; Smales, 2015; Voigt et al., 2015; Arnett et al., 2016).

Current knowledge on potential population level impacts of both onshore and offshore wind energy infrastructure is lacking. This review found no recent studies specifically demonstrating an effect of offshore wind turbines on bat populations in Europe. One long-term study in Germany raised concerns that dramatic declines in *P. nathusii* and *N. noctula* observed in a region where the species only occur during migration could be attributable to onshore wind energy expansion in the area (Bernd, 2021).

Determining the threat of wind energy development on migratory bats highlights the common problem of how to assess threats when critical data is lacking. A number of modelling approaches have been adopted to investigate population-level impacts at onshore wind farms. Studies by Roscioni et al. (2013, 2014) in Italy and Santos et al. (2013) in Portugal combined species distribution models for bats with the spatial distribution of wind turbines at sites that were undergoing wind farm development. These studies modelled the likely incidence of each wind farm in bat flight corridors by overlaying existing and planned turbine locations on potential commuting corridors to determine areas of probable mortality. A similar modelling approach has also been used by Hedenström & Rydell (2013) who showed that deployment of onshore wind turbines in Sweden will have a negative effect on Swedish populations of *N. noctula* if no mitigation measures are adopted.

Research by Diffendorfer et al. (2015, 2019) has attempted to assess population-level effects of wind energy facilities in the USA, including a probabilistic, quantitative assessment method based on fatalities, species demography/range and turbine data, as well as a broader methodology using ecological knowledge, demographic models and the potential biological removal concept i.e. an estimated mortality rate before a population becomes unsustainable. The authors conclude that assessment methodologies are based on simplifying assumptions and suffer from unreliable or absent empirical data, a theme that is common throughout studies on wildlife population-level impacts of wind energy facilities.

When empirical data for a focal species is lacking, data from similar species, or structured elicitation of expert opinion, can be used for conservation decision-making or to inform modelling approaches. Frick et al. (2017) used expert elicitation and population projection models to explore whether fatalities from wind turbines threaten the population viability of *Lasiurus cinereus*, a wide-spread migratory species comprising the highest proportion of bat fatalities (38%) at wind energy facilities in North America (Arnett & Baerwald, 2013). They show that mortality from wind turbines may drastically reduce population size and increase the risk of extinction. For example, if the initial *L. cinereus* population size is near 2,500,000 bats and annual population growth rate is similar to rates estimated for other bat species, it is estimated that their population could decline by as much as 90% in the next 50 years. However, the study also concluded that site or population-specific differences in demographic parameters may affect the validity of extrapolating patterns observed in local studies to broader spatial scales. It is acknowledged that different methodological approaches for scaling up individual impacts to the population level can affect the estimates and that even comprehensive monitoring and advanced modelling may not capture the full complexity of bat interactions with wind turbines (May et al., 2019).

Assessment and Reduction of Impacts to Bats from Offshore Wind Turbines

Ecological Impact Assessment Pre-Construction

As a result of the mounting evidence documenting bats in the offshore environment either during migration or foraging at sea, current EUROBATS guidance indicates that offshore wind farms should be surveyed with the same robustness as onshore wind farms with evidence of mortality forming part of the Environmental Impact Assessment (EIAs) for any development project (Cox et al., 2013; Rodrigues at al., 2014).

EIA is a recognised process across Europe and is carried out by research institutes or consultants at the request of the government or developers. Within an EIA, Ecological Impact Assessments (EcIAs) assess the species-specific effects of the proposed development. In the UK the planning and permitting process is allocated to different government and non-government bodies. The Department for the Environment, Food and Rural Affairs (Defra) is the body responsible for policy relating to protection of the marine environment through a program called the Offshore Wind Enabling Actions Programme (OWEAP). This program involves a series of SNCBs, e.g. Natural England, who give statutory nature advice on the EIA as part of the consenting process. Offshore wind development is organised through leasing rounds with an overall Strategic Environmental Assessment (SEA) carried out by the government and subsequent Strategic Environmental Impact Assessment (SEIA) carried out by the developer during the bidding process. If the completed SEIA identifies significant impacts on the marine environment, developers are required to undertake more detailed assessments on the impact of the specific project and propose avoidance, mitigation and compensation measures to the SNCBs.

Collecting baseline data prior to offshore wind development is important to understand the normal behaviour, distribution, and movement patterns of bats, not only to inform strategic planning of offshore development but also for comparison with post-construction monitoring to determine whether changes occur and how to address these in the future. It is recognised that collecting baseline data for bats at offshore development zones is likely to present significant logistical considerations in comparison to land-based development zones due to the challenge of surveying from boats and offshore structures as well as the greater spatial distribution of turbines in the offshore environment.

There are currently no ecological assessment guidelines for bats and offshore developments in the UK. Available guidance is focused on bats and onshore wind turbines (NatureScot et al., 2021) or summaries of general mitigation of onshore wind turbine-related mortality (e.g. adjusting turbine siting and layout, creation of buffer zones and curtailment; Reason & Wray, 2023). Official guidelines have been developed for Germany covering areas in the Baltic Sea (Bach et al., 2013) and experience in these areas has been adopted in *Guidelines for consideration of bats in wind farm projects Revision 2014* published by EUROBATS (Rodrigues et al., 2014). Recent guidance has also been developed by the Danish Hydrological Institute (Skov, 2023) and Wageningen Marine Research (Lagerveld et al., 2020) that covers bat and bird monitoring and methods to assess fatality risk at offshore wind turbines.

The development of species collision risk models/fatality risk assessments require information on wind farm layout and design envelope specifications coupled with remote-sensing technologies such as boat surveys, high-definition aerial surveys, radar surveys and telemetry. However, there are few methods that have been developed and robustly tested that can provide data on large scale movement patterns and be used to assess the abundance, distribution, behaviour and flight height/speed of bats offshore. A number of methods are currently in research and development and have been discussed where relevant through this report.

EUROBATS guidelines (Rodrigues et al., 2014) suggest that the most productive pre-construction surveys should combine observations from both land and sea and concentrate on the migration periods unless available data (e.g. occurrence data on boats or offshore structures) indicate bat presence at other times of the year.

The guidelines suggest that surveys from land should be at prominent coastal landmarks where bats may depart offshore in the direction of the planned development and include both manual and long-term acoustic monitoring from the ground and at height. Acoustic surveys should be complemented with infrared or thermal imaging videography or, if possible, radar tracking.

EUROBATS guidance recommends that boat surveys (either transects or at stationary points) should be carried out from April-June and from August-October (depending on the locality) at least twice a week, in the area of the proposed wind farm with potential summer surveys undertaken for near-shore installations to detect bats foraging offshore. Continuous automated monitoring should cover both migration periods and also June-July for near-shore wind farms. If possible, it is also recommended that continuous automated monitoring should be undertaken from offshore structures e.g. oil/gas platforms, research platforms or buoys. Depending on the location of the proposed development, surveys should be undertaken from regular night ferries crossing areas that are suspected to be important for bat migration.

Whilst boat surveys allow direct observations of bats along transects, which can gather important information such as presence, behaviour, or flight height (see Ahlén et al., 2009), the areas which can be covered are limited by the field of view, visibility at night and the vast areas in which offshore development zones occupy compared to onshore. As a result, remote acoustic surveys on offshores structures such as buoys are currently the primary means for assessing pre-construction bat activity in offshore environments, from which collision risk is inferred (See Case Study 1; Case Study 4). Acoustic detectors are able to record the calls of bats up to 40 m (Barataud et al., 2020) although actual detection range is species specific and depends on frequency of vocalization, intensity, and orientation of the bat to the microphone. The data gathered can be used to identify the presence of species, characterize seasonal and temporal activity patterns at a local scale, and relate such patterns to weather and wind turbine operational conditions. However, pre-construction acoustic bat activity has been found to be a poor predictor of actual fatality rate at onshore turbines (no data is available for offshore wind farms). Studies by Hein et al. (2013) and Lintott et al. (2016) found that pre-construction acoustic measurements of bat activity do not predict the risk to bats accurately, with Hein et al. (2013) finding that there was no significant relationship between pre-construction acoustic measurements of bat activity and the number of postconstruction fatalities across 12 wind farms in the US. If the physical structure of wind turbines attracts bats, or the alteration of the habitat changes how bats interact with turbines, then pre-construction surveys may underestimate the postconstruction mortality risk for bats. This is of particular importance in the offshore environment as the construction of turbines significantly changes an otherwise featureless landscape.

Nevertheless, establishing the species assemblage at a site may have some value in identifying the presence of species at high collision risk and/or of particular conservation concern in the region. Pre-construction acoustic surveys may therefore still be useful as the data (e.g. nightly and seasonal peaks of activity, migratory hotspots, or weather) may provide an indication of sensitive areas or the extent of mitigation that is required (Lintott et al., 2016).

An additional means of collecting baseline information pre-construction is the use of automated radio telemetry through networks such as MOTUS Wildlife Tracking System.

Automated radio telemetry systems consist of radio tags (small transmitters) and stations (receivers with antennas that record signals from “tagged” organisms within detection range). The MOTUS Wildlife Tracking System is an international collaborative research network that uses coordinated arrays of automated stations that are all monitoring the same frequency to detect tagged animals over broader spatial scales. Examples of research conducted using this technology has been described previously in regard to establishing migratory movements of bats between the British Isles and Europe. Currently most MOTUS stations are situated at prominent locations along coastlines and therefore only gives information about probable departure/arrival points. Recent guidance has been published in the US for deploying MOTUS stations on offshore wind turbines and buoys which will allow for more detailed analysis of bat flight paths over open sea (Loring et al., 2023).

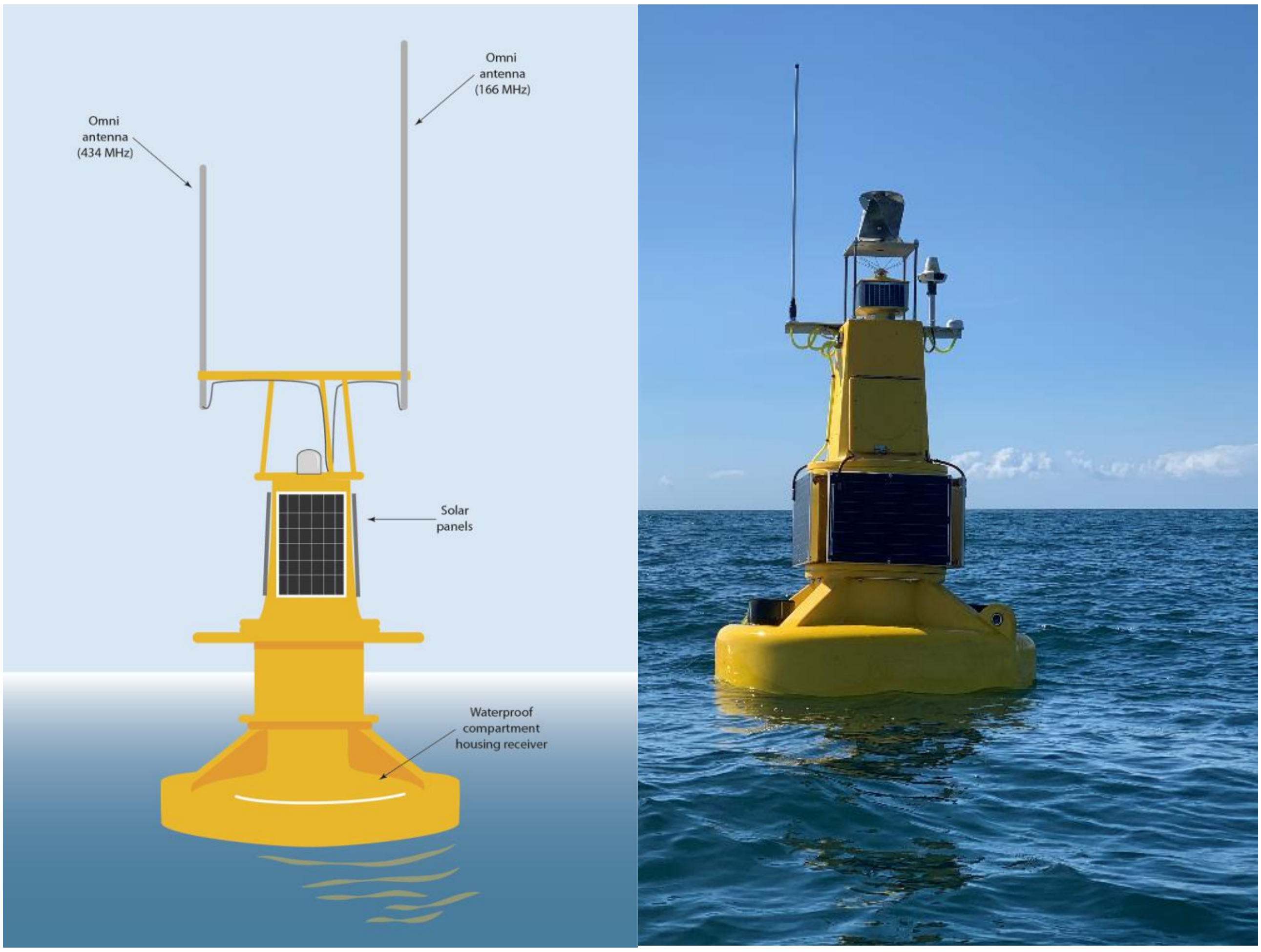


Figure 12. Left: Diagram of MOTUs station with standard dual-mode omni-directional antenna configuration installed on an offshore buoy. Image from Iain Stenhouse, BRI Right: Operational DB1750 MOTUS offshore buoy. Photo from Aanderaa, a Xylem brand.

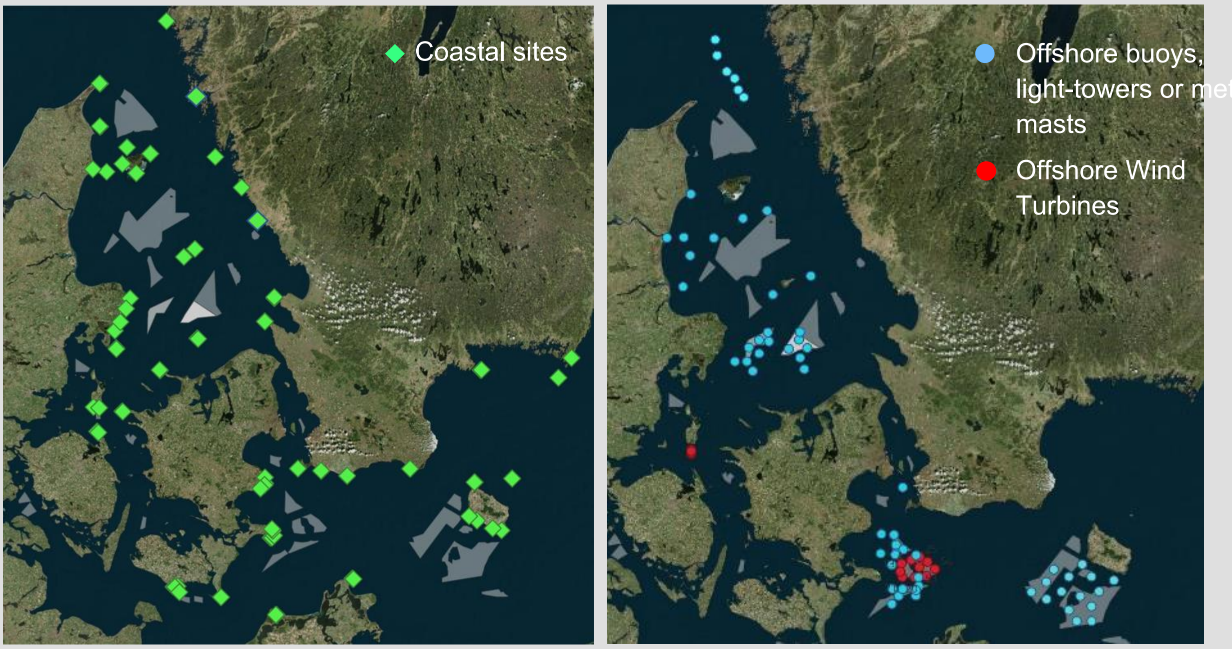
Monitoring for Bats Post-Construction

The post-construction monitoring of operating windfarms is an essential step for both comparative analysis with baseline surveys, to establish whether mitigation methods are successful, and to increase our understanding of the potential impacts of turbines on different bat species. Whilst there is no formal UK guidance for post-construction monitoring of bats at offshore wind farms, guidance for onshore turbine development states that post-construction monitoring is only required where mitigation involves turbine curtailment (NatureScot, 2021). However, the assessment of cumulative impacts of existing and proposed wind farms is usually a requirement of a formal EIA and therefore post-construction monitoring would have a wider benefit in improving our overall understanding of how bats interact with wind turbines and how we can minimise impacts across all wind farm sites (Rodrigues et al., 2014). This would be of particular importance where wind farms are placed along migration routes and cross international boundaries (e.g. the southern North Sea).

Case Study 4 – Kattegat West Baltic Bats Project

The Kattegat West Baltic Bats Project (KABAP) is the most comprehensive coordinated effort to investigate bat behaviour in offshore wind farms development areas in the Kattegat – SW Baltic Sea region.

Bats are known to be killed at offshore wind farms but the magnitude of fatalities is poorly understood at offshore turbines compared to onshore turbines. For wind energy developers this presents legal and permitting risks, as well as operational risks. These include economic and grid stability risks associated with emerging curtailment requirements. Currently curtailment parameters are poorly qualified by data and there is a need for better understanding of bats at sea.



The project spans across several countries including Sweden, Denmark, Germany, and Norway. With over 140 bat detectors throughout the area, with 84 at coastal sites, 65 installed on buoys and 14 installed directly on turbines. KABAP maps the geographical variation in bat migrations, activity patterns, phenology, and their responses to weather conditions. KABAP's partners include the Danish Energy Agency, Energinet and Vattenfall, and data collection and analyses are carried out by universities and consultancies. The findings will provide robust basis to inform impact assessments for future offshore wind farm and evaluate appropriate mitigation measures to support coexistence with offshore renewable energy projects. The first reporting of these results is due at the end of 2024.

To assess the impacts of wind turbines on bats, EUROBATS guidelines state that studies should use standardised methods to produce comparable results with pre-construction baseline surveys. Monitoring the impacts of wind energy on bat activity will only have a scientific value if the results can be analysed along with the original status of bat activity in the area before wind farm construction (Rodrigues et al., 2014).

Studies suggest post-construction monitoring should take place for a minimum of three years during the operational phase of the wind farm to assess impacts on both resident and migrating species (attractiveness, changes in behaviour and mortality) and to highlight possible yearly variations. However, in the offshore environment, due to the effects on bat activity resulting from significant habitat modification (e.g. introducing features), six years of monitoring may be necessary to gain a complete understanding of the changes (Rodrigues et al., 2014; NatureScot, 2021). To evaluate any measures put in place to either avoid, reduce, mitigate or compensate for the impact of wind turbines on bats, EUROBATS and NatureScot guidelines recommend a comprehensive monitoring scheme should be put in place that focuses on activity levels and mortality rates (Table 6 in Section 3. Workshops, outlines the pros and cons of some the different methods of monitoring as discussed by delegates).

Acoustics

In contrast to pre-construction acoustic surveys, post-construction acoustic bat activity at onshore turbines is generally a good predictor of fatality rate (Kunz et al., 2007; Baerwald & Barclay 2009, 2011). Acoustic surveys can be used to assess bat activity and behaviour following construction of turbines and to assess the need for operational mitigation (i.e. methods to limit impacts whilst the turbine is operational). In order to obtain standardised and therefore comparable data, the recordings made must allow identification of calls down to species or group of species level, meaning that post-construction acoustic surveys should utilise full spectrum automatic detectors deployed, as a minimum, for the same duration and extent as during pre-application surveys. Nacelle-level surveys should be used to supplement ground-based equipment designed to replicate the survey effort undertaken at the pre-application stage (see Roemer et al., 2017).

It is recognised that acoustic monitoring at nacelle height will likely be more important than monitoring at turbine base heights as this will record bat activity in more of the rotor-swept zone which represents the area of greatest collision risk. Consistent with ground-based monitoring, EUROBATS guidelines recommend that acoustic monitoring from the nacelle should last at least three consecutive years and cover the annual cycle of bat activity (spring until autumn, depending on the geographical region).

EUROBATS guidelines (Rodrigues et al., 2014) suggest that for direct comparisons associated technical information should be described in the reporting and includes:

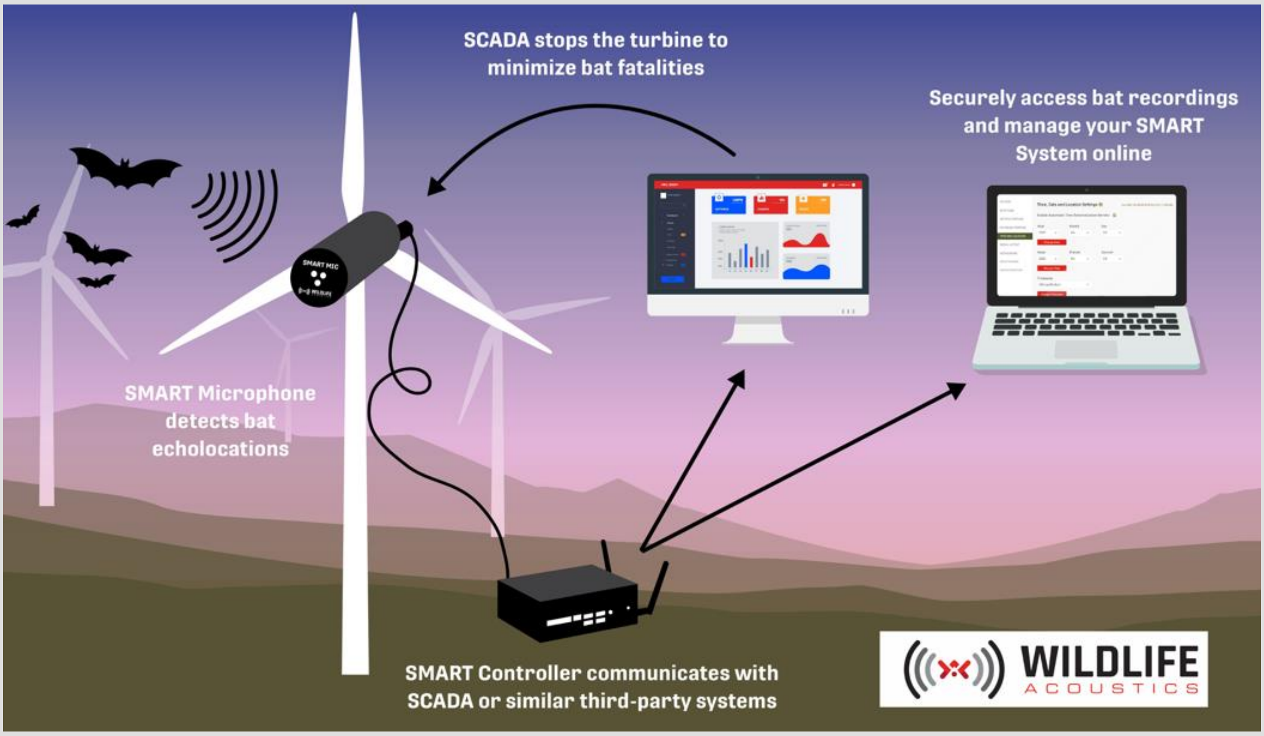
- detector type and analysis software
- sensitivity parameters of the detectors
- location of the detector within the nacelle
- working and failure period of the detector

Echolocation calls of bats are often species-specific and range in frequency from 8 – 200 kHz which can be used for species identification. However, for the assemblage of bat species found in seas around the British Isles recordings up to 100 kHz will be sufficient (Boshamer & Bekker, 2008; Leopold et al., 2014; Lagerveld et al., 2017a, b).

Case Study 5 – Wildlife Acoustics SMART System for Offshore

Wildlife Acoustics' Song Meter with Analysis and Remote Transfer (SMART) System is a solution for long-term remote monitoring in offshore wind environments, and for communicating bat presence in real time to operators and researchers.

SMART can be integrated with SCADA or other control systems to allow operators to curtail turbine operation in the presence of bats. In turn this could minimize turbine downtime, potentially eliminating the need for blanket curtailment and increasing annual energy production. For example, SMART could detect when migratory activity starts and communicate that to a wind farm operator.



Each SMART System comprises 1-3 ultrasonic Microphones plus a Controller (a Linux computer) that processes sound, stores files and communicates with users and turbine control systems.

- To minimise expensive servicing, SMART microphones are built for reliability, with two microphone elements to choose from, plus an inbuilt mic tester and heater. They have a rugged, all-weather design and have been salt and fog tested for offshore applications. An EMI shielded enclosure and conversion from analogue to digital signal inside the microphone reduces electrical interference. These microphones have a 5-year warranty and are designed for long-term monitoring in marine environments.
- Connection to the SMART Controller is via Wi-Fi, Cellular or Ethernet and a Gateway Dashboard web browser interface allows authorized users to securely download recordings and activity summaries, and manage the SMART System, online.
- Wildlife Acoustics next-generation Kaleidoscope Pro analysis algorithms on the controller use sophisticated digital signal processing to enhance Signal to Noise Ratio (SNR), detect bat pulses, extract bat call parameters, and use that information to trigger or scrub recordings. Pre and post-trigger settings capture bats approaching and leaving, improving identification.

Ultrasound frequencies in general have limited reach; depending on the species, habitat and weather conditions and can vary from less than 5 m to 100 m (Adams et al., 2012; Barataud, 2016).

The position and the mounting-direction of the microphone as well as the choice of the recording device (both microphone and recorder) are of great importance and where possible recording devices specifically made for deployment offshore should be used (see Case Study 5; Adams et al., 2012; Lagerveld et al., 2019). Note that the sensitivity of microphones decreases over time and therefore regular replacement, or re-calibration may be required. This should be considered early in the design process due to the logistical constraints with accessing offshore turbines. Whilst the protocol for acoustic monitoring on onshore turbines is now well established, it is worth noting that acoustic monitoring on offshore turbines is in its infancy. Accessibility issues to maintain equipment, exposure to harsher environments, and still-developing technology make offshore acoustic monitoring problematic. For onshore installations it is recommended that acoustic monitoring takes place concurrently with carcass searches (NatureScot, 2021). As carcass searches are not possible for offshore wind farms, a number of other post construction monitoring techniques are available which can provide different information on the interactions of bats with offshore wind turbines and are discussed further below.

In summary, the use of acoustic surveys can give valuable information on the activity, behaviour and species assemblage of bats in areas impacted by wind farm development. In comparison to pre-construction surveys, undertaking acoustic monitoring post-construction and covering all parts of the turbines (especially at the nacelle to cover the rotor-swept zone) can be a good predictor of fatality rate as well as providing a means to assess operational mitigation requirements. However, as with most technologies there are limitations to the use of acoustic monitoring that should be considered especially for use in an offshore setting. The detection capabilities of bat detectors can vary significantly from less than 5 m to 100 m depending on the species, habitat and weather conditions making their use for large spatial scales limited. Furthermore, accessibility issues to install and maintain equipment, exposure to harsher elements and the paucity of technology options designed specifically for offshore deployments can make acoustic monitoring problematic.

Videography

Videography is increasingly being used for post-construction monitoring of bats in offshore wind farms with a wide range of applications being tested and implemented using mainly technologies developed for application within other fields like defence and security. Whilst the use of camera techniques may suffer in inclement weather, they have the ability to distinguish flying bats from birds and are able to detect bats in the rotor-swept zone, something not possible with radar systems.

Infrared Imaging (IR)

IR capable digital cameras feature CCD (Charged Coupled Device) or CMOS (Complementary Metal Oxide Semiconductor) sensors that are sensitive to light with wavelengths in the range from 400-1100 nm. The visible spectrum of the human eye ranges from approximately 380-780 nm (Mangold et al., 2013) therefore this increased sensitivity extends the range of wavelengths recorded and allows visualisation of bats in lower light levels. Digital cameras cannot operate in full darkness as image sensors record the reflected light from an object when illuminated by a light source, such as the sun or lamps. At night-time when no ambient light is available, an additional IR light source is required to record an image.

Thermal Imaging

Thermal imaging (Long Wave Infra-Red) produces images based on wavelengths emitted from the radiant heat that objects produce that would otherwise not be visible to the human eye. Thermal cameras are sensitive in the mid wave infrared (MWIR), or long wave infrared (LWIR) spectrum range from 2-15 µm (Dakin, 2017). Thermal imaging devices detect differences in the natural thermal radiation (heat) of objects in the environment that are warmer than the absolute zero point (-273°C). Thermal imaging devices convert the infrared radiation (heat) they receive into a digital signal that is converted into a visual representation of the infrared radiation, known as a thermal image or thermogram (Fig. 12). Thermal cameras can be used in any light conditions and require no additional light sources to illuminate the surveyed area. In addition, a thermal camera performs better in foggy and rainy conditions in comparison to a daylight or IR camera. However, cloud cover may lower performance due to reduced contrast in temperature between animals and the environment (Beier & Gemperlein, 2004; Horton et al., 2015).

Selecting the right thermal camera equipment for offshore post-construction monitoring is essential for survey accuracy. Several camera characteristics are important to consider when collecting footage at night, including resolution, frame rate and thermal sensitivity. Comprehensive guidelines for the use of thermal imaging for surveying bats can be found in *Thermal Imaging: Bat Survey Guidelines published* by Bat Conservation Trust (Williams, 2021) with a summary of main points included below.

The resolution of the camera defines the amount of detail a camera image can capture, i.e. at what size and distance objects are still visible. The typical resolution for thermal (Long Wave Infra-Red) cameras is low (320x240 or 640x480 pixels) compared to digital cameras using daylight or near-infrared, and therefore reduces a small or remote object to a few pixels making it harder to track bats at distance, limiting its use at industrial facilities such as offshore wind turbines. Increasing the focal length of the camera by using different lens will increase the detection range but at the same time the field of view (FOV) will decrease, and objects can easily be lost when they fall outside the image (Matzner et al., 2015).

Frame rate or refresh rate defines the temporal resolution of the thermogram and in order to detect and recognise bats in flight, a minimum frame rate of 30 Hz is recommended. A higher frame rate results in more detailed and sharper images of moving objects, whilst a lower frame rate will not provide the sufficient quality required for the accurate detection of flights, resulting in animals becoming a ‘blur’. Thermal sensitivity is indicated as NETD (Noise Equivalent Temperature Difference) and is expressed in mK (milli-Kelvin). NETD changes with the temperature of an object and when compared to other objects in its surrounding, the NETD decreases leading to a better sensitivity (Rai et al., 2018). The lower the NETD number quoted, the better the thermal sensitivity. For bat survey applications a thermal sensitivity of 20-50 mK is required.

The majority of thermal imaging devices on the market are known as ‘uncooled’ devices and are generally appropriate for surveying bats in most circumstances. However, to survey offshore wind turbines it is generally necessary to use cooled cameras that achieve very high frame rates, thermal sensitivity and image quality which is required to cover the rotor swept zone (Matzner et al., 2015).

The reported detection distance of bats is up to 100 m (Matzner et al., 2015), 120 m (Lagerveld et al., 2017a) and 150 m (Molis et al., 2019), using thermal or near-infrared cameras. Cameras are typically applied for recording 2D footage (e.g. Matzner et al., 2015; Cullinan et al., 2015), but can also be used in a stereoscopic setup to track bats in 3D space (Lagerveld et al., 2017a; Matzner et al., 2020; Gilmour et al., 2021). Whilst Stereovision is more complicated as the cameras need to be synchronized and calibrated, this method is able to assess the actual 3D flight. Collisions and barotrauma events associated with wind turbines are likely to be much more detectable using a stereoscopic setup since abrupt changes in flightpath can be quantified (Lagerveld et al., 2017a; Matzner et al., 2020; Gilmour et al., 2021).

In summary, the use of videography for monitoring bats around wind farms is an important technique that can record bat activity and behaviour as well as how bats specifically interact with turbines, including in the rotor-swept zone, something not possible with radar systems. In the absence of carcass searches, the use of videography it currently the only viable option to detect bat collisions with turbine blades and when used in a stereoscopic setup can also be used to track bat flight paths around turbines. However, there are limitations to the use of videography that should be considered especially for use in an offshore setting. The reported detection distance of bats using thermal or near-infrared cameras is up to 150 m meaning that a single camera system would only be able to cover one turbine. Furthermore, accessibility issues to install and maintain equipment as well as exposure to harsher elements offshore can make using videography at scale problematic.

Radar

Radar is commonly used in monitoring birds and bird-fluxes, providing valuable data on migratory intensity and flight paths. Radar can be used to map flying animals in the range from <100 m to >200 km depending on the equipment, species, number of individuals and flight view angle (Gauthreaux & Belser, 2003; Desholm et al., 2006). Radar works on a similar principle to bat echolocation whereby radio wave pulses are transmitted and the returning reflections (echoes) of these on the surrounding objects are analysed based on elapsed time between pulses and echoes, and characteristics of the echoes. Radar can identify the distance, height, direction, course, and speed of flying objects and are able to work in most environmental conditions as they are unaffected by light level and can penetrate fog and clouds but do decrease in efficiency during heavy rainfall or snow.

Figure 13. Top: ThermalTracker-3D camera system for monitoring bats at wind farms and extracting 3-D movement trajectories. Photo from Pacific Northwest

National Laboratory. Bottom: Thermal image of bat (circled) flying near an onshore wind turbine. Photo from Paul Cryan https://www.usgs.gov/media/images/

Access to relatively cheap marine surveillance radars as well as open source doppler weather radar data across Europe have allowed radar to be utilised for studying the spatiotemporal patterns of birds, including in the offshore environment. Furthermore, due to the advances in radar technology, high-performance radars with optimal capacity for tracking of flying birds offshore, including 3-D tracking capabilities and efficient filtering of sea clutter, are now available (Skov, 2023).

There are a number of different types of radar deployed in the offshore environment and typically utilise X-band or S-band wavelengths and the advantages and disadvantages of different types of radar are described in Snoek et al. (2016). Currently whilst radar does allow for separation of avian and non-avian (e.g. insects) radar signals including the classification of size, it is not currently possible to reliably distinguish bats from nocturnal birds (Zaugg et al., 2008). In addition, it is not currently possible to monitor fatalities using radar as flying animals cannot be tracked when flying in the rotor swept zone (R. Cox, 2024, pers. comm.)

Increasingly, videography methods are being paired with radar to obtain species-specific and geo-referenced data on bird movements over large areas. Whilst this is not currently possible for bat species, developments in radar technology may lead to fully integrated radar and camera systems that allow 3-D tracking of bats over multiple spatial scales.

In summary, the use of radar for monitoring bats around offshore wind farms constitutes a promising area of research and development due to the accessibility of relatively cheap surveillance radars optimised for the marine environment and their ability to map flying animals at spatial scales from <100 m to >200 km. However, as it is not currently possible to reliably distinguish bats from nocturnal birds, the use of radar to monitor bats offshore is not a viable option for offshore monitoring. The future advancement of radar and integration with other systems would be an important development for monitoring bats offshore, especially due to its long-range capabilities.

Strike Detection Systems

Despite not being currently available for use in operational wind farms, the use of sensor arrays to directly detect collisions with turbine blades is a promising avenue of research especially for offshore turbines where typical fatality assessments such as carcass searches are not possible. Studies using vibro-acoustic impact sensors in the rotor blade of test turbines onshore have been able to detect an impact signal from a collision using objects weighing between 57 g and 140 g (Wiggelinkhuizen et al., 2006, 2010). When combined with bioacoustic and optical nodes in a multisensory array, Hu et al. (2017) were able to detect 48% of all collisions with moving experimental turbine blades. However, the authors conclude that further research is required to improve technology capabilities and integration of the system to increase detection rates. Currently it seems unlikely that small, high-risk migratory bat species such as *P. nathusii* (6-15 g) or even *N. noctula* (18-40 g) will be detectable with this type of system.

In summary, currently the quantification of fatality risk can only be achieved using videography to detect direct collisions, however these camera techniques are subject to a number of critical limitations which make their adoption over the scale of an entire wind farm unlikely. The use of integrated strike detection systems within the turbine blades would constitute a profound advancement in the ability to monitor bat fatalities in the offshore environment and at a scale not possible by other systems.

Mitigation Measures for Impacts on Bats

The mitigation hierarchy indicates that development planning should first seek to avoid then reduce significant effects and in cases where this is not possible, they must be adequately mitigated. Mitigation options should be considered at several stages of development: in the initial site assessment, pre-application (embedded mitigation including in the design of the turbines themselves), pre-construction and then, if necessary, at the post-construction stage (NatureScot, 2021).

A number of mitigation options are currently available that seek to limit the negative impacts of windfarm developments on bats. Whilst there is limited literature available on mitigating the impact of offshore wind farms specifically, there are a number of options that have been described in guidance relating to onshore windfarms and bats, or have direct evidence supporting their efficacy at reducing impacts.

The best strategy to avoid the risk to bats, which will benefit both bat conservation and renewable energy economic viability, is preventative planning at the initial site assessment and pre-application stages of any development (Rodrigues et al., 2014; NatureScot, 2021; Reason & Wray, 2023). Taking into account bat activity and behaviour during the screening and scoping phases of a wind farm development will lead to evidence-based spatial and strategic planning that may avoid further mitigation and associated financial implications during later stages of offshore wind development. This includes adjusting the proposed layout, location or design of the turbines within a development zone, to avoid areas that have been shown to have high bat activity or important migratory pathways where turbines might pose a particular risk of bat collisions. Current guidance for onshore wind development recommends that appropriate impacts assessments should gather sufficient information on spatial and temporal patterns of bat activity with the proposed development site (NatureScot, 2021).

Recognising the increasing pressure for renewable energy across Europe for climate change mitigation, the European Commission is supporting the development of a toolkit to inform renewable energy deployment that will help Member States develop Wildlife Sensitivity Mapping (WSM) within their own countries and regions (European Commission’s Joint Research Centre, 2024). These sensitivity maps will not replace the need for site-specific assessment but will instead act as a guide during early screening assessments.

Whilst no current sensitivity maps for bats are available for offshore development zones, projects conducted onshore have shown the benefits of this approach in guiding strategic planning of onshore wind farms. In the western Black Sea Region of Romania, a deterministic model of wind energy sensitivity maps for bats was included in the national guidelines for wind farms and as a result some developers have eliminated planned turbines from potentially sensitive areas (Măntoiu et al., 2015). Sensitivity mapping in this area has reduced the overall number of units, in some cases by more than half of the size of the initial project. Further projects are now underway to identify bat migratory pathways in the region via a range of telemetry towers in conjunction with a bioacoustics monitoring program that includes offshore data. Continued data collection will allow bat sensitivity models to be calibrated and updated.

It is recognised that sensitivity mapping should be treated with caution as assessing the abundance and distribution (including migratory corridors) of bats is challenging and subject to changes over time and therefore strategic level data may quickly become out of date (Davy et al., 2020). Sensitivity maps should be used in a way that does not lead to misleading assumptions such as “low-risk areas” which may lead to areas being exempt from any EIA and bat protection measures. Guidance by EUROBATS (2023) recommends that wind turbine siting based on sensitivity maps, even in “low-risk areas” should be followed by monitoring post installation (in combination with curtailment / bat-friendly operation algorithms).

(Table 7 in Section 3. Workshops, outlines the pros and cons of some of the different mitigation methods as discussed by delegates.)

Turbine Curtailment

Wind turbine curtailment, including feathering turbine blades (pitching the blades out of the wind to reduce rotation speeds) and/or raising the cut-in speed (the wind speed at which blades start to turn), has been readily adopted both onshore and offshore in several European countries as an effective strategy to minimize bat fatalities. As bat activity in relation to the weather conditions measured at the nacelle in offshore wind farms, is very similar to what has been observed on land (i.e. higher activity on warm, calm nights), there is no indication that curtailment strategies are less suitable than those used onshore (Boonman, 2018).

Reducing rotation speed while idling

Some models of wind turbines (usually older ones at onshore facilities) will continue to rotate freely at low wind speeds that are not sufficient to produce electricity (idling) but can still cause bat fatalities. There is evidence that bat casualties at wind farms can be reduced by feathering the blades to reduce rotation speeds below 2 RPM while idling. The reduction in speed resulting from feathering compared with normal idling may reduce fatality rates by up to 50% (Arnett et al., 2013; NatureScot, 2021). As this option does not result in any loss of output, it is currently recommended in NatureScot (2021) onshore guidance as best practice, that rotation speeds while idling are reduced when practically possible and where there remains uncertainty over the risk posed to bats.

Blanket Curtailment

Blanket curtailment involves feathering turbine blades above the manufacture's cut-in speed, typically 2.0-3.0 m/s), and/or raising the cut-in speed of wind turbines (e.g. to 4.0-7.0 m/s) with associated loss of power generation. The UK guidance for *Bats and Onshore Wind Turbines: Survey, Assessment and Mitigation* (NatureScot, 2021) determined that "the threshold values at which turbines are feathered should be site specific and informed by bat activity peaks at that location, but as an indication, they are likely to be in the range of wind speeds between 5.0 and 6.5m/s and at temperatures above approximately 10 or 11ºC measured at the nacelle". However, the revenue losses resulting from such measures, if based solely on wind speed or season, are often considered high and in the context of rising energy prices, some energy companies are re-assessing whether curtailment strategies could be modified to use lower cut-in speeds (e.g. reducing from 5.5 to 5.0 m/s).

Smart Curtailment

Some wind energy installations use wind speed in combination with other environmental variables found to be predictive of bat activity. Research by Barré et al. (2023) suggests that algorithm-based curtailment that includes a range of features including landscape, weather conditions, seasonality, and turbine functioning is more effective and causes less energy loss for operators compared to blanket curtailment. In their models, algorithm curtailment reduces average exposure (as measured by acoustic indices) for long-range echolocators (20-29%) and mid-range echolocators (7-12%), both of which are at particular risk from turbines.

In addition, there are several projects developing and testing "smart curtailment" strategies that optimize a curtailment regime through the combination of weather data (wind speed and direction, temperature, etc.), real-time bat activity and/or other parameters (e.g. period of the year, and time of day). An example of this is the Turbine Integrated Mortality Reduction (TIMR; Case Study 6) system which combines bat activity and wind speed data to make near real-time curtailment decisions (Hayes et al., 2019). The TIMR system was found to significantly reduce (by 84.5%) fatality estimates at onshore turbines compared to turbines not using the TIMR system. Whilst the approach reduced the estimated annual revenue at the wind energy facility by ≤3.2%, the authors estimated that the curtailment time for treatment turbines was ~48.5% less than would have been expected for turbines operated under a standard blanket curtailment rule used in North America (curtailment if wind speed <6.9 m/s).

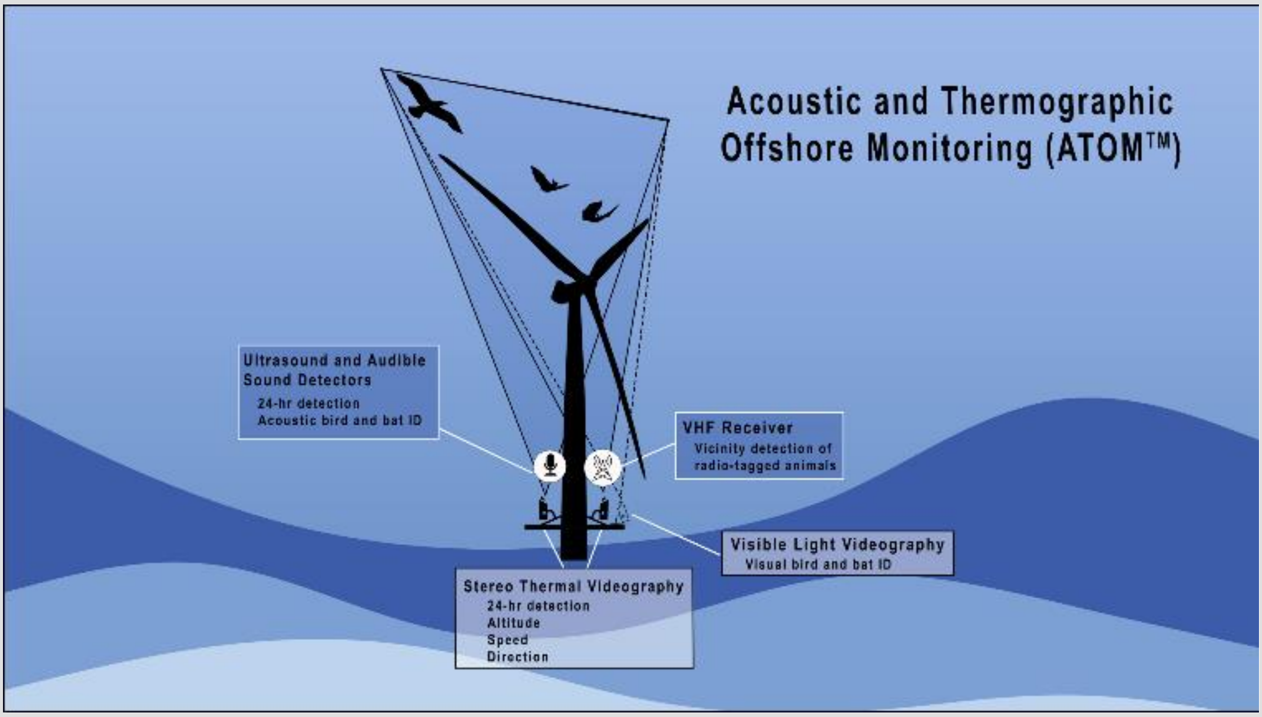
There are a range of other systems currently in use or under active development, including “DT-Bat” which uses a combination of modules (thermal imaging and ultrasound) to detect and track bats, and Wildlife Acoustics “SMART” system (ultrasound only), that can be connected to turbine SCADA systems (Case Study 5) to produce real-time turbine switch off in response to the presence of bats. However, it is important to note that none of these systems have been evaluated in their effectiveness in reducing bat fatalities offshore and their use should therefore be considered experimental until their value has been demonstrated through formal fatality surveys.

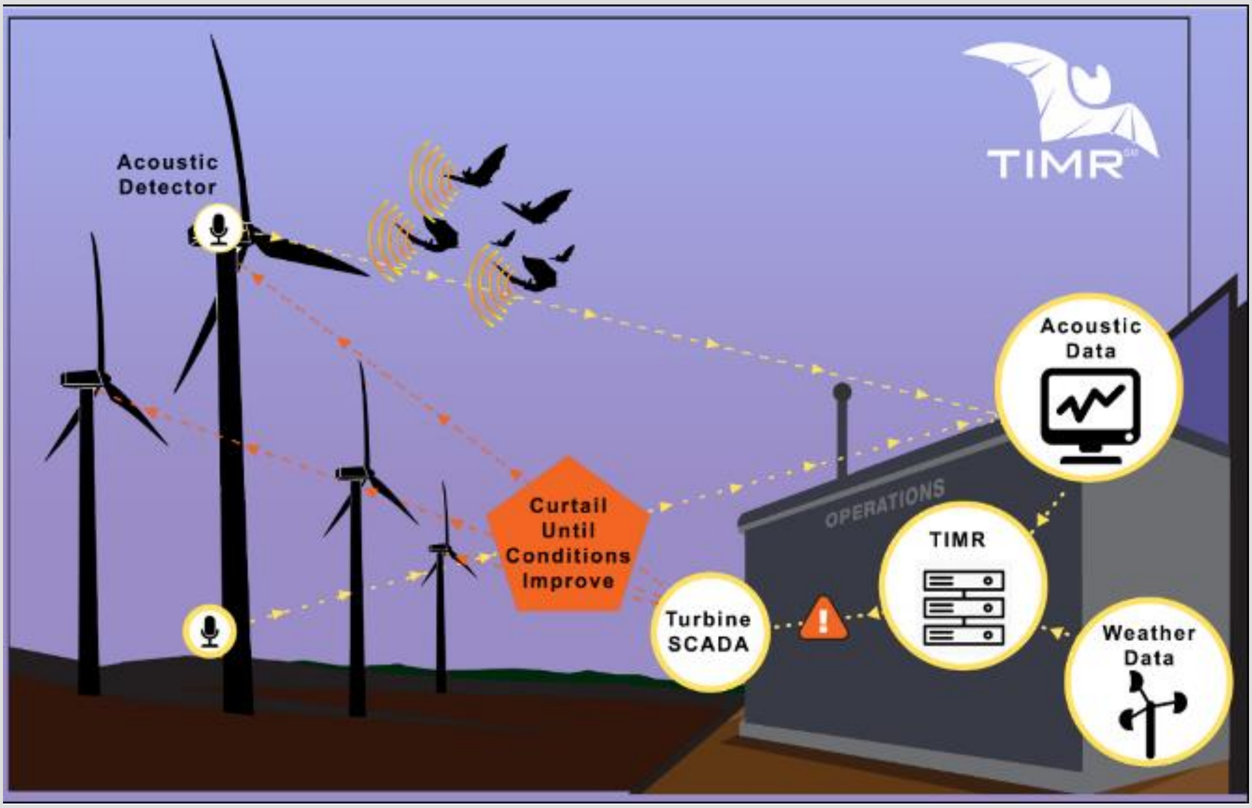
Case Study 6 – ATOMic TIMR: A Multi-Sensor Approach for Bat-Turbine Interaction Monitoring and Mitigation

The accelerated development of offshore wind energy production and its potential impact on bats and birds is highlighting a major knowledge gap about bat presence and behaviour – how often are bats present in the offshore environment and what do they do there?

Using a unique Acoustic and Thermographic Offshore Monitoring system (ATOM™), deployed on two Coastal Virginia Offshore Wind (CVOW) pilot turbines located 23 nautical miles (42 km) offshore Virgina, we have monitored and characterized bat presence offshore throughout the year and around-the-clock, through thermal imagery, HD video, and acoustics.

The first two years of this three-year project have been analysed, and the results so far are intriguing. Three species have been identified in our data, all migratory tree-roosting bats: hoary bat, Eastern red/Seminole bat, and silver haired bat. Bats show a very strong seasonal pattern with most detections occurring during the fall (late August to early November) and are probably associated with fall migration. Interestingly, we recorded significant activity during daylight hours, and that was correct for all three species. We have recorded significant foraging activity, both aerial hawking and gleaning off the tower. In many instances bats were present while turbine blades were moving, and while we documented micro-avoidance behaviour and a few air-displacements we never documented a collision.





Top: ATOM™ monitoring technology. **Bottom:** TIMR℠ mitigation technology

To mitigate collision risk, Normandeau developed its Turbine Integrated Mortality Reduction (TIMR℠) system that detects bat activity near the turbine and communicates directly with the facility "brain" to implement real-time smart curtailment.

The current focus is to combine the two technological approaches and expand and improve their sensor-array to increase covered area and detection, classification, and response capabilities, for a better understanding of the post-construction aerosphere and increased protection to its inhabitants – bats, birds, and insects.

E. Amichai, G. M. Forcey, M. Vukovich, and J. R. Willmott
Normandeau Associates, Inc., 13100 Tech City Circle, Suite 500, Alachua, FL 32615

Deterrents

In contrast to methods that aim to mitigate the negative impacts of wind turbines by shutting down turbines when bat activity is recorded thereby reducing fatality risk, there are a number of methods that have been tested that aim to deter bats from turbines while they remain operational. The main deterrent approach that has been tested is the use of ultrasound to dissuade bats from approaching wind turbines, although these have currently only been tested at onshore wind farms. In the USA, a number of studies have shown substantial reduction in bat fatalities at operational wind energy facilities using this method (Horn et al., 2008; Arnett et al., 2013; Romano et al., 2019; Weaver et al., 2020). Research by Romano et al. (2019) found an overall reduction of bat fatalities of 29.2% (2014) and 32.5% (2015) using deterrent system jets that produced a broad-band sound designed to overlap the entire range of frequencies (~30-100 kHz) generated by and audible to most bat species. Weaver et al. (2020) used a deterrent system consisting of six subarrays, each emitting a continuous high frequency sound ranging from 20-50 kHz. The authors also report a significant reduction in bat fatalities for *L. cinereus* and *Tadarida brasiliensis* (by 78% and 54%, respectively). However, most studies conclude that the effectiveness was highly species-specific and whilst deterrents have potential as a mitigation strategy, further research is needed to improve their applicability for a wider range of species and there are currently no examples of successful deterrent strategies using ultrasound in a European setting or offshore.

Experiments on using deterrents have also been conducted on European bat species, although not in the context of wind farm mitigation. Studies by Gilmour et al. (2020) tested the effect of an acoustic (ultrasonic speaker) and a radar (X-band Marine Radar) system to deter bats and found that ultrasonic deterrence (together with or without radar) decreased overall bat activity by ~80%, whereas radar was not effective alone. However, similar to the research conducted in the USA, the effect of the ultrasound treatment was highly species-specific and while *P. pipistrellus* and *P. pygmaeus* reduced their activity by 40--80% and 30-60% respectively, *Myotis* spp. species did not. The positive deterrent effect on bat species in this study may prove to be a potential method for deterring *Pipistrellus* spp. from offshore wind turbines. However, habituation effects to these deterrents have not yet been assessed and further research is required to determine the effectiveness of acoustic deterrents in a European offshore context and for migratory species who are a particularly vulnerable to offshore wind impacts i.e. *P. nathusii*.

Lighting

There are a number of hypotheses regarding bat attraction to offshore wind farms, however few strategies have focused on reducing potential attractants at a landscape scale. Reducing attractive cues, such as distant stimuli or known aggregating factors for insect prey, may prove an effective approach to reducing bat collisions from wind energy development. Reducing attractive features is sometimes known as passive deterrence.

Changing lighting at wind farms to those that emit wavelengths that are less attractive to bats and their insect prey but are still approved for obstruction lighting could be tested to reduce the potential attraction (CAA, 2016; Voigt et al., 2018; Simões et al., 2017). Furthermore, facilities could utilise Aircraft Detection Lighting Systems (ADLS) that reduce light pollution at wind farms by activating obstruction lighting only when approaching aircraft are detected in the vicinity. Further research is required to determine how effective changes to obstruction lighting would be on the attractiveness of wind turbines to bats in an offshore context or at the scale of a whole wind farm rather than individual turbines.

3. Workshops

Aim

Two stakeholder workshops were delivered on Zoom on 8th and 15th February 2024, both sessions were 3 hours 30 minutes. The purpose of the workshops was to consult, via guided discussion, a panel of experts and stakeholders on the potential impact of offshore wind farms on migrating bats and bat populations in English waters, the methods available for survey and monitoring in the offshore environment and mitigation solutions available to minimise impacts, drawing on knowledge from onshore, offshore, national and international where appropriate. Also, to identify existing industry guidance and opportunities to develop further guidance and policy in this area.

The aims and objectives of the workshop including key questions were determined through discussion between BCT, university of West of England and Natural England, based on the findings of the literature review.

Full details of the workshops are included in Appendix A stakeholder affiliations, Appendix B Agenda for the workshop, Appendix C Agenda for the workshop, Appendix D workshop slides, and are summarised below.

Objectives

Objectives of Workshop 1

1. To introduce the 'Assessing migration of bat species and interactions with Offshore Wind Farms in British Waters' project to experts and stakeholders
2. To summarise the results of the literature review to date
3. To present examples of international lessons learnt and best practice in relation to bats and offshore wind farm development
4. To discuss the reliability of translating knowledge of the impacts of wind energy on bats and best practice approaches from onshore to offshore
5. To discuss the reliability of translating knowledge of the impacts of wind energy on bats and best practice approaches from an international to an English setting
6. To discuss potential options to standardise pre-construction assessments – pros and cons of different methods, standardising an approach.
7. To encourage attendees to provide input by midday on Tuesday 13th February on monitoring and mitigation methods
8. To encourage attendees to provide input by midday on Tuesday 13th February on available, published best practice
9. To encourage attendees to provide input by midday on Tuesday 13th February on evidence gaps, with an indication of their view on prioritisation
10. Potential options to standardise post-construction monitoring of bat activity and interactions with turbines – pros and cons of different methods, standardising an approach

11. Potential options to standardise post-construction mitigation (e.g. curtailment, acoustic deterrents) – pros and cons of different methods, standardising an approach.
12. Whether there is enough evidence available to warrant standardising mitigation for offshore wind in England/the UK.
13. Opportunities to develop industry best practice guidance and influence policy in relation to bats and offshore wind consenting and what it would recommend given current knowledge.

Facilitators

The workshop was facilitated by the Bat Conservation Trust (BCT) and the University of the West of England (UWE).

Workshop participants

Thirty-five individuals attended both workshops with an additional nine attendees joining Workshop 1 and seven different attendees joining Workshop 2. Workshop agendas are included in Appendices A and B.

An email was sent to a wide list of potential participants who have previously, or were currently conducting, bat research or have collected relevant bat data. In order to manage the size of the workshop and facilitate discussion each organisation was then asked to field one or two representatives, limited to those who could most confidently discuss the bat data and evidence held by their organisation. The full list of the number of representatives is included in Annex 1. Attendees included representatives from:

Government	Department for Energy Security and Net Zero Department for Environment, Food and Rural Affairs Dutch Ministry of Infrastructure and Water Management
Statutory Nature Conservation Bodies	Joint Nature Conservation Committee Natural England Natural Resources Wales NatureScot Northern Ireland Environment Agency
Academia	EUROBATS Royal Belgian Institute of Natural Sciences

	Évora University Leibniz Institute for Zoo and Wildlife Research National Renewable Energy Lab Paris Natural History Museum (bat migration) Royal Belgian Institute of Natural Sciences University of Sussex University of the West of England
Bat Groups	Irish Nathusius' Pipistrelle Working Group Living Record Bedfont and Colne Valley Bat Research Bat Conservation Ireland Bat Conservation Trust Norwich Bat Group
Ecological consultants	Bach-Freilandforschung, Germany Plecotus - Estudos Ambientais, Unip. Lda, Portugal APEM BSG Ecology Natural Power Normandeau Associates
Industry Offshore wind developers	Orsted Scottish Power Renewables Vattenfall Equinor RWE

Equipment suppliers	Wildlife Acoustics
NGOs	Vincent Wildlife Trust

Workshop format

Consultation took place via guided discussion workshops with both open-ended and more targeted questions, facilitated by the project team. Questions to help guide these discussions were included in the agendas to allow participants to consider responses.

To ensure a comprehensive approach and maximise participation during these workshops, responses were collated using a Miro online whiteboard. Miro is a digital collaboration platform to facilitate remote team projects and involved participants adding digital sticky notes expressing their thoughts onto the relevant frame on the online whiteboard. The workshop provided an opportunity for international information sharing.

All points raised by workshop participants were added to the miro boards to show the broad range of evidence and views. The migration of bats to and from the UK is an emerging field, there is currently a paucity of evidence. As the evidence base in relation to bat migration develops, as more baseline data is collected, future research should focus of consensus building amongst stakeholders of the highest priority evidence gaps, research required to close those evidence gaps and recommendations to reduce impacts to migrating bats.

Presentations

A series of presentations were delivered by international experts involved in bat migration and offshore wind work over the course of the two stakeholder workshops. A list of the presentation titles, the presenter names and their organisations are provided below, to illustrate the breadth of topics and level of international representation.

- Assessing Migration of Bat Species and Interactions with Offshore Wind Farms in English Waters: Introduction to the Project – Tamara Rowson, Natural England, UK

- Assessing Migration of Bat Species and Interactions with Offshore Wind Farms in English Waters: Literature Findings to Date – Jack Hooker, Bat Conservation Trust, UK

- Bats Within the WOZEP Programme: Gained Knowledge and Research Difficulties – Marije Wassink, Rijkswaterstaat / Ministry of Infrastructure and Water Management, The Netherlands. See Case Study 2.

- Kattegat and West Baltic Bats Project (KABAP) – Robin Cox, Vattenfall, UK. See Case Study 4.

- UK MOTUS Tagging – Jane Harris, Norfolk and Norwich Bat Group, UK

- Assessing Migration of Bat Species and Interactions with Offshore Wind Farms in English Waters: Literature Findings to Date: Outputs from workshop 1 – Jan Collins, BCT, UK

- EUROBATS Intersessional Working Group on Wind Farms and Bat Populations – Luisa Rodrigues, EUROBATS

- Bat Migration Routes in Europe – Charlotte Roemer, Paris Museum of Natural History, France. See Case Study 7.

- Migratlane: Characterising the Use of the North-east Atlantic Arc by Birds and Bats – Anais Pessato, Paris Museum of Natural History, France. See Case Study 3.

- Offshore Wind and Bats: Knowledge from Germany – Antje Seebens-Hoyer, Nature and Biodiversity Conservation Union, Germany. See Case Study 1.

- Bats and Wind Energy Studies in the US – Cris Hein, National Renewable Energy Lab, USA

- ATOMic TIMR: A Multi-Sensor Approach for Bat-Turbine Interaction Monitoring and Mitigation – Eran Amichai, Normandeau Associates, USA. See Case Study 6.

- Being Smart about Bats at Wind Farms: Introducing Wildlife Acoustic's Smart System – Fran Tattersall, UK. See Case Study 5.

Slides from some of these presentations are provided in Appendix D.

Translating evidence/knowledge/methods

During Workshop 1, delegates were invited to add sticky notes to Miro online whiteboard frames on the topic of which evidence, knowledge and methods can potentially be translated from onshore to offshore, and from international to the UK, and which probably cannot. Tables 4 and 5 summarise the main results of this exercise. Unknowns were also identified as part of this exercise; however, these have been included in the Evidence Gaps section.

Table 4. Delegate's views on which evidence, knowledge and methods can be translated from onshore to offshore and which cannot.

Potentially can translate	Probably cannot translate
Bat activity and behaviour: the occurrence of insects around the turbines that could attract foraging bats, the effect of turbine lights in attracting bats, the possibility of bat attraction to wind turbines for other reasons, the timing of migration, the types of weather conditions when bats migrate.	**Bat activity and behaviour:** flight height, behaviours whilst migrating offshore, level of attraction, level of exploration of turbines in seascape, response to seascape is different to landscape, the extent of offshore activity relating to migratory bats or other types of bat movements (e.g. local bats foraging offshore), impact of weather more pronounced offshore with migration switching on/off.
Impact: The possibility of bats colliding with turbines.	**Impact:** mechanisms for collision risk, number of fatalities, whether larger offshore turbines and rotor swept area increase the risk, does the larger distance between turbines reduce the risk.
Bat activity monitoring: acoustic, MOTUS, thermal videography, at height monitoring, industry knowledge of fitting sensors, new strike detection technologies.	**Bat activity monitoring:** ability to access equipment, impact of conditions on equipment, fitting detectors might be different on offshore turbines (e.g. which location), short range of bat detector in contrast to longer blades, cannot do carcass searches offshore.
Mitigation: impact of feathering, efficacy of curtailment, shut down procedures.	**Mitigation:** blanket curtailment at offshore scale could be a problem for grid stability, curtailment economics different.

Table 5. Delegate's views on which evidence, knowledge and methods can be translated from Europe/other international work to the UK and which cannot.

Potentially can translate	Probably cannot translate
Bat activity and behaviour: activity patterns and behaviours from same species or species groups, the phenomenon of coastal migration and foraging offshore, flight characteristics when crossing open water, effect of weather, length of daily movements, effect of topography for 'jumping off'.	**Bat activity and behaviour:** extent of offshore foraging, night phenology due to amount of open water to cross, effect of migration route characteristics, effect of specific weather events, behaviours of species not found in the UK
	Impact: Cumulative impacts are likely to be different with differing levels of development in different locations.
Bat activity monitoring: survey methodologies, suitable equipment for offshore environment, new technologies, use of offshore infrastructure for monitoring, technical requirements for sensors.	
Mitigation: impact of feathering, efficacy of curtailment, shutdown procedures	
Collaboration: how to share knowledge and data, how to collaborate	

There was some discussion among delegates about the difference (in terms of collision risk) between direct migration at a low level above the surface of the water (as observed by Ahlén et al., 2007 & 2009) and exploratory behaviour, which has been observed offshore in Germany, where bats fly up and down turbines and lighthouses (see Case Study 1). This led to discussions about bats potentially flying between the turbines of an offshore wind farm and being unaware of the presence of the turbines. However, bats use a variety of senses as they move across a landscape or seascape and their first perception of a wind farm is likely to be via sight, mechanoreception (vibration, touch and pressure discrimination) or thermoreception (temperature discrimination) (Romo et al., 2022). Bat vision is capable of detecting distant objects in dim light (Shen et al., 2010) and, although detection range is likely to be species specific and dependant on object size and contrast to the surroundings, it will generally be within a few kilometres (Boonman et al., 2013; Eklöf et al., 2014). Mechanoreception and thermoreception may be even further; the wake effect of operational turbines can be up to a few kilometres on the downwind side of a turbine (Porte-Agel et al., 2019). If bats are able to detect wind turbines at this distance they may be subsequently attracted to investigate them.

A particularly important difference delegates highlighted between onshore and offshore is that carcass searching is not possible offshore because casualties will fall into the sea. This is the primary means by which the impact of onshore wind turbines on bats and the efficacy of mitigation measures such as curtailment have been monitored.

Strategic planning and pre-construction assessment

Delegates were next invited to add sticky notes to Miro online whiteboard frames on the topics of considering bats in strategic planning for offshore wind and baseline characterisation/impact assessment for individual offshore wind farms. Delegate's contributions were then used to inform discussions both in smaller, mixed groups and in plenary.

Strategic planning

One of the key themes arising from the discussions was the need to study bat migration movements at a wide scale, which could potentially inform marine spatial prioritisation for future rounds of offshore wind in the UK. Siting decisions have already been made for Offshore Wind Leasing Round 4 (creating the opportunity for 8GW of new offshore wind projects around England and Wales[2]) and Offshore Wind Leasing Round 5 (to establish a new floating wind sector in the Celtic Sea[3]). However, such decisions have not yet been made for future rounds.

Delegates suggested monitoring bats from existing offshore infrastructure such as buoys, platforms, weather masts, research stations and existing offshore wind farms, and boats or ferries, as this could potentially identify areas that would be less suitable for offshore wind development due to higher levels of bat activity. Potential departure/arrival points onshore can also be monitored, initially focusing more effort where the distance between land masses is shortest. There was some discussion around the suitability of different types of buoys for bat monitoring, with larger buoys supporting WiFi connectivity considered the most appropriate, although the most expensive, option.

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[2] https://www.thecrownestate.co.uk/our-business/marine/Round4

[3] https://www.thecrownestate.co.uk/our-business/marine/round-5

Some international case studies that were presented in the workshops illustrate strategic approaches to bat monitoring offshore, including Case Studies 1 to 4.

Bat survey methods that were identified by delegates for strategic planning included acoustic detectors, MOTUS tracking, thermal imaging cameras, radar and satellite tagging. See Table 5 for the pros and cons of the different methods. A strategic approach to bat monitoring would require the right combination of these technologies (as each provides different types of data) and a good sampling design. Delegates noted that, due to the long lead in time for offshore wind, any guidance produced for surveying bats would need to be broad as technology will change over time.

Delegates were keen to see a variety of bat species included in monitoring (for example *N. noctula* and *N. leisleri* are both migratory species) not just a focus on *P. nathusii*. Also, that monitoring should be carried out for as long as possible and cover both day and night, as it is possible that bat migration may continue into daylight hours (see Lagerveld et al., 2014, 2017). It was also suggested that the relationship between the occurrence of insects at sea and the presence of bats could be studied; swarms of insects can potentially be detected using radar.

Finally, it was noted that data collection for bats should be standard, in the same way as it is the accepted requirement for seabirds. There should be a formal obligation, possibly through Development Consent Orders or marine licence conditions, for data to be collected by developers. Guidance is needed to inform the approach and data sharing is essential. At the strategic level, adequate funding, guidance and international collaboration will be required to support ongoing work in this area. The opportunity to collaborate at a European level already exists through the Agreement on the Conservation of Populations of European Bats (EUROBATS). The UK is a signatory to this Agreement, which was set up under the Convention on the Conservation of Migratory Species of Wild Animals (the Bonn Convention). See *Update from the EUROBATS Chair for Wind Turbines and Bat Populations Intersessional Working Group* slides in Appendix D; this group has started work on guidelines for bats and offshore wind by designing the structure/headings for the document. It is likely that this work will take at least a year to complete. The guidance will cater for all countries that are signed up to the EUROBATS Agreement, including the UK, although there may be country-specific considerations that are not included. Ideally, a representative from the UK should sit on this group to ensure that any UK guidelines produced are complementary rather than duplicating effort. Whilst there is no international data repository for EUROBATS, there is one for seabirds and marine mammals[4]. The potential to add bats to this international database should be explored.

[4] https://www.ices.dk/data/data-portals/Pages/European-Seabirds-at-sea.aspx

In the US, there is a collaboration focussed on the Atlantic (the Regional Wildlife Science Collaborative), which has developed a science plan[5] including bats. The UK could potentially benefit from learning gained through such collaborative efforts.

On the topic of data sharing at a UK level, a few examples were identified by delegates, including:

- Planning Offshore Wind Strategic Environmental Impact Decisions (POSEIDON[6]) – a project led by Natural England aiming to establish an evidence base to support the sustainable development of offshore wind. It is large-scale, cross taxa, standardises the data collected and provides clear graphic illustration and modelling. The scope for POSEIDON is currently data collection for benthic habitats, marine ornithology and marine mammals. It is possible that layers for bat data could be added in the future, providing data standards can be met. POSEIDON currently uses data from The Centre for Environment, Fisheries and Aquaculture Science (CEFAS), which holds data from across Europe, so there is potential to include international data to provide more confidence to any modelling work. The POSEIDON project is currently projected to run until 2025; it has not been determined how the database will be managed after this time. It is part of the Offshore Wind and Evidence and Change Programme (OWEC), led by the Crown Estate, with the data made publicly available via the Marine Data Exchange.

- Marine Data Exchange – a collection of offshore marine industry data and evidence created and operated by the Crown Estate[7]. Early conversations with the Marine Data Exchange indicate that this would be a suitable national repository for data collected in marine and very coastal environments such as lighthouse sites.

These databases cover the UK only and do not currently include bats as a receptor of impacts from offshore wind, however there is potential for bats to be added.

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[5] https://rwsc.org/science-plan/

[6] https://naturalengland.blog.gov.uk/2023/02/01/poseidon-offshore-wind-and-nature/

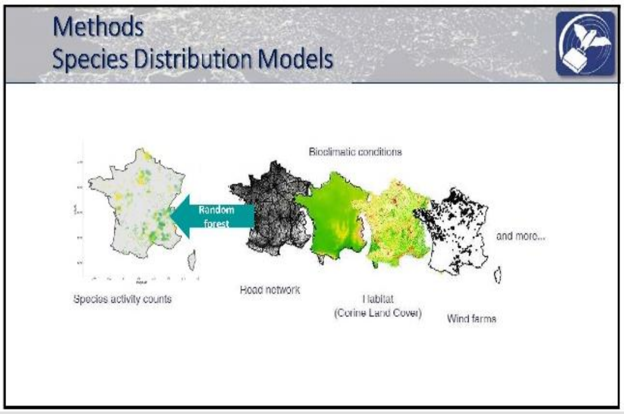
[7] https://www.marinedataexchange.co.uk/

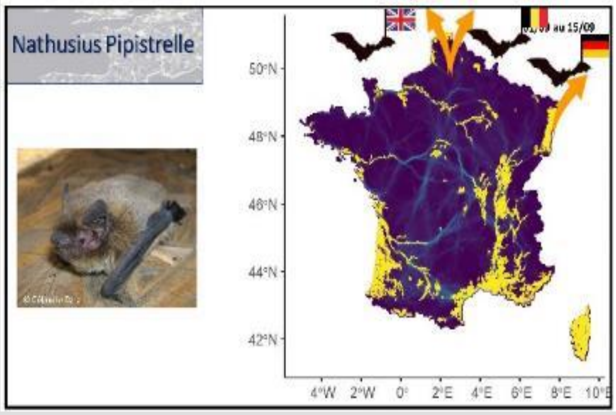
The Paris Natural History Museum is running a collaborative database project to study spatio-temporal changes in bat activity and highlight areas of conservation priority at a European level (see Case Study 7). In the USA there are two databases collating information for the Pacific and Atlantic hosted on the Tethys website[8], alongside various reports, publications and tools. Learning could be gained from how these have been set up and are maintained/managed.

Case Study 7 – Bat migration routes in Europe: an acoustic venture

Bat Migration Routes in Europe started in 2021 and is funded until 2026. The aim of this project is to bring together all the bat enthusiasts and bat workers who have collected passive acoustic recordings in Europe and make a common dataset to study bat migration routes. The perspective of the maps that will be created in this project is to designate areas of conservation priorities for bats and inform spatial planning, notably for wind energy development.

The project is coordinated by the French Museum of Natural History, in collaboration with more than 80 active partners from almost 30 countries in Europe. The methodology is currently being built in collaboration with 16 researchers from different countries in Europe. It consists in using the dataset from the French citizen science programme Vigie-Chiro as a proof of concept to create species distribution models (SDM) and connectivity models. For the SDM, a random forest algorithm is trained to predict the number of bat passes per night according to more than 300 predictors (habitat, bioclimatic conditions, topography, human activities, etc.).





The predictions are then made every two weeks between March and October. For the connectivity model, we used the method of the randomised shortest paths. We use the areas with the highest activities every two weeks as start and arrival points, and then calculate the most probable connectivity between these areas in the spring and then

[8] https://tethys.pnnl.gov/

again in the autumn. For the map of movement costs, we used the inverse of the highest value of activity for each pixel during the spring or the autumn respectively.

The maps created fit very nicely with previous knowledge obtained in the literature thanks to capture and roost data. The acoustic overlap between species is mainly tackled by the automatic identification. For instance, the map of the Nathusius' Pipistrelle is completely different from the map of the Kuhl's Pipistrelle and fit their ecology. Nonetheless, limits in this process are highlighted in some areas such as Corsica where residual activity of species such as the Nathusius' Pipistrelle can be observed in the predictions, when it was never confirmed there. However, when hotspots of activity are considered, this residual activity is too low to be included.

As a perspective, we want to create maps for offshore activity and connectivity, but we lack data at the moment. We collect sound files (WAV or RAW). They need to be organised in folders according to our requirements, and all the metadata need to be filled in a table. Data is to be uploaded directly to our server. The necessary information is available on the website bat-migration-europe.netlify.app.

Thanks to a EUROBATS funding, we support non-profit structures in countries underfunded for bat research and conservation with an Audiomoth donation.. Instructions for applications can be found on the website.

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Pre-construction surveys and impact assessment

Many of the discussions in the previous section are also relevant to pre-construction surveys at the site level, for example the use of existing infrastructure for bat monitoring, the bat monitoring methods that can be deployed, the need for regulatory obligations to carry out such monitoring, and the need for international collaboration and data sharing. In addition, infrastructure may be deployed at a site-specific level (for example weather masts or wave rider buoys) for offshore wind farm projects and bat monitoring could be carried out from those. CEFAS already have a network of wave rider buoys that feed-back data in real time[9]. There may be potential to incorporate bat monitoring onto these buoys. Discussions with CEFAS would be required to establish the practicalities of this, including

[9] https://www.cefas.co.uk/data-and-publications/wavenet/

costs, data transfer capabilities and liabilities. The installation of bat monitoring equipment on buoys as part of a standard suite of equipment in a national strategic array could be used to inform strategic planning. The potential to develop this as best practice and integrate with established infrastructure should be explored as a future project.

One of the key themes arising from this discussion, however, was that bats change their behaviour in the presence of wind turbines in the seascape (similar to seabirds) and therefore pre-construction surveys at the site level may be of limited value in predicting likely collision impacts during operation. However, these surveys can identify the presence of bats, the species present, their relative abundance at different locations and provide a baseline for post-construction surveys to be compared against. Because of the lack of information on bats offshore in UK waters, pre-construction surveys at the site level can add value, particularly if the data collected is shared centrally.

Currently, there is no guidance available on how to carry out *pre-construction surveys* to inform the planning and development of individual offshore wind farms in UK waters. For example, it would be useful to understand how long to monitor for, when to monitor, how many bat detectors would be required and how the results should be interpreted. Delegates suggested it would also be useful to have guidance on which types of buoys can be used for bat monitoring and how detectors can be fitted to them. Also, how bat monitoring equipment can be fitted to other infrastructure such as weather masts and wind turbines. Finally, it would be useful to know which equipment has been tested and proven in the offshore environment.

Delegates from Germany explained that two consecutive years of monitoring bats from buoys is required for new developments in German waters with a minimum of five detectors (although this is dependent on the size of the proposed wind farm) and for the whole of the migration period. Observations are that very high levels of bat activity offshore occur over a small number of nights (see Case Study 1).

Wildlife Acoustics have developed a bat detector that is salt and fog tested, has a solar panel and satellite connectivity to download data (see Case Study 5). Batcorders have also been effective in monitoring bats offshore in Germany.

It was also noted that there is no guidance available for carrying out *impact assessments* for new offshore wind farms. There was much discussion about bats colliding with offshore wind turbines and whether or not these losses will impact populations. However, as the presentation *Bats within the WOZEP programme: Gained Knowledge and Research Difficulties* (see Case Study 2) identified, it is not possible to develop collision risk models without knowing how many individuals migrate and how many individuals are at risk. Models to assess population impacts cannot be developed without knowing population parameters, such as overall migrating population size, which are also not available. In addition, wider impacts may include lighting and disturbance during the pre-construction and construction phases, and displacement. These disturbance and displacement impacts are even more challenging to assess.

Post-construction bat monitoring methods

Between the workshops, delegates were invited to add sticky notes to Miro online whiteboard frames on the topic of post-construction bat monitoring methods. Delegate contributions were then used to inform discussions in the second workshop both in smaller, mixed groups and in plenary.

Two outputs were proposed from these exercises: a list of pros and cons of different monitoring methods and a list of options to standardise post-construction monitoring.

Pros and cons of different bat monitoring methods

Different bat monitoring methods and their pros and cons, as identified by delegates in the second workshop, are included in Table 6 below. It was noted that there may be similarities between monitoring migrating bats and monitoring migrating birds, and therefore some of the 'cons' in the table below may have already been overcome by the ornithological community – a recommendation has therefore been included to collaborate with ornithologists working in the field of offshore wind.

Table 6. List of post-construction bat monitoring methods and their pros and cons, as identified by delegates.

Method	Pros	Cons
All	Long-term monitoring will build up a picture of spatio-temporal bat use It is possible to collect daytime data Methods can be very effective when used in combination	The cost when deploying at scale Can not detect barotrauma Hard to link any of methods to population impacts Many of the methods do not identify the specific risks Long timelines for implementation offshore
Acoustic	Captures bat data within rotor swept zone Can use floating bat detectors Gain info on timing/weather when bats are migrating Easy to do Cheaper than other methods	Limited range of detection, offshore wind turbines huge No behavioural information except feeding buzzes Cannot distinguish between individuals No good if bats are not echolocating

Method	Pros	Cons
	Existing studies have deployed detectors at different heights on turbines Collects a lot of data Can identify species Can establish if bats are feeding through feeding buzzes Can get omnidirectional mics Can have multiple mics from one detector, on 100m cable Can erect mics on top or underneath nacelle or on tower Some manufacturers have built in a heater to remove excess humidity from the microphone Provides good temporal resolution if a bat detector is on a tower but not detecting into the blade swept area (because the blades have moved into the wind) it is still valuable to know that bats are flying close to the turbine.	False positives and false negatives Cannot quantify risk of fatality Difficult to install retrospectively offshore Difficult to access for servicing etc. Can be unreliable, e.g. equipment failure in offshore environment If recording bats in rotor swept zone for curtailment that may be too late to avoid collision If put bat detectors on towers they will not move into the prevailing wind like the blades do, so not always detecting into the blade swept area, Wind and noise from rotating blades (wave noise less of a problem as it is low frequency) High humidity offshore could potentially affect detector operation Not known how weather conditions affect bat detection Detector placement will vary with wind turbine manufacturer Data retrieval Cyber security – wind turbines are nationally important infrastructure, there are concerns about hacking of control systems (although cyber security standards are being drafted) Could still be costly at scale – Wildlife Acoustics Smart Detectors are $2,999 for a controller and $1,999 per mic, with up to 3 mics per controller. Other systems are available; these costs are provided as an indication.

Method	Pros	Cons
MOTUS	Get biometric information, including sex and age class Best practice is available on timing/weather conditions for trapping and bat weights suitable for tagging. Can use offshore Could use around the edge of a windfarm to see if bats enter Long range Know approximate route bats have travelled onshore and offshore, plus potential departure/landing points, but the reliability of this depends on the density of receivers. Know the distance bats have travelled Know the time taken to travel between detection points Provides good spatial resolution	Trapping and tagging bats is invasive. The battery life of the tags is short Dependent on the locations of receivers Costly £10,000 per station Only a few individuals can be tagged/provide data
Thermal Videography	Can give a better understanding of interactions with turbines (3D tracking exact routes) Could capture collision events Can establish size and shape of target object Can look at bat activity in terms of timing/weather conditions Can quantify if there are bats around that are not echolocating	Costly Still hard to quantify collision risk Limited detection range, harder to track bats at a distance Cannot identify species, gender, age class Hard to triangulate field of vision that is useful
Radar	Great potential for providing data Can also be used for assessing the health of the blades	Not yet sufficiently developed for wider application and smaller targets Requires other methods to establish where blades are being struck and which taxa / species

Method	Pros	Cons
		Needs to be fitted during blade manufacture Expensive
Collision detection in blade (emerging technology)	Great potential for providing data Can also be used for assessing the health of the blades	Not yet sufficiently developed for wider application and smaller targets (e.g. <50g) Requires other methods to establish where blades are being struck and which taxa / species Needs to be fitted during blade manufacture Expensive
GPS tags	Collect biometric data during tagging	Too heavy except for our largest bat species Issue of collecting data because tag cannot be retrieved Trapping and tagging bats is invasive Only a few individuals can be tagged/provide data
Satellite tags	Data retrieval possible Collect biometric data during tagging	Too heavy except for our largest bat species Trapping and tagging bats is invasive Only a few individuals can be tagged/provide data

Options to standardise post-construction monitoring

Delegates felt that the choice of method for post-construction bat monitoring would depend on why the data is being collected. For example, different methods would be required to monitor bat migratory movements through a new wind farm in comparison to the methods that would be used to establish if there were any bat collisions with parts of the turbines. It was suggested that a strategic plan should be developed at a national level and monitoring should primarily be in areas where migrating bats have already been detected. Delegates felt that a statutory obligation for developers to carry out monitoring, through their development consent order, would be required to implement this.

The scale of offshore wind was cited as a challenge, with questions raised on how to get a representative sample. One suggestion was to monitor turbines that are perpendicular to predicted migratory routes. Another suggestion was to monitor bats both inside and outside of the wind farm to detect migratory movements. Some suggested acoustic detectors should be fitted to all turbines, with additional monitoring at some of the turbines. For turbine-by-turbine curtailment based on bat activity this level of coverage would, of course, be necessary. Building the MOTUS network by installing receivers within each wind farm development and as well as other offshore infrastructure was suggested, to build a bigger picture of bat movements. Delegates suggested it would be wise to align bat monitoring with bird monitoring, for example through the use of radar, and, to learn from what is known about birds; for example, do bats follow the same patterns in their migration?

Delegates felt it important that maintenance visits should be scheduled for any equipment fitted offshore; these must be scheduled well in advance and carry a variety of health and safety considerations. Also, that action plans should be developed in case of equipment failure.

Delegates raised questions around how long to carry out bat monitoring at a new offshore wind farm; should this just be for a few years or is it relevant to monitor bats for the lifetime of a project? This does depend on the chosen mitigation strategy and how its efficacy is being monitored/managed. The results of the monitoring could potentially dictate how long monitoring continues for. However, the challenge of bat migration routes altering due to climate change was raised again. One delegate noted, however, that for offshore wind farms, monitoring of mitigation and compensation often includes adaptive management requirements[10]. If the impacts are greater than or different from what was predicted, then other measures may be required. Adaptive management measures could equally apply to bat monitoring and mitigation if monitoring was carried out for the lifetime of the project, so that alterations of migration routes due to climate change could be detected and accounted for.

Finally, the importance of data sharing and international collaboration was raised again. Delegates felt that data sharing should be made an obligation at the UK level and via EUROBATS. Also, that this could be facilitated by setting up a central repository for European-wide bat data. POSEIDON and the Marine Data Exchange were again cited as UK examples of good practice in the sharing of data on other taxa (see earlier comments), to which bats could be added. Delegates felt that there would also have to be a statutory obligation for data to be submitted where post-consent monitoring is being undertaken. The Offshore Wind Evidence Knowledge Hub was referenced; this is a database that holds bat reports but not raw data. Celtic Sea Power was also referenced; this is a

[10] https://naturalresources.wales/guidance-and-advice/business-sectors/marine/using-adaptive-management-for-marine-developments/?lang=en

Cornwall Council-funded company who are working with a range of key stakeholders on a variety of projects. One is the Data Hub Project, which involves the collection of an extensive, shared data resource for the Celtic Sea. Offshore Wind Leasing Round 5 includes aims to establish floating wind in the Celtic Sea – delegates highlighted that little is known about how bats interact with floating wind, how detectors and cameras can be installed on floating wind and so on.

Post-construction bat collision mitigation methods

Between the workshops, delegates were invited to add sticky notes to Miro online whiteboard frames on the topic of post-construction bat collision mitigation methods. Delegate contributions were then used to inform discussions in the second workshop both in smaller, mixed groups and in plenary.

Two outputs were produced from these exercises: a list of pros and cons of different mitigation methods and a list of options to standardise post-construction bat collision mitigation.

Pros and cons of different bat collision mitigation methods

Table 7. Different bat collision mitigation methods and their pros and cons, which were identified by delegates in the second workshop.

Method	Pros	Cons
Smart curtailment based on bat activity measured using a bat detector at the turbine	Reduces losses in energy production across the array Can be used year round, not just in migration period More effective in scenarios where bats are foraging at the turbines Experimental studies have shown that sensor-based curtailment is effective Could take an individual turbine approach Lots of knowledge from onshore	Offshore developers unfamiliar with concept If bats are detected at the turbine it is too late to stop the impact Length of time taken to stop the turbine – stoppages are generally planned days in advance Potential degradation of turbines Unrealistic to stop turbines for one bat detected, thresholds would have to be set but limited data to base these thresholds on Reduces the predictability of power generation Potential impacts on grid stability Loss in energy production (needs to be calculated)

Method	Pros	Cons
		System can fail Complex – additional technology Existing studies based onshore Risk of false negatives Risk of false positives Increased cost to consumer Curtailment offshore probably some years away due to the lead in time for offshore wind projects in the UK
Active curtailment based on bat activity by radar	Already used for birds onshore (not offshore in UK) Could detect groups of bats before they reach the turbines Could detect bats gathering at the coast before departing in particular weather conditions	Could this deter or harm bats? Reduces the predictability of power generation Potential impacts on grid stability Loss in energy production (needs to be calculated) Developers not familiar with curtailing offshore Increased cost to consumer Curtailment offshore probably some years away due to the lead in time for offshore wind projects in the UK
Acoustic deterrents	If effective could avoid the need for curtailment and associated issues	Uncertainty around responses from different bat species Limited range Bats can become habituated, effect changes We do not know if there is an impact on other taxa – unintended consequences Risk of extending offshore migration (survival?) if bats avoid Risk of harming bats

Options to standardise post-construction bat collision mitigation

Delegates felt that mitigation by design, i.e. avoiding construction in areas that pose a risk to bats or changing the design of the turbines to minimise impacts on bats, would be the most cost-efficient options. Increasing the gap between sea level and the lower rotor sweep has been applied as mitigation by design for birds, for example. However, this may be less effective for bats as they have been observed exploring tall structures in the seascape such as lighthouses and wind turbines. Mitigation by design could also include blade feathering below the turbine cut-in speed, which does not result in loss of power production but has been shown to reduce impacts on bats in an onshore setting (Arnett et al., 2013).

Other options discussed were various forms of curtailment. This included blanket curtailment initially after construction, followed by evidence-based ‘unlocking’ of turbines with Smart bat detector systems (fitted into the turbines to detect bats and shut down operation to avoid impacts). There was some discussion about the need to consider where the wind speed is measured (e.g. at the nacelle or at the transition piece) when curtailing turbines according to wind speed to avoid bat collisions. There was a suggestion to monitor bats (or groups of bats) as they approach the turbines, rather than when they reach the turbines, and apply active curtailment. Delegates recognised that in some countries offshore wind turbines are being curtailed to avoid bird and bat collision (e.g. the Netherlands); it was suggested that data should be shared and an international approach developed.

There are various projects in the US looking into bat behaviour (see Case Study 6), and sensor-based curtailment, model-based curtailment, a variety of different deterrent technologies, strike detection systems, thermal cameras and LiDAR systems and Artificial Intelligence/Machine Learning classification. The UK can benefit from the evidence gathered in these studies, with lots of information already publicly available.

Delegates suggested that considerations for bats should be included in the offshore wind leasing process in the UK, including mitigation measures such as curtailment if relevant. However, some delegates felt that there is not enough evidence currently to apply mitigation across the board, although others referenced knowledge from the North Sea such as the Netherlands.

Existing or planned guidance

Between the workshops, delegates were invited to add sticky notes to Miro online whiteboard frames on the topic of existing or planned guidance.

The EUROBATS IWG on wind turbines and bat populations has recently set up a working group for offshore wind guidance; so far, the group have developed a list of contents but it may take another year for the guidance to be published. A UK representative, Professor Fiona Mathews, sits on this group and BCT has offered to review the guidance produced.

Other countries have developed and published guidance for bats and offshore wind, including Germany (in 2013 - due to be updated alongside the EUROBATS guidance) and Portugal (in 2017). There is potential for guidance documents from other countries to be translated and used to develop UK guidelines. The New York State Energy Research and Development Authority developed short-term guidance for bats and offshore wind farms.[11]

Natural England has developed 'Offshore Wind Marine Environmental Assessments: Best Practice Advice for Evidence and Data Standards'[12]. This was funded by Defra's Offshore Wind Enabling Actions Programme (OWEAP). The guidance focuses on seabirds, marine mammals, benthic habitats and species and fish, which are currently the key ecological receptors currently identified for offshore wind. The best practice guidance advises on how data and evidence should be used to support consenting. Best practice advice for bats could be developed and added to this suite of documents. Another source of information is the Offshore Wind and Knowledge Hub[13]. This connects stakeholders across the industry and facilitates the sharing of data and information.

Barriers and Opportunities

During the final session of the second workshop, delegates were asked to consider what the barriers and opportunities are to bats being considered in offshore wind projects in the UK. This was discussed both in smaller, mixed groups and in plenary.

Barriers

Delegates commented that bat migration is only newly understood in the UK; historically it was thought that UK bats did not undertake migration, therefore there are many evidence gaps (although note the evidence that is available from other countries bordering the North Sea). In addition, there is no concrete evidence confirming that bats collide with offshore wind turbines from any country, although existing knowledge suggests that this is a strong possibility. Finally, it is not known whether losses resulting from offshore wind development are significant enough to impact bat populations.

Some suggested that developers may be reluctant to accept that there is an ecological impact pathway without further evidence. However, offshore wind developers are constantly trying to reduce their environmental impact and innovate in terms of development. Studying bats offshore is challenging and requires a long lead in time to get equipment fitted. Industry representatives in the workshop suggested that this can take up to two years if fitting equipment retrospectively.

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[11] https://tethys.pnnl.gov/publications/bat-workgroup-report-state-science-workshop-wildlife-offshore-wind-energy-2020

[12] https://naturalengland.blog.gov.uk/2022/04/13/offshore-wind-best-practice-advice-to-facilitate-sustainable-development/

[13] Offshore Wind Evidence and Knowledge Hub (owekh.com)

Delegates identified that migrating bats are not currently a consenting risk for offshore wind in England and therefore there is no business or commercial incentive to consider them. In addition, there is no guidance available for bats and offshore surveys, impact assessment, monitoring and mitigation and no database available so that data can be collated into one place.

Opportunities

Several delegates highlighted that the UK has a number of obligations relating to bats, including the Habitats Directive, the Bonn Convention and the EUROBATS Agreement. A representative of Defra attends EUROBATS and *P. nathusii* is a priority species under this agreement.

EUROBATS provides the opportunity for a European approach, which could be tied together by the new bats and offshore wind guidance currently in production by the Intersessional Working Group. In the meantime, the guidance available in other countries (for example Germany, Portugal and the USA) could be used to develop UK-specific best practice, although one delegate warned that country-specific guidance would likely make things difficult for industry.

It was identified that awareness raising and collaboration between researchers and industry (both developers and operators) would be essential in moving forwards.

Awareness raising in the industry could be facilitated through industry groups such as the Offshore Renewables Joint Industry Programme (ORJIP) and Southern North Sea Offshore Wind Farm (SNSOWF) developer's group. In Ireland, there is a new agency involved in Irish Sea offshore consenting; this may provide an opportunity for awareness raising. Alternatively, Research and Development teams could be targeted for awareness raising as there is often budget available.

Collaboration with wind turbine engineers will be needed to establish where bat monitoring equipment can be fitted, how it can be powered and maintained, how data can be retrieved and the potential for and impact of curtailment. Wind turbines have warranties and making changes to them (such as drilling holes for bat detector mics) could void the warranty. There are European examples of fitting bat monitoring equipment to offshore turbines, from which learning could be gleaned. Also, industry representatives who quantify the profitability of wind energy should be engaged, so that the impact of curtailment on power generation offshore is better understood.

There is a need to plan ahead and look at bat monitoring at offshore developments that are currently at the pre-consent stage.

Most delegates found the workshops informative and useful and were keen to continue the conversation via a forum or regular international stakeholder workshops. Information and reports can be posted on the Offshore Wind Evidence and Knowledge Hub. However, a shared database of bat records will be required for a truly collaborative approach. This could be via POSEIDON and the Marine Data Exchange, but it would be valuable for data to also be shared at an international level.

Finally, delegates recognised that there needs to be a regulatory obligation for wind farm developers to monitor bats and consider mitigation. The UK could examine how other countries (e.g. the Netherlands) have acted in their respective policy landscapes.

Natural England could potentially develop best practice guidance for bats to add to the existing advice. Defra are developing offshore wind minimum standards to reduce impacts on a variety of receptors for both fixed and floating wind, which could take bats into account (e.g. by including blade feathering at low wind speeds).

4. Evidence Gaps

BCT's Science Team undertook an exercise with internal and external stakeholders in relation to the National Nathusius' Pipistrelle Project in 2019 to identify priority evidence gaps in relation to bat migration and offshore wind. A 'Theory of Change' approach was used to identify a long-term outcome (which was: 'Risks to migrating bats from offshore wind energy are avoided or mitigated'), then a series of intermediate outcomes, then the evidence gaps that were, at the time, barriers to reaching the intermediate outcomes.

Between the workshops discussed in Section 3. above, delegates were invited to add sticky notes to Miro online whiteboard frames to identify evidence gaps. They were asked to prioritise their evidence gaps as high, medium, or low priority. However, only a few evidence gaps were placed as medium or low priority by delegates, and many more were identified but not given a priority level during different sessions over the two workshops. Prioritisation of evidence gaps has therefore not been included here but is considered in the Discussion and Recommendations section below.

Evidence gaps from the literature review, the two stakeholder workshops and the 2019 BCT exercise described above have been collated below, separated into key themes.

Population-level impacts

- Do losses resulting from wind turbine collision have an impact at the population level?
- What are the population trends of migrating bats in Europe?
- Can genetics be used to target conservation effort to the most impacted populations?
- What proportion of populations are migrating across e.g. the North Sea, the English Channel, the Irish Sea, during the spring and autumn?
- What proportion of populations are resident?
- What are the demographics of migrating bats?
- What are the survival rates of migratory bats in the absence of wind turbines?
- Are there predators offshore that affect survival?

Migration routes, phenology and behaviour

- What are the onshore and offshore migratory routes in and around the UK?
- Are bats dispersed as they migrate or are there specific routes taken?
- Do bats travel together in groups or individually?
- Do their routes change over time?
- How flexible are bats in terms of routes chosen?

- Are there seasonal differences in migration routes, between spring and autumn migrations?
- Do bats use specific landmarks onshore to migrate?
- Do bats congregate at the coast before migration? If so, where are the gathering points?
- Where are the hopping off points?
- What distances between land masses are problematic?
- Do bats use jet streams when migrating?
- Do bats respond to weather conditions in the same way onshore and offshore?
- Do bats sometimes turn around during migration in specific/challenging weather conditions?
- What conditions encourage or deter migration?
- Do migrating bats behave in the same way as migrating birds?
- What can be learnt from bird migration and offshore wind studies?
- At what time of the year do bats migrate and what influences this (e.g. life cycle, wind speed, wind direction, temperature, cloud cover)?
- What are the temporal migration windows in different regions?
- At what time of night do bats migrate and what influences this (e.g. wind speed, wind direction, temperature, cloud cover)?
- What proportion of bats are actively migrating during the day?
- What influences migration both onshore and offshore (e.g. wind speed, wind direction, temperature, cloud cover)?
- What is the gradient of activity with increasing distance from the coast?
- At what height above sea level do bats fly when crossing open water?
- Is flight height determined by weather conditions such as wind?
- At what speed are bats migrating when crossing open water?
- Which species of bat migrate into the UK?
- Which species migrate across different water bodies?
- Do populations of the same species in different locations behave in different ways?
- Do bats make stop-overs?
- How do they use stopover points (e.g. resting, feeding)?
- How important are stopover points to successful migration?

Bats and offshore wind turbines/infrastructure

- Does bat behaviour change because of offshore wind development?
- Do offshore wind farms cause bats to change their migratory route? What impact does this have?
- Are bats attracted to turbines and why? For example, is it lighting or for roosting, foraging, socialising or swarming?
- How do bats behave around offshore wind turbines?

- Do bats roost, forage, socialise or swarm around wind turbines and what influences this?
- What proportion of bats do not echolocate when migrating or when flying around wind turbines?
- What are the call characteristics when they are echolocating?
- What proportion of bats fly straight through wind farms?
- Do bats get killed at offshore wind turbines?
- What number of casualties are involved?
- Which species are susceptible to collision?
- What conditions influence collisions?
- How does turbine size impact bat interactions?
- How does other offshore infrastructure impact bats?
- How do bats react to the presence of new islands, as proposed for Dogger Bank?
- Are there any positive impacts, for example migrating bats using turbines to feed or roost?

Foraging/prey availability

- Are local bats travelling offshore to forage?
- How far do local bats travel offshore?
- At what time of year do local bats travel offshore for foraging?
- Which species of bats forage offshore?
- How does bat activity relate to insect density offshore?
- Where do insects congregate offshore?
- What are the insect migration routes?
- Are bats attracted to wind turbines for feeding?
- Are bats using temperature as a cue when searching for insect prey?

Technology/methods for survey/monitoring

- How do we monitor the impact of offshore wind turbines on migrating bats?
- What are the best methods to study the collision risk for bats resulting from offshore wind development?
- Drones are routinely used to inspect turbine blades – could they also be used to collect bat-related data?

Technology/methods for collision mitigation

- How effective are different collision mitigation measures for different UK species?
- What is the cost benefit of installing multiple smart monitoring systems on an array, compared to blanket curtailment informed by time of year, time of day, weather conditions?
- What is the most efficient and effective method of operational curtailment?
- How effective are acoustic deterrents for different UK species?
- Do acoustic deterrents have a negative impact on bats and/or other species?
- Would reducing turbine lighting reduce the chance of bat collision?
- Are there other, better methods of collision mitigation available?

Understanding more about the population of *Pipistrellus nathusii* in the UK

These gaps were from 2019 BCT exercise only.

- Where do bats migrating into the UK originate?
- What is the distribution of *P. nathusii* in the UK?
- Where do migratory individuals overwinter?
- How do *P. nathusii* move within the UK? (Fit model to recapture data to look at dispersal distances, timings, variation with age and sex).
- How does the spring and autumn migratory movement differ, in terms of numbers, routes, sex etc. Could we compare proportion of juveniles in autumn to non-parous individuals in spring to estimate over-winter survival?
- What are *P. nathusii* foraging habitat preferences (large scale and micro)?
- What are *P. nathusii* roosting preferences?
- What is their roosting behaviour?
- Does the make-up and stability of maternity roosts differ between the UK and the continent?
- What determines whether *P. nathusii* females give birth in the UK? Can we for instance compare the body condition of females that breed in the UK to elsewhere?
- How can we improve on the population estimate for *P. nathusii* in the UK? (e.g. mark recapture).
- What proportion of the UK population is resident versus migratory?
- How do the needs of the resident and migratory population differ?
- What are the absolute numbers of individuals moving into and out of the UK? Can we use mark-recapture?
- Can we monitor trends in *P. nathusii* population and conservation status?

Assessing current and future colonisation of the UK by non-resident bat species

These gaps were from 2019 BCT exercise only.

- Which species of bat are increasing their range into the UK (e.g. *Pipistrellus kuhlii*, *Hypsugo savii*)?
- Which species of bat may colonise the UK in the future?
- Are these movements being driven by climate change?
- Do we need to take action to facilitate climate adaptation?
- Will there be negative impacts on resident species?

5. Discussion and Recommendations

From the literature review, analysis of outputs from the NNPP, and stakeholder engagement it is evident that bat species do migrate from Europe to Britain. The strongest evidence base is for *Pipistrellus nathusii,* although there are still many evidence gaps relating to this species. For other species there is relatively little or no evidence regarding migration. Filling these evidence gaps should be a priority.

There is appetite among UK and European stakeholders to progress the issue of bat migration and offshore wind in the UK; this was clear from the two stakeholder workshops (as described in Section 3) and subsequent, enthusiastic communications and offers of collaboration. There are legal obligations for the UK to better understand the impact of offshore wind on bats and act, where issues are identified, through a variety of different statutory routes.

Options include strategic-level bat monitoring of high priority locations to inform Marine Spatial Prioritisation but also site-based surveys pre-construction and monitoring post-construction. The value of site-based monitoring pre-construction was brought into question by some workshop delegates, bearing in mind bats will change their behaviour in the presence of wind turbines and collision impact cannot be easily predicted. Similar discussions have been held among experts involved in onshore work over the last few decades. The approach taken by Natural England offshore in relation to marine mammals was to not require site specific surveys, assume species presence and mitigate accordingly. However, pre-construction bat surveys can establish presence, species of bat, relative abundance at different locations and provide a baseline for post-construction comparison. Very little is known about bat presence offshore (this is restricted to a small handful of locations) in contrast to the onshore situation (where pre-construction surveys have been maintained) so this would add extra value – areas where bats are picked up pre-construction could then be subject to post-construction surveys and even potentially mitigation. A statutory obligation to do this would be required, through the consenting process.

Guidance would be needed to facilitate strategic and site based surveys and should be aligned with guidance in preparation by EUROBATS.

It would add further value for all data to be collated centrally, nationally and also at the international level, and there are already a number of opportunities to do this (e.g. the Marine Data Exchange and the European Seabirds at Sea database).

There are many opportunities to learn from our European and US colleagues; international collaboration and knowledge sharing is essential. Knowledge sharing with ornithologists and identifying techniques where both birds and bats can be (or already have been) monitored by the same equipment, could also provide a stepping stone. Awareness raising among decision makers and industry is an essential step in educating stakeholders that this is an important issue and working together on solutions.

The specific recommendations below are based on the literature review engagement with projects and the two stakeholder workshops.

Raising awareness

- The UK's legal obligations with respect to the protection of migratory bats should be highlighted to decision makers in the relevant Government Departments (Defra and DESNZ). The UK should examine how other countries (e.g. the Netherlands) have taken action in their respective policy landscapes.
- Government funding should be made available to build capacity for bats and offshore wind work within Natural England, other Statutory Nature Conservation Bodies, Non-governmental organisations and academic institutions.
- A programme of awareness raising activities should be developed to inform offshore wind developers and operators that bats are a potential impact receptor for offshore wind. This could include presentations to industry conferences or stakeholder meetings (e.g. Offshore Renewables Joint Industry Programme (ORJIP), Renewables UK, Southern North Sea Offshore Wind Farm Developers Group (SNSOWF) and the Irish Sea consenting agency) or articles in relevant publications/social media. Funding and capacity will be needed for this.

Strategic data collection

- A timeline and plan should be developed to facilitate strategic, national monitoring of bat movements on and offshore to inform future Offshore Wind Leasing Rounds. This should be afforded adequate funding. It should include developing a national plan of high priority bat monitoring locations on and offshore such as oil and gas platforms, buoys, met masts, ferries, lighthouses and prominent headlands. The Centre for Environment, Fisheries and Aquaculture Science (CEFAS) already have a network of wave rider buoys that feedback data in real time. There may be potential to incorporate bat monitoring onto these buoys. Discussions with CEFAS would be required to establish the practicality of this, costs, data transfer practicalities and liabilities. Bat monitoring should be carried out using acoustic detectors and by building the MOTUS network (in collaboration with ornithologists) both on and offshore, with associated bat tagging and tracking projects.
- The plan should include submission of all data to a centralised database (see below) to inform distribution/migration route mapping and inform Marine Spatial Prioritisation. Learning should be gained from other, similar European and US projects and collaboration enabled where possible. For example, the Migratlane Project by the Paris Natural History Museum is carrying out bat monitoring from

ferries; is there potential to support and expand the network into English waters to contribute to strategic-level bat monitoring?

Site-based data collection

- Best practice guidance could be developed to facilitate pre-construction surveys offshore at the site level by developers, using wave rider buoys, met masts and other available offshore infrastructure. Pre-construction surveys can establish bat presence and species (although it is more difficult to establish absence), and provide a baseline for post-construction monitoring to be compared against.
- Best practice guidance could be developed to facilitate post-construction monitoring at offshore wind turbine sites by developers. These should be designed to detect changes in bat activity after construction compared to before construction and to monitor interactions of bats with wind turbines. This monitoring should focus in areas where bats have been recorded pre-construction and may include monitoring for the lifetime of the project and adaptive mitigation and management depending on the results, bearing in mind that bats may change their migration habits as our climate changes.
- Maintenance visits should be scheduled for any equipment fitted offshore; these must be scheduled well in advance and include health and safety considerations. Action plans should be developed in case of equipment failure.
- Data collection for protected bat species offshore should be an offshore industry-wide standard, in the same way as it is the accepted requirement for seabirds.
- Best practice should include the timely submission of all data to a centralised database (see below), adding to the overall picture of bat movement offshore and around offshore wind turbines.
- There should be a formal statutory obligation, possibly through Development Consent Orders or marine licence conditions, for data to be collected, collated and shared by developers.

Data collation and sharing

- Conversations should be initiated with national data projects such as Poseidon and the Marine Data Exchange to establish how bat data collected through strategic monitoring and site-specific surveys (see above) could be included in these UK databases. During these discussions, good practice examples such as the Tethys website[14] could be explored.
- Consideration should also be given to how international data collation and sharing could be facilitated. Whilst there is no international data repository for EUROBATS,

[14] https://tethys.pnnl.gov/

there is one for seabirds and marine mammals[15]. The potential to add bats to this international database, or others, should be explored.

Production of guidance

- The UK should continue to be represented on the EUROBATS subgroup producing guidance for bats and offshore wind.
- Bats and offshore wind guidance available from other European countries should be translated into English and applicability to the UK context assessed.
- Preliminary guidance for bats and offshore wind should be published for the UK, which should be in alignment with the EUROBATS guidance regardless of which is published first.
- Guidance on monitoring bats in the offshore environment (including migratory bats and bats moving offshore for other reasons such as foraging) should be incorporated into the Natural England best practice advice on data and evidence standards for offshore wind and international best practice data collection methods included. This should include best practice for maintaining equipment and monitoring its reliability and durability but not be too prescriptive because technology is rapidly developing.
- Bats should be considered for inclusion in the Defra Offshore Wind Environmental Standards (OWES), which are standards for the design, construction, operation, monitoring and decommissioning of offshore wind farms that aim to reduce negative environmental impacts. Measures may include blade feathering below the cut-in wind speed (to reduce the risk of bat casualties with no associated loss in energy production), increasing the cut-in wind speed, different forms of curtailment or on-demand aircraft warning lights on the turbines rather than constant lights, which may reduce bat attraction. The height of the lower blade sweep has been increased as a method to mitigate bird collision; this may not be effective for bats, which exhibit exploratory behaviour up, down and around wind turbines.

Collaboration with experts and industry

- Collaboration with offshore wind farm engineers and those calculating the profitability of wind farms should be facilitated through a series of meetings to establish the suitability of installing monitoring equipment in an array or on substations. These discussions should examine the potential for blade feathering below the cut-in wind speed, increasing the cut-in wind speed, and whether various forms of curtailment (e.g. based on one or more of: time of the year, time of the night, temperature, wind speed, wind direction, bat activity) are

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[15] https://www.ices.dk/data/data-portals/Pages/European-Seabirds-at-sea.aspx

practical/economical. Key terms should be defined (e.g. different types of curtailment – blanket, active, smart) so that all stakeholders have a shared understanding.

- A programme of training for marine teams (e.g. turbine engineers and skippers of crew transfer vessels) on looking out for bats and what to do if they find a bat. This could include a standard industry toolbox talk and information sheet to be delivered prior to offshore deployment. Approaches to this for different taxa could be explored to inform how this is done.
- Observations and records collected by marine teams (following the programme of training) should be collated centrally, with a new process/method established to do so.
- Stakeholder collaboration should be continued through regular stakeholder workshops and online forums. Members should be encouraged to post bat research and monitoring information on the Offshore Wind Evidence and Knowledge Hub.
- Collaboration should be arranged with ornithologists working in the field of offshore wind, to discuss similarities between bird and bat migration, and how difficulties have been overcome in offshore bird monitoring and impact assessment. In addition, monitoring methods (e.g. radar, videography) deployed for birds could also be used to monitor bats – this should be explored. Indeed, there is the possibility that bat data has been collected passively during bird monitoring and it could be extracted and analysed.

Evidence gaps

- Funding should be sought to progress knowledge in areas identified as evidence gaps.
- The most significant, but most challenging, evidence gaps appear to be:
    - What are the offshore migratory routes of bats in and around the UK?
    - How do we monitor the impacts of offshore wind on migratory bats and their populations?
    - Do bats get killed at offshore wind turbines? What number of casualties are involved? Which species are susceptible to collision? What conditions influence collisions?
    - If bats do get killed, does this have an impact at a population level?
    - Do OWF arrays cause macro or micro avoidance and displacement or act as an attraction for feeding socialising and resting.
- In the absence of the evidence listed above and bearing in mind the pace of offshore wind development, is it reasonable to apply collision risk mitigation as a precautionary approach? If so, some key evidence gaps are:
    - How do we best mitigate for the potential impact of offshore wind on migratory bats and their populations?
    - What is the most efficient (in terms of energy production) and effective (in terms of preventing bat collisions) method of operational curtailment?

    - Are other, better methods available to mitigate for collision risk?
- The evidence gaps highlighted in this report should be added to the Offshore Wind Environmental Evidence Register (OWEER). The Crown Estate provides funding through the Offshore Wind Evidence and Change Program (OWEC), with the research priorities steered to some degree by the OWEER.

Modelling

- We recommend modelling of capture data from the National Nathusius Pipistrelle Project (using for example Bayesian methods to account for the highly spatially clustered nature of the data) to investigate seasonal changes in the distribution and abundance of GB bat species, and to investigate how these seasonal patterns are affected by species, sex, age, reproductive status, and GB, continental and/or maritime weather conditions at the time of capture or in the period preceding capture. The Bat Conservation Trust are making preparations to compete this analysis, which will inform collision risk mapping and analysis.

6. List of tables

7. List of figures

Figure	Description
7	2024 Distribution of MOTUS wildlife tracking stations across northwest Europe. An interactive map of all MOTUS stations worldwide along with detailed metrics on individual receivers can be found at https://motus.org/ Map data - © 2024 GeoBasis-DE/BKG © 2009 Google Imagery 2024 TerraMetrics.
8	Potential bi-directional migration corridors across the English Channel between England, the Channel Islands and France and potential corridors between the UK and Ireland including the Isle of Man. Orange arrows indicate possible migration corridors as identified during the literature review. The evidence for migration across these broad fronts varies geographically and should only be taken as an indication. Detailed discussion of the evidence base surrounding each of these corridors is discussed further within this review.
9	Bat occurrence recorded at offshore windfarms in Spring 2019. Left picture: unidentified bat species roosting in the floor grate of an offshore turbine at the Belgian Nobelwind Wind Farm (8th April 2019). Right picture: Unidentified bat species roosting on an offshore wind turbine foundation in the Belgian C-Power Wind Farm (30th April 2019). © Royal Belgian Institute of Natural Sciences 2024.
10	Sensory cues and potential pollutants at wind energy facilities and the distances they are likely perceived by bats. [1]Katinas et al. (2016), [2]Stilz and Schnitzler (2012), [3]Boonman et al. (2013), [4]Eklöf and Jones (2003), [5]Porté-Agel et al. (2020), [6]Lundquist et al. (2019), [7]Reddy et al. (2021). Graphic from Jonasson et al. 2024. *A Multisensory approach to understanding bat responses to wind energy developments*. Mammal Review doi: 10.1111/mam.12340.
11	Straight line flight trajectories of single *P. nathusii* bat crossings between England and Europe (as recorded from recapture of ringed bats or MOTUS detections of tagged bats) overlaid on map of operational and projected future wind farms. Buffers around wind farms represent a zone of influence for bat species travelling through these areas based on sensory cues of wind energy facilities and the distances they are likely perceived by bats as summarised in Figure 10.

Figure	Description
12	Left: Diagram of MOTUs station with standard dual-mode omni-directional antenna configuration installed on an offshore buoy. Image from Iain Stenhouse, BRI Right: Operational DB1750 MOTUS offshore buoy. Photo from Aanderaa, a Xylem brand.
13	Top: ThermalTracker-3D camera system for monitoring bats at wind farms and extracting three-dimensional movement trajectories. Photo from Pacific Northwest National Laboratory. Bottom: Thermal image of bat (circled) flying near an onshore wind turbine. Photo from Paul Cryan https://www.usgs.gov/media/images/

8. List of bat species

Species Name	Scientific Name
Barbastelle	*Barbastella barbastellus*
Isabelline serotine	*Eptesicus isabellinus*
Northern bat	*Eptesicus nilssonii*
Serotine	*Eptesicus serotinus*
Savi's pipistrelle	*Hypsugo savii*
Hoary bat	*Lasiurus cinereus*
Common bent-wing bat	*Miniopterus schreibersii*
Lesser mouse-eared bat	*Myotis blythii*
Greater mouse-eared bat	*Myotis myotis*
Natterer's bat	*Myotis nattereri*
Greater noctule	*Nyctalus lasiopterus*
Leisler’s bat	*Nyctalus leisleri*
Noctule	*Nyctalus noctula*
Kuhl's pipistrelle	*Pipistrellus kuhlii*
Nathusius' pipistrelle	*Pipistrellus nathusii*

Species Name	Scientific Name
Common pipistrelle	*Pipistrellus pipistrellus*
Soprano pipistrelle	*Pipistrellus pygmaeus*
Brown long-eared bat	*Plecotus auritus*
Grey long-eared bat	*Plecotus austriacus*
Greater horseshoe bat	*Rhinolophus ferrumequinum*
Mehely's horseshoe bat	*Rhinolophus mehelyi*
Greater mouse-tailed bat	*Rhinopoma microphylum*
Mexican free-tailed bat	*Tadarida brasiliensis*
European free-tailed bat	*Tadarida teniotis*
Naked-rumped tomb bat	*Taphozus nudiventris*
Parti-coloured bat	*Verpertilio murinus*

9. List of abbreviations

Abbreviation	Full Description
ADLS	Aircraft Detection Lighting Systems
BCT	Bat Conservation Trust
CCD	Charged Coupled Device
CMOS	Complementary Metal Oxide Semiconductor
CMS	Convention on Migratory Species
COP	Conference of the Parties
DEFRA	Department for the Environment, Food and Rural Affairs
DUKES	Digest of UK Energy Statistics
EcIA	Ecological Impact Assessment
EIA	Environmental Impact Assessment
FOV	Field of view
GPS	Global Positioning System
GW	Gigawatt
HRA	Habitats Regulations Assessment
Hz	Hertz

Abbreviation	Full Description
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Service
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared
IUCN	International Union for Conservation of Nature
kHz	Kilohertz
LWIR	Long-wave infrared
MCZ	Marine Conservation Zone
MW	Megawatt
MWIR	Mid-wave infrared
NBN	National Biodiversity Network
NETD	Noise Equivalent Temperature Difference
NGO	Non-governmental Organisation
NNPP	National Nathusius' Pipistrelle Project
OWEAP	Offshore Wind Enabling Actions Programme
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Abbreviation	Full Description
RPM	Revolutions per minute
SEA	Strategic Environmental Assessment
SEIA	Strategic Environmental Impact Assessment
SPP	All species of a higher taxon
SWTs	Small Wind Turbines
TWh	Terawatt hours
UNEP	United Nation Environmental Programme
WCMC	World Conservation Monitoring Centre

10. Glossary

Word	Description
Aerosphere	The body of air surrounding the earth.
Algorithm	A process or set of rules to be followed in calculations or other problem-solving operations, i.e. curtailment algorithms may combine data from bat activity, weather, landscape features, turbine functioning and seasonality to compute the most effective curtailment strategy.
Antagonistic	Acting in opposition.
Arrays	Spatial layout of a unit of turbines.
Aspect Ratio	The ratio of the wing span/length to wing breadth.
Assemblage	A taxonomically related group of species populations that occur together in space.
Attrition	Gradual process of wearing down, weakening, or destroying something.
Barotrauma	Physical tissue damage caused by an unrelieved pressure differential between a surrounding gas as caused by the turbine blades and an unvented body cavity (e.g., lungs of a bat).
Bi-directional	Movement in two (usually opposite) directions.
Biometric	Approaches to quantify a set of observable characteristics.
Blanket Curtailment	Turbine curtailment strategy based solely on wind speed or season.

Word	Description
Cumulative	Formed by or resulting from accumulation or the addition of successive parts or elements.
Curtailment	The action or fact of reducing or restricting something e.g. wind turbine curtailment to reduce rotation speeds and protect bat species.
Cut-in speed	The wind speed at which turbine blades start to turn.
Demographic	Statistics that describe populations and their characteristics.
Devolved	To transfer or delegate power or responsibility to others.
Diurnal	Happening or active during the daytime.
Echolocation	The location of objects by reflected sound.
Expert Elicitation	The synthesis of opinions of experts on a subject where there is uncertainty due to insufficient data.
Feathering	Pitching the turbine blades out of the wind to reduce rotation speeds.
Fecundity	The state of being fertile and capable of producing offspring.
Gleaning	Prey is taken from surfaces such as leaves or the ground.
Grey Literature	Used to describe a wide range of different information that is produced outside of traditional publishing and distribution channels, and which is often not well represented in indexing databases.

Word	Description
Hawking	Prey is caught whilst airborne.
Holistic	Approach characterized by the belief that the parts of something are interconnected and can be explained only by reference to the whole.
Infrastructure	The basic physical and organizational structures and facilities (e.g. buildings, roads, power supplies) needed for the operation of a society or enterprise.
Intraspecific	Arising or occurring within a species or between members of the same species.
Migrant	An animal that migrates.
Mitigation	The action of reducing the severity, seriousness or harmfulness of something.
Nacelle	The nacelle sits atop the tower and contains the gearbox, low- and high-speed shafts, generator, and brake.
Paucity	A small amount of something; less than enough of something.
Phenology	The study of periodic events in biological life cycles and how these are influenced by seasonal and interannual variations in climate, as well as habitat factors (such as elevation).
Plasticity	The adaptability of an organism to changes in its environment or differences between its various habitats.
Probabilistic	Based on or relating to how likely it is that something will happen.

Word	Description
Radio Telemetry	Technique used to track the movement and behaviour of animals by using the transmission of radio signals to locate a transmitter attached to the animal of interest.
Somatosensation	Somatosensation is the physiological result of a physical stimulus changing into a neural signal that activates pathways resulting in the sensations of touch, temperature and pain.
Smart Curtailment	Turbine curtailment strategy based on a combination of environmental variables, seasonality and real-time bat activity data.
Spatiotemporal	Relating to both space and time.
Stable Isotope Analysis	Identification of isotopic signature, abundance of certain stable isotopes of chemical elements within organic and inorganic compounds. Isotopic analysis can be used to understand the flow of energy through a food web or to reconstruct past environmental and climatic conditions. For example, the continental and latitudinal patterns of hydrogen isotopes in rainfall are predictable and these values are often reflected in new bat fur keratin. Migratory bat species are known to moult (and grow new fur) in summer before migration therefore the summer habitat and/or breeding origin of bats can be inferred by identifying the hydrogen isotopes of fur samples.
Stimuli	An agent (such as an environmental change) that directly influences the activity of a living organism or one of its parts.
Trajectory	The path described by an object moving in air or space under the influence of such forces as thrust, wind resistance, and gravity.
Turbulence	Violent or unsteady movement of air or water, or of some other fluid.

Word	Description
Ultrasound	Ultrasound refers to any sound waves with frequencies greater than 20kHz.
Vagrant	A phenomenon in biology whereby an individual animal appears well outside its normal range.
Wing Loading	Total mass of an object divided by the area of its wing.

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Appendix A. Stakeholder affiliations

Organisation	Individual
APEM	Jason Guile
Bach-Freilandforschung	Lothar Bach
Bat Conservation Ireland	John Curtin
Bat Conservation Ireland	Niamh Roche
Bat Conservation Trust	Jan Collins
Bat Conservation Trust	Katherine Boughey
Bat Conservation Trust	Lisa Worledge
Bat Conservation Trust	Rhian Minter-Owen
Bedfont and Colne Valley Bat Research	Patty Briggs
BSG Ecology	Peter Shepherd
Department for Energy Security and Net Zero	Anna Pastore
Department for Environment, Food and Rural Affairs	Lucie Guirkinger
Dutch Ministry of Infrastructure and Water Management	Henri Zomer
Dutch Ministry of Infrastructure and Water Management	Marije Wassink
Equinor	Anne-Laure Szymanski
Equinor	Kari Mette Murvoll
Equinor	Johiris Rodriguez
EUROBATS	Luisa Rodrigues
Irish Nathusius' Pipistrelle Working Group	Tina Aughney
JNCC	Kirsi Peck
JNCC	Catherine Burton
Leibniz Institute for Zoo and Wildlife Research	Antje Seebens-Hoyer
Living Record	Adrian Bicker
National Renewable Energy Lab	Cris Hein
Natural England	Tamara Rowson
Natural England	Kat Walsh
Natural England	Christine Hipperson-Jervis
Natural England	Victoria Copley

Organisation	Individual
Natural Power	Laura Shreeve
Natural Resources Wales	Sam Dyer
NatureScot	Rob Raynor
Normandeau Associates	Eran Amichai
Northern Ireland Environment Agency	Jon Lees
Norwich Bat Group	Jane Harris
Norwich Bat Group	Ewan Parsons
Orsted	Celestia Godbehere
Paris Natural History Museum (bat migration)	Charlotte Roemer
Paris Natural History Museum (bat migration)	Anaïs Pessato
Plecotus - Estudos Ambientais, Unip. Lda	Pedro Alves
Royal Belgian Institute of Natural Sciences	Robin Brabant
Royal Belgian Institute of Natural Sciences	Yves Laurent
RWE	Elsa Lamb
Scottish Power Renewables	Pete Robson
Scottish Power Renewables	Catriona Burrow
University of Sussex	Fiona Mathews
University of the West of England	Paul Lintott
University of the West of England	Jack Hooker
Vattenfall	Robin Cox
Vincent Wildlife Trust	Daniel Hargreaves
Wildlife Acoustics	Fran Tattersall
Wildlife Acoustics	Paul Howden-Leach

Appendix B. Agenda for stakeholder workshop 08/02/2024

This workshop took place on 8th February 2024 between 9.30-13.00 via Zoom.

Aim of Workshops

To consult, via guided discussion workshops, a panel of experts and stakeholders on the potential impact of offshore wind farms on migrating bats and bat populations in English waters, the methods available for survey and monitoring in the offshore environment and mitigation solutions available to minimise impacts, drawing on knowledge from onshore, offshore, national and international where appropriate. Also, to identify existing industry guidance and opportunities to develop further research, guidance and policy in this area.

Facilitators: This workshop is being run by Bat Conservation Trust (BCT) and the University of the West of England (UWE). Your facilitators and hosts for the day are:

- Jan Collins, Head of Biodiversity, BCT
- Lisa Worledge, Director of Conservation, BCT
- Katherine Boughey, Head of Science and Monitoring, BCT
- Jack Hooker, Research Scientist, BCT
- Paul Lintott, Senior Lecturer in Conservation Science, UWE

Objectives of Workshop 1: Scene setting, international best practice, start discussions

1. To introduce the 'Assessing migration of bat species and interactions with Offshore Wind Farms in English Waters' project to experts and stakeholders
2. To summarise the results of the literature review to date
3. To present examples of international lessons learnt and best practice in relation to bats and offshore wind farm development
4. To discuss the reliability of translating knowledge of the impacts of wind energy on bats and best practice approaches from onshore to offshore
5. To discuss the reliability of translating knowledge of the impacts of wind energy on bats and best practice approaches from an international to an English setting
6. To discuss potential options to standardise pre-construction survey and impact assessments – pros and cons of different methods, standardising an approach

7. To encourage attendees to provide input by midday on Tuesday 13th February on monitoring methods

8. To encourage attendees to provide input by midday on Tuesday 13th February on mitigation methods

9. To encourage attendees to provide input by midday on Tuesday 13th February on available, published best practice

10. To encourage attendees to provide input by midday on Tuesday 13th February on evidence gaps, with an indication of their view on prioritisation

Proposed outputs, to be included in project reporting:

- Case studies highlighting international lessons learnt about bats and offshore wind farm development and progress with monitoring bat migratory movements through MOTUS - presentations by experts and stakeholders (point 3 above)
- A list showing which knowledge/best practice can potentially be translated from work on bats and onshore wind to bats and offshore wind, and which probably cannot, and an evaluation of why, including unknowns (point 4 above)
- A list showing which knowledge/best practice can be translated from work on bats and wind energy internationally to an English setting, and which cannot, and why, including unknowns (point 5 above)
- A list of pros and cons of different methods for pre-construction survey and impact assessment for bats and offshore wind (point 6 above)
- A list of options to standardise pre-construction surveys and impact assessment (point 6 above)
- A list of post-construction monitoring methods, with an indication of whether they are tested/proven methods or emerging technologies to inform discussions at the next workshop (point 7 above)
- A list of post-construction mitigation methods, with an indication of whether they are tested/proven methods or emerging technologies to inform discussions at the next workshop (point 8 above)
- A list of published best practice for bats and offshore wind (point 9 above)
- A list of evidence gaps prioritised by the attendees (point 10 above)

Agenda

Note that you can enter the Zoom waiting room at 09.00 but we will not be admitting people to the meeting until 09.20

Time	Activity	Lead by
09.30	Welcome and housekeeping (5 minutes)	Jan Collins, BCT
09.35	'Assessing migration of bat species and interactions with Offshore Wind Farms in English Waters' – scene setting (5 minutes)	Tamara Rowson, NE
09.40	'Assessing migration of bat species and interactions with Offshore Wind Farms in English Waters' - literature review findings to date (10 minutes)	Jack Hooker, BCT
09.50	WOZEP Past and current research plans (10 minutes)	Henri Zomer or Marije Wassink, Dutch Ministry of Infrastructure and Water Management
10.00	Kattegat West Baltic Bats Project (KABAP) (10 minutes)	Robin Cox, Vattenfall
10.10	UK MOTUS Tagging over the last 3 years (10 minutes)	Jane Harris, Norwich Bat Group
10.20	Q & A (20 minutes)	Jan Collins, BCT
10.40	**Introduction to Miro board.** **Exercise inputting to Miro boards, all attendees to add post it notes (20**	Jan Collins, BCT

Time	Activity	Lead by
	minutes but attendees can continue into the break if needed): FRAME 1 (yellow, green and orange) - What evidence / knowledge / methods *potentially can* be translated from studies of bats and onshore wind to the offshore situation, which *probably cannot* and why? What are the unknowns? FRAME 2 (yellow, green and orange) - What evidence / knowledge / methods *potentially can* be translated from studies of bats and offshore wind internationally to England or the UK, which *probably cannot* and why? What are the unknowns?	
11.00	**Short break (15 minutes)**	
11.15	**Discussion in plenary on key points raised in the last session (15 minutes)**	Jan Collins, BCT
11.30	**Exercise inputting to Miro boards, all attendees to add post it notes (20 minutes):** FRAME 3 (lime green) - What information/methods relating to bats are available to inform the strategic planning of new offshore wind farms? (e.g. could existing bat migration data be used to inform strategic planning?) FRAME 4 (green) - What information/methods are available to inform baseline characterisation and	Paul Lintott, UWE

Time	Activity	Lead by
	impact assessments for bats for individual offshore wind farms?	
11.50	**Discussion session in breakout rooms, 11 people per group, mixed industries, project team members to lead and make notes on Miro board (40 minutes)** Using the Miro board lists from the last exercise: 1. What are the pros and cons of different strategic planning and pre-construction assessment methods? 2. What could a standardised approach to strategic planning look like? 3. What could a standardised approach to baseline characterisation surveys look like?(e.g. principles, types of surveys, survey area and buffer, sampling approach, frequency and duration, data standards, monitoring and sharing) 4. What could a standardised approach to impact assessment include? (e.g. how to assess potential disturbance, displacement and barrier effects, collision risk, cumulative impacts)	Paul Lintott, UWE
12.30	**Discussion in plenary on key points raised in the last discussion session (20 minutes)**	Paul Lintott, UWE

Time	Activity	Lead by
12.50	**In plenary – introduction of exercises to be completed by attendees by midday on Tuesday 13th February. Miro boards will stay open between now and then. (5 mins)** **FRAME 5 (purple) - Identifying methods of post-construction monitoring** Attendees to add methods to Miro boards, to inform discussions in workshop 2. Indicate whether methods are tested/proven or emerging technologies for the future. **FRAME 6 (blue) - Identifying methods of post-construction mitigation** Attendees to add methods to Miro boards, to inform discussions in workshop 2. Indicate whether methods are tested/proven or emerging technologies for the future. **FRAME 7 (pink) - Identifying any published best practice** Attendees to add titles/links to any available published best practice for bats and offshore wind. **FRAME 8 (pink, blue and purple) Identifying and prioritising evidence gaps in relation to bat migration and offshore wind –** Attendees to add evidence gaps to Miro boards, self-categorised into high,	Jack Hooker, BCT

Time	Activity	Lead by
	medium and low priority for processing by the project team before the next workshop.	
12.55	**Round-up, plan for the next workshop and close (5 mins)**	Jan Collins, BCT

Appendix C. Agenda for stakeholder workshop 15/02/2024

This workshop took place on 15th February 2024 between 9.30-13.00 via Zoom.

Aim of Workshops

To consult, via guided discussion workshops, a panel of experts and stakeholders on the potential impact of offshore wind farms on migrating bats and bat populations in English waters, the methods available for survey and monitoring in the offshore environment and mitigation solutions available to minimise impacts, drawing on knowledge from onshore, offshore, national and international where appropriate. Also, to identify existing industry guidance and opportunities to develop further guidance and policy in this area.

Facilitators: This workshop is being run by Bat Conservation Trust (BCT) and the University of the West of England (UWE). Your facilitators and hosts for the day are:

- Jan Collins, Head of Biodiversity, BCT
- Lisa Worledge, Director of Conservation, BCT
- Katherine Boughey, Head of Science and Monitoring, BCT
- Jack Hooker, Research Scientist, BCT
- Paul Lintott, Senior Lecturer in Conservation Science, UWE

Objectives of Workshop 2: Main discussions relating to offshore wind in English waters and conclusion

To discuss (with respect to bats and offshore wind in English Waters):

- Potential options to standardise post-construction monitoring of bat activity and interactions with turbines – pros and cons of different methods, standardising an approach
- Potential options to standardise post-construction mitigation (e.g. curtailment, acoustic deterrents) – pros and cons of different methods, standardising an approach
- Whether there is enough evidence available to warrant standardising mitigation for offshore wind in England/the UK
- Opportunities to develop industry best practice guidance and influence policy in relation to bats and offshore wind consenting and what it would recommend given current knowledge

Proposed outputs to be included in project reporting:

- A list of pros and cons of different methods for post-construction monitoring and mitigation for bats and offshore wind (points 1-2 above)
- A list of options to standardise post-construction monitoring and mitigation (point 1 above)
- A consideration of the necessity for mitigation, given current knowledge (point 2 above)
- A list of options for developing industry best practice guidance and influencing policy (point 3 above)

Agenda

Note that you can enter the Zoom waiting room at 09.00 but we will not be admitting people to the meeting until 09.20

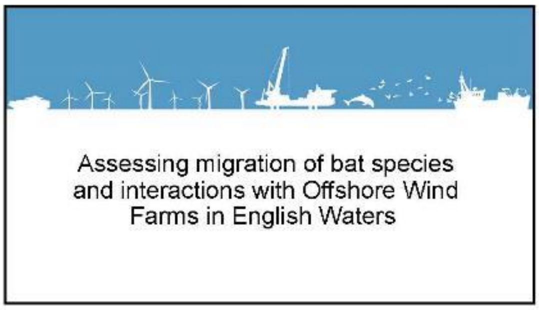
Time	Activity	Lead by
09.30	Welcome and housekeeping (5 minutes)	Jan Collins, BCT
09.35	Feedback and outputs from workshop 1 and between workshops exercise (10 minutes)	Jan Collins, BCT
09.45	Update from the EUROBATS Chair for Wind Turbines and Bat Populations Intersessional Working Group (5 minutes)	Luisa Rodrigues, EUROBATS
09.50	Bat Migration routes in Europe (5 minutes)	Charlotte Roemer, Paris Natural History Museum
09.55	MIGRATLANE - multi-source data modelling to characterise the use of maritime & coastal areas by bats (5 minutes)	Anais Pessato, Paris Natural History Museum

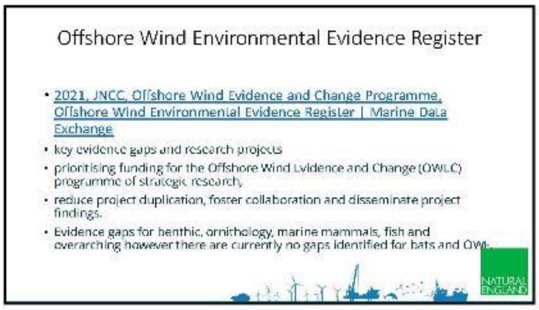
Time	Activity	Lead by
10.00	Offshore wind and bats, knowledge from Germany (10 minutes)	Antje Seebens-Hoyer, Nature and Biodiversity Conservation Union, Germany
10.10	Working to Resolve Environmental Effects of Wind Energy- Perspectives from the US (10 minutes)	Cris Hein, National Renewable Energy Lab
10.20	Thermal Imaging/ Acoustic monitoring offshore in the US. Mitigation tech - TIMR (10 minutes)	Eran Amichai, Normandeau Associates (pre-recorded talk)
10.30	SMART system for remote monitoring and live curtailment (10 minutes)	Fran Tattersall or Paul Howden-Leach, Wildlife Acoustics (pre-recorded talk)
10.40	Q & A (15 minutes)	Jack Hooker, BCT
10.55	**Discussion session in breakout rooms, max 10 people per group, mixed industries, project team members to lead and make notes on Miro board (40 minutes)** **1.** What are the pros and cons of different post-construction monitoring methods? (use lists populated between workshops on different methods available) 2. What could a standardised approach to post-construction monitoring look like? 3. What are the pros and cons of different post-construction mitigation	Katherine Boughey, BCT

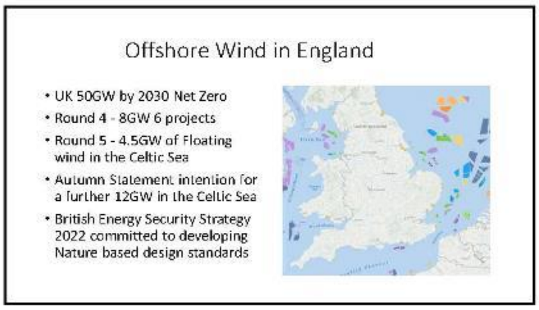
Time	Activity	Lead by
	methods? (use lists populated between workshops on different methods available) 4. What could a standardised approach to post-construction mitigation look like? Is there enough evidence to warrant applying mitigation for collision risk for new and/or existing offshore?	
11.35	**Short break (15 mins)**	
11.50	**Discussion in plenary on key points raised in the last discussion sessions (15 minutes)**	Katherine Boughey, BCT
12.05	**Discussion session in breakout rooms, max 10 people per group, mixed industries, project team members to lead and make notes on Miro board (35 minutes)** 1. What are the barriers to us doing all of the things we have talked about in the UK (we are the world leader in offshore wind!)?, e.g. strategic planning, surveys, monitoring and mitigation 2. What opportunities are available to develop industry best practice? 3. What opportunities are available to develop policy in relation to bats and offshore wind consenting? 4. What opportunities are available to continue these discussions?	Paul Lintott, UWE
12.40	**Discussion in plenary on key points raised in discussion session and any other final points (15 minutes)**	Paul Lintott, UWE

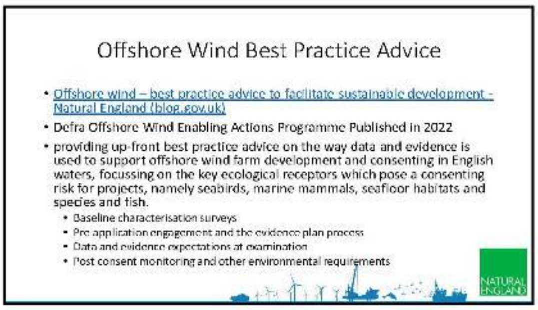
Time	Activity	Lead by
12.55	**Round-up, next steps and close (5 minutes)**	Jan Collins, BCT

Appendix D. Workshop Slides

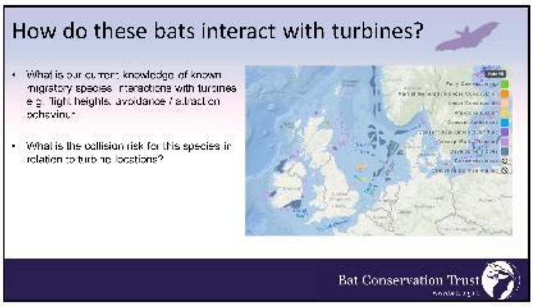






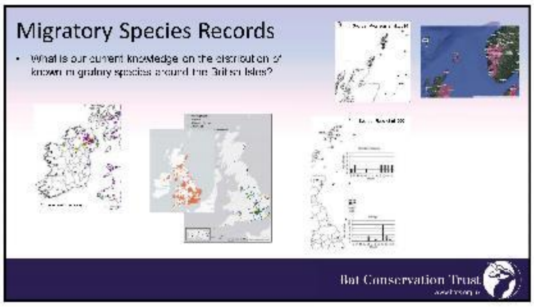



Assessing migration of bat species and interactions with Offshore Wind Farms in English Waters.
Literature and evidence review findings to date
UWE Bristol
Bat Conservation Trust

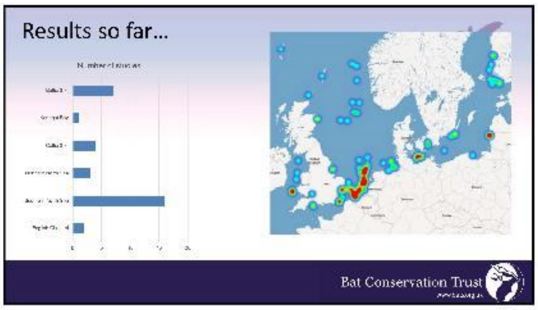

How do these bats interact with turbines?
• What is our current knowledge of known migratory species interactions with turbines e.g. flight heights, avoidance / attraction behaviour
• What is the collision risk for this species in relation to turbine locations?
Bat Conservation Trust

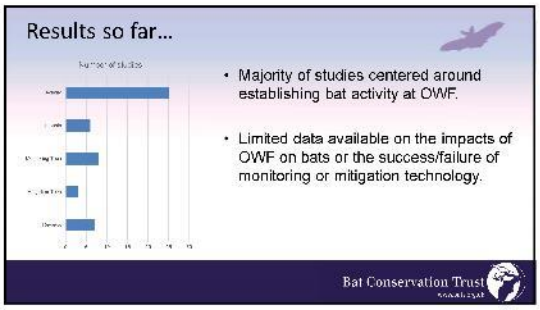

Evidence Review
• Summary of current knowledge from onshore wind research.
EUROBATS
6
Bats in the Anthropocene: Conservation of Bats in a Changing World
UWE Bristol
Bat Conservation Trust

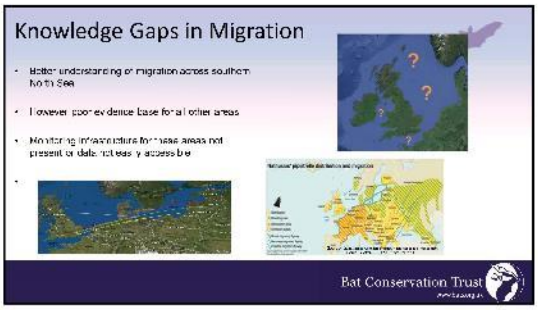

LITERATURE REVIEW
Scientific literature
Grey literature
Literature has been split between into 2 categories
Bat migration to the UK from Europe, and from England to Ireland, Northern Ireland, Scotland, Wales, Channel Islands and Isle of Man (e.g over the North Sea, English Channel, Celtic Sea)
Bat Interactions with Offshore Wind Turbines
Bat Conservation Trust

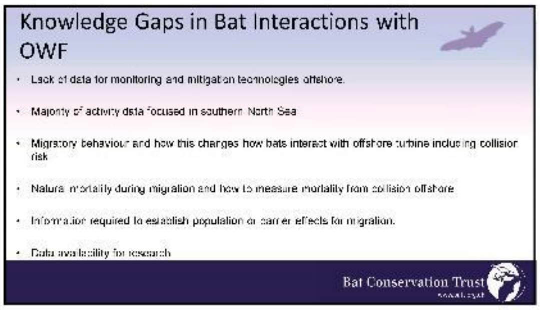

Migratory Species Records
• What is our current knowledge on the distribution of known migratory species around the British Isles?
Bat Conservation Trust

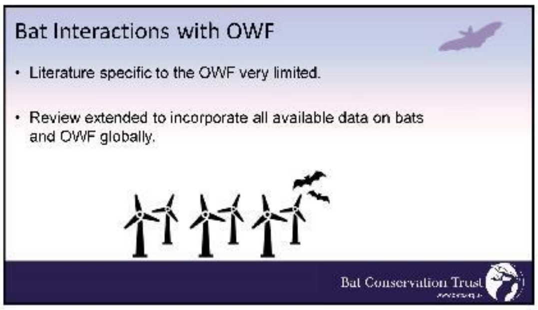

Bat migration
• Literature specific to the UK very limited.
• Review extended to incorporate all offshore and coastal migrations in NW Europe.
• Also includes relevant knowledge from onshore migration studies.
Bat Conservation Trust

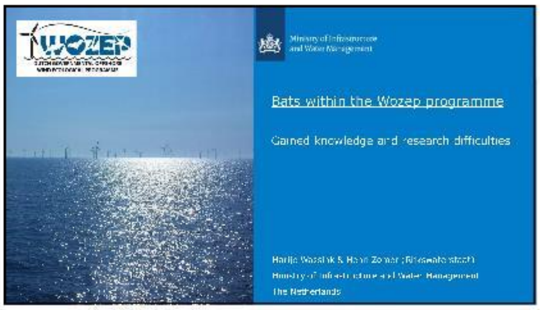

Results so far…
Bat Conservation Trust


Results so far…
• Majority of studies centered around establishing bat activity at OWF.
• Limited data available on the impacts of OWF on bats or the success/failure of monitoring or mitigation technology.
Bat Conservation Trust

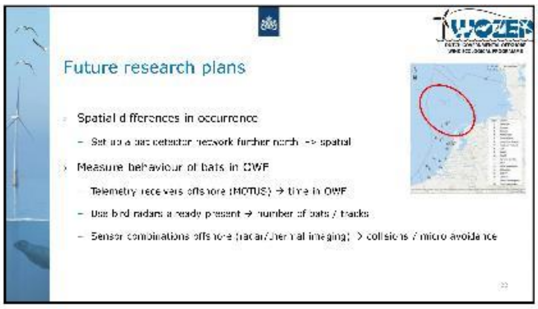

Knowledge Gaps in Migration
• Better understanding of migration across southern North Sea
• However poor evidence base for all other areas
• Monitoring infrastructure for these areas not present or data not easily accessible
Bat Conservation Trust

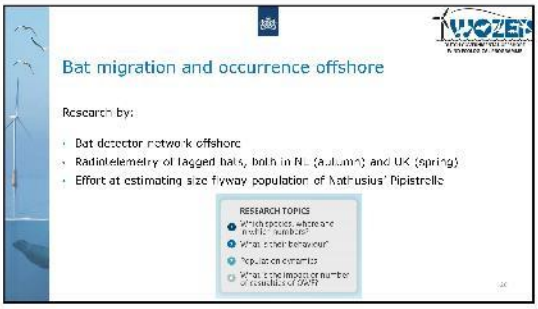

Knowledge Gaps in Bat Interactions with OWF
• Lack of data for monitoring and mitigation technologies offshore.
• Majority of activity data focused in southern North Sea
• Migratory behaviour and how this changes how bats interact with offshore turbine including collision risk
• Natural mortality during migration and how to measure mortality from collision offshore
• Information required to establish population or barrier effects for migration.
• Data availability for research
Bat Conservation Trust

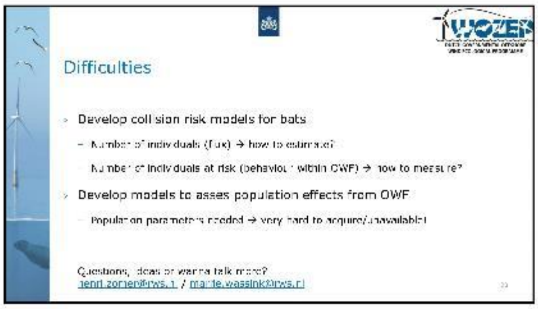

Bat Interactions with OWF
• Literature specific to the OWF very limited.
• Review extended to incorporate all available data on bats and OWF globally.
Bat Conservation Trust

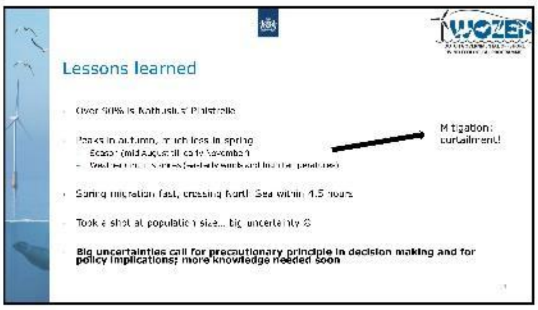

WOZEP
Ministry of Infrastructure and Water Management
Bats within the Wozep programme
Gained knowledge and research difficulties
The Netherlands


Wozep
Research effects of offshore wind farms on ecology, because:
Birds / bats / marine mammals / fish / benthos / ecosystem effects
Roll out of OWF > speed of knowledge development

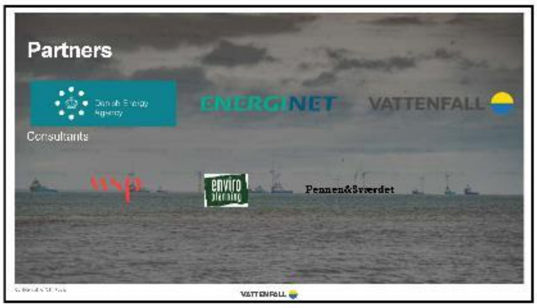

Future research plans
Spatial differences in occurrence
Measure behaviour of bats in OWF
Sensor combinations offshore (radar/thermal imaging) → collisions / micro avoidance


Bat migration and occurrence offshore
Research by:
Bat detector network offshore
Radiotelemetry of tagged bats, both in NL (autumn) and UK (spring)
Effort at estimating size flyway population of Nathusius' Pipistrelle
RESEARCH TOPICS

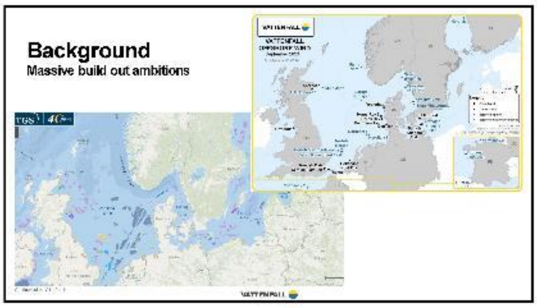

Difficulties
Develop collision risk models for bats
Develop models to asses population effects from OWF
Questions, ideas or wanna talk more?

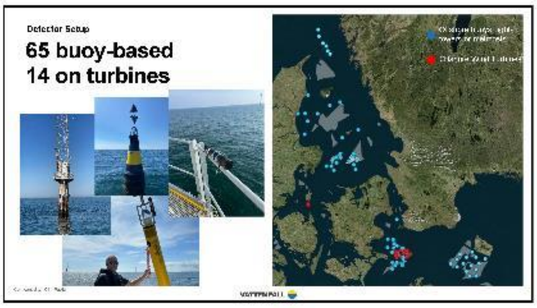

Lessons learned
Peaks in autumn, much less in spring
Mitigation: curtailment!
Spring migration fast, crossing North Sea within 4.5 hours
Took a shot at population size… big uncertainty
Big uncertainties call for precautionary principle in decision making and for policy implications; more knowledge needed soon

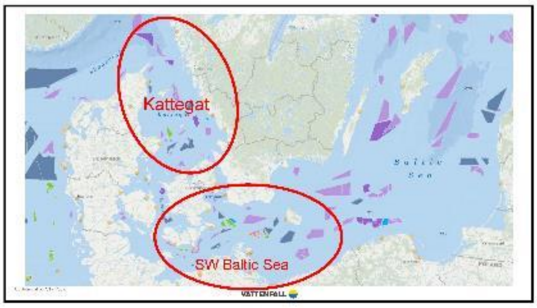

Kattegat & West Baltic Bats Project (KABAP)
BCT Bats and Offshore Wind Workshop 8th Feb 2024
Robin Cox, Vattenfall
VATTENFALL


Partners
ENERGINET
VATTENFALL
Consultants
Pennen&Sværdet

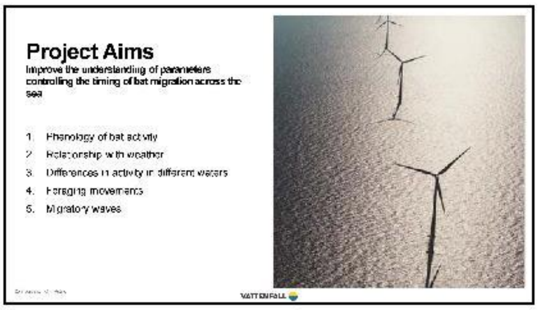

Background for Project
Bats known to be killed at offshore windfarms but magnitude poorly understood offshore compared to onshore
Legal and permiting risks
Operational risks – emerging curtailment requirements
VATTENFALL

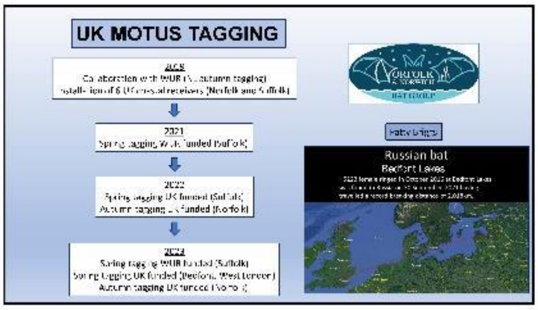

Background
Massive build out ambitions
VATTENFALL

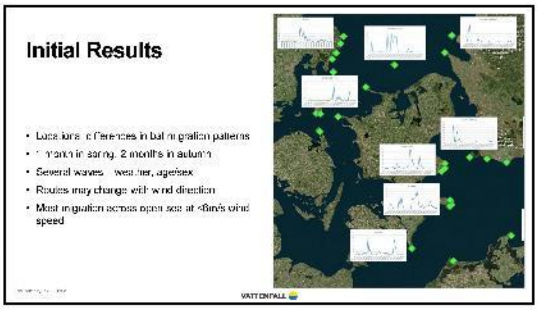

Detector Setup
65 buoy-based
14 on turbines
VATTENFALL


Kattegat
SW Baltic Sea
VATTENFALL


Detector Setup
84 Coastal Sites
VATTENFALL

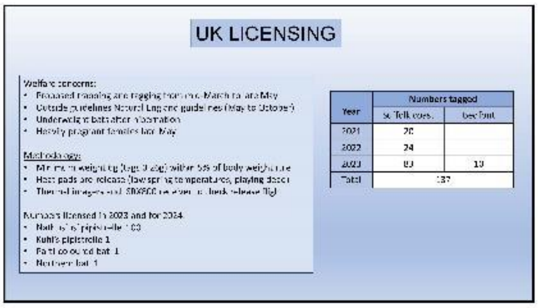

Project Aims
Improve the understanding of parameters controlling the timing of bat migration across the sea
1. Phenology of bat activity
2. Relationship with weather
3. Differences in activity in different waters
4. Foraging movements
5. Migratory waves
VATTENFALL

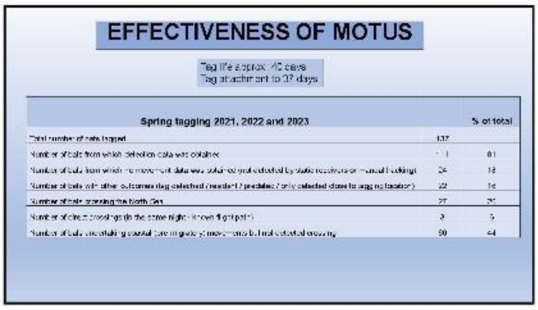

UK MOTUS TAGGING
2021
2022
Spring tagging UK funded (Suffolk)
Autumn tagging UK funded (Norfolk)
2023
Spring tagging WUR funded (Suffolk)
Autumn tagging UK funded (Norfolk)
Russian bat
Bedfont Lakes

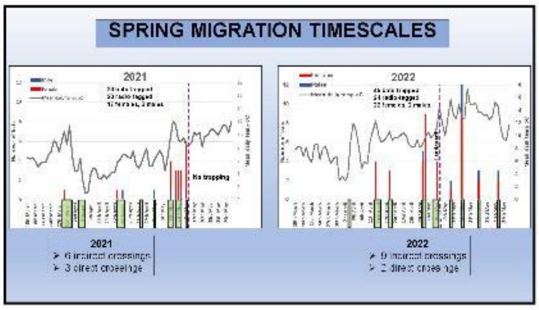

Initial Results
Several waves
Routes may change with wind direction
VATTENFALL

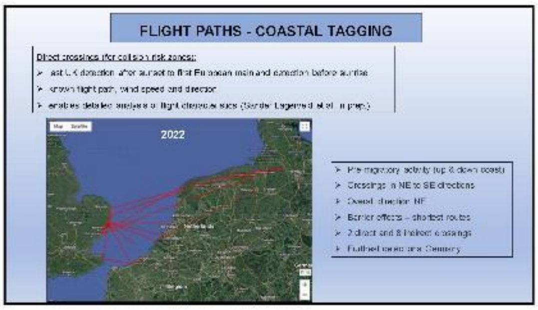

UK MOTUS TAGGING LOCATIONS

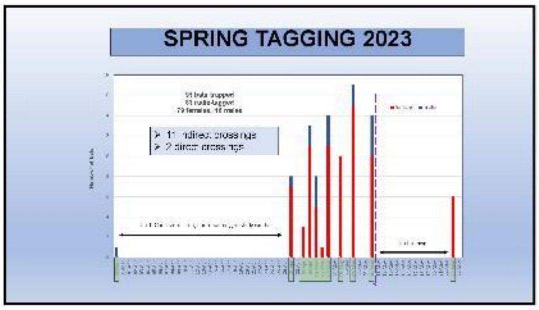

Next Steps
Data collection on-going
First reporting end 2024
Further studies
expand area
VATTENFALL


UK LICENSING
Welfare concerns:
Methodology:
Kuhl's pipistrelle 1
Numbers tagged
Year
2021
2022
2023
Total

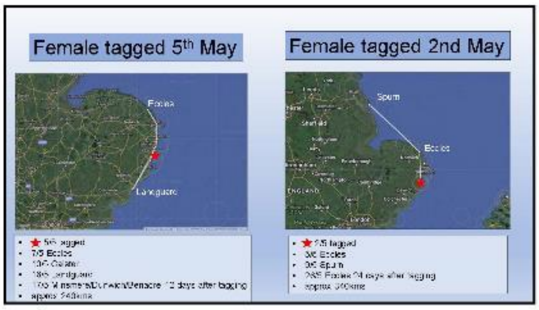

EFFECTIVENESS OF MOTUS
Spring tagging 2021, 2022 and 2023
% of total

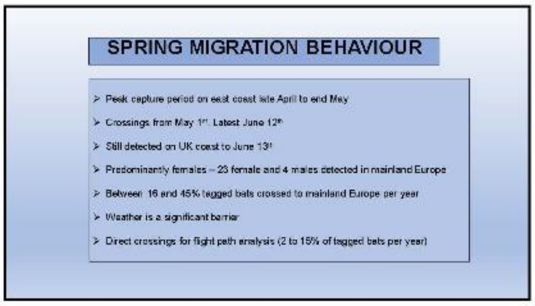

SPRING MIGRATION TIMESCALES
2021
No trapping
2022
2021
➢ 6 indirect crossings
➢ 3 direct crossings
2022
➢ 9 indirect crossings
➢ 2 direct crossings

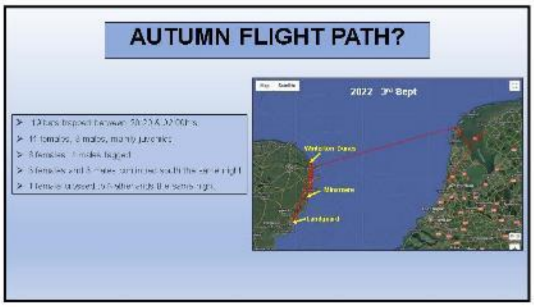

FLIGHT PATHS - COASTAL TAGGING
2022
➢ Crossings in NE to SE directions
➢ Barrier effects – shortest routes


SPRING TAGGING 2023

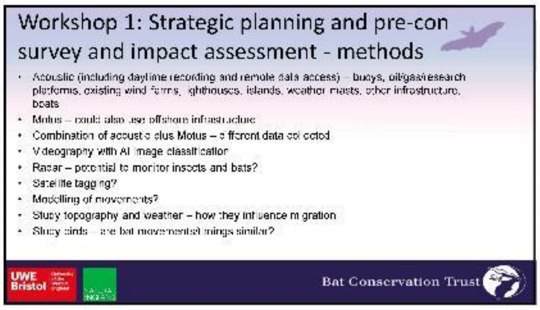

FLIGHT PATHS - INLAND TAGGING


Female tagged 5th May
Female tagged 2nd May
Spurn


SPRING MIGRATION BEHAVIOUR
➢ Peak capture period on east coast late April to end May
➢ Crossings from May 1st. Latest June 12th
➢ Still detected on UK coast to June 13th
➢ Predominantly females – 23 female and 4 males detected in mainland Europe
➢ Between 16 and 45% tagged bats crossed to mainland Europe per year
➢ Weather is a significant barrier
➢ Direct crossings for flight path analysis (2 to 15% of tagged bats per year)


AUTUMN FLIGHT PATH?
2022 3rd Sept
Minsmere
Landguard

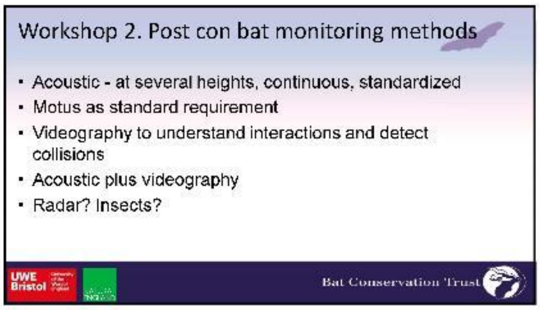

Assessing migration of bat species and interactions with Offshore Wind Farms in English Waters.
Outputs from workshop 1
UWE Bristol
Bat Conservation Trust

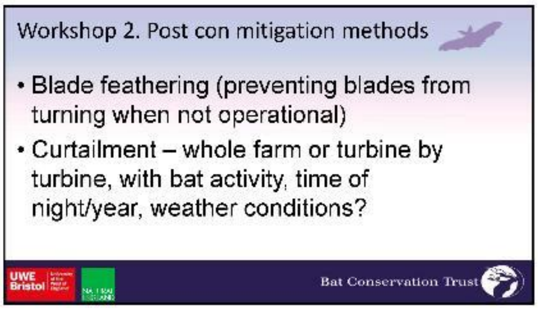

Workshop 1: Strategic planning and pre-con survey and impact assessment - methods
Acoustic (including daytime recording and remote data access) – buoys, oil/gas/research platforms, existing wind farms, lighthouses, islands, weather masts, other infrastructure, boats
Motus – could also use offshore infrastructure
Combination of acoustic plus Motus – different data collected
Videography with AI image classification
Radar – potential to monitor insects and bats?
Satellite tagging?
Modelling of movements?
Study topography and weather – how they influence migration
Study birds – are bat movements/timings similar?
UWE Bristol
Bat Conservation Trust

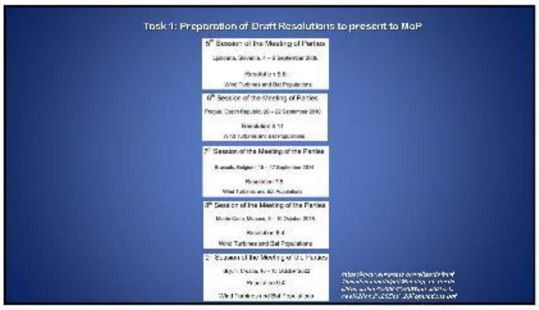

Workshop 1: Onshore to offshore
UWE Bristol
Bat Conservation Trust


Workshop 1: Discussions – main messages
Need marine spatial prioritisation
Look at strategic level / broad scale migratory movements to inform strategic planning
Pre-construction surveys constrained – behaviour changes
Use offshore infrastructure for acoustic / Motus but also think about what bats are doing onshore before departing
Think about other species besides Nathusius' pip, also insects!
Need for a database for data sharing, e.g. Poseidon
Need for guidance for practitioners
Need for awareness raising in industry
International collaboration needed
UWE Bristol
Bat Conservation Trust

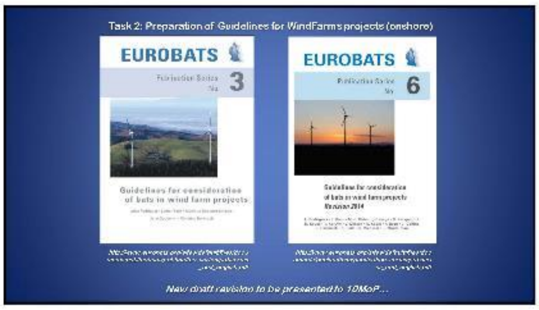

Workshop 1: International to UK
Effect of weather on migration
UWE Bristol
Bat Conservation Trust

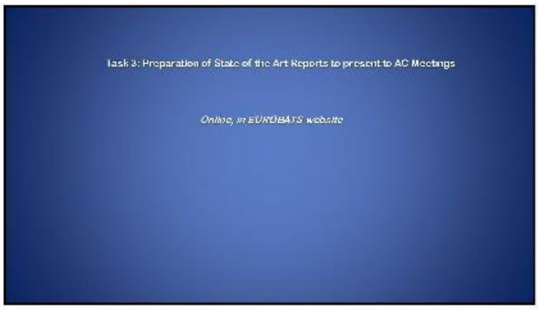

Workshop 2. Post con bat monitoring methods
Acoustic - at several heights, continuous, standardized
Motus as standard requirement
Videography to understand interactions and detect collisions
Acoustic plus videography
Radar? Insects?
UWE Bristol
Bat Conservation Trust


Workshop 2. Post con mitigation methods
• Blade feathering (preventing blades from turning when not operational)
• Curtailment – whole farm or turbine by turbine, with bat activity, time of night/year, weather conditions?
UWE Bristol
Bat Conservation Trust


Task 1: Preparation of Draft Resolutions to present to MoP


EUROBATS Intersessional Working Group
on Wind Farms and Bat Populations
Co-coordinators:
Luisa Rodrigues and Branko Karapandza

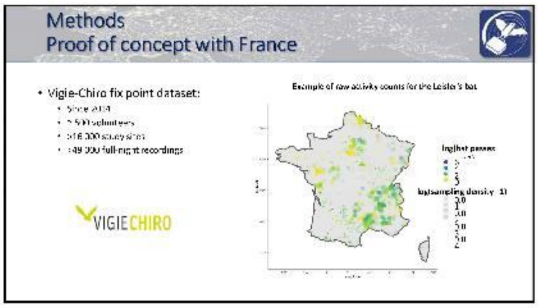

Task 2: Preparation of Guidelines for WindFarms projects (onshore)
EUROBATS
3
Guidelines for consideration of bats in wind farm projects
EUROBATS
6
New draft revision to be presented to 10MoP...


Task 3: Preparation of State of the Art Reports to present to AC Meetings
Online, in EUROBATS website

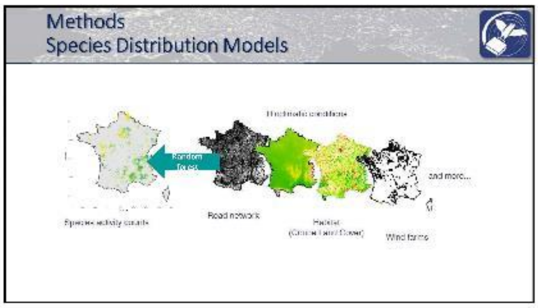

Task 4: Preparation of Guidelines for WindFarms projects (offshore)
Just starting...

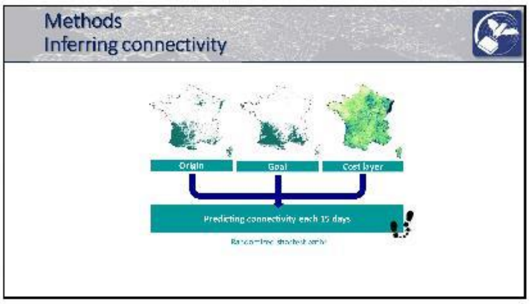

Objectives
Start: April 2021 - End: August 2026
• Study spatio-temporal changes in bat activity in Europe
• Highlight areas of conservation priority

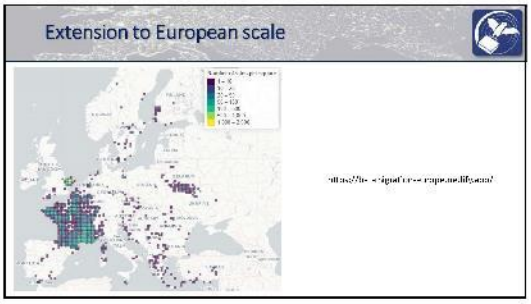

Thank you for your attention!
Luisa Rodrigues (luisa.rodrigues@icnf.pt)

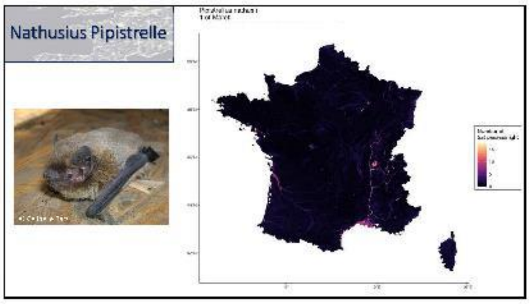

Methods
Proof of concept with France
• Vigie-Chiro fix point dataset:
• 49 000 full-night recordings
Example of raw activity counts for the Leisler's bat
VIGIECHIRO

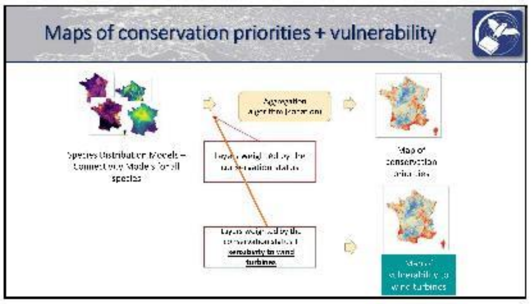

Bat migration routes in Europe
CESCO
NATURALIA
OFB
EUROBATS

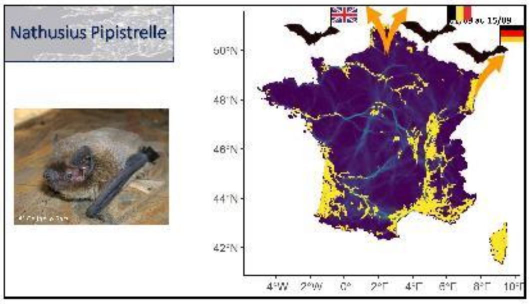

Methods
Species Distribution Models
Random forest
Species activity counts
Road network
Habitat
Wind farms
and more...


Methods
Inferring connectivity
Origin
Goal
Cost layer
Predicting connectivity each 15 days


Extension to European scale

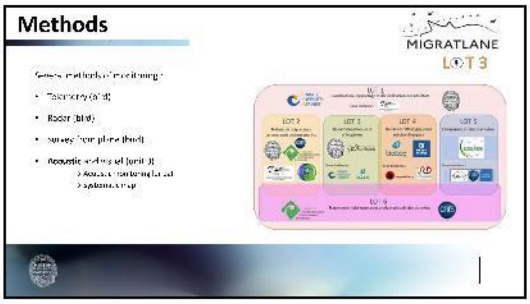

Nathusius Pipistrelle


Maps of conservation priorities + vulnerability
Aggregation
Map of
conservation
Maps of
vulnerability to
wind turbines

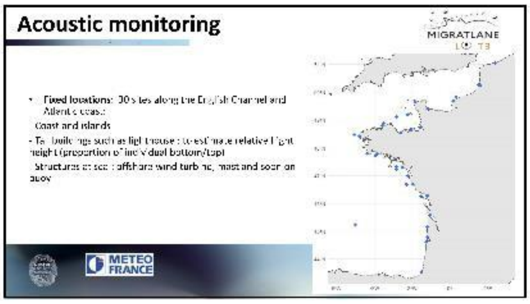

Nathusius Pipistrelle
50°N
48°N
46°N
44°N
42°N
4°W
2°W
0°
2°E
4°E
6°E
8°E
10°E


Co-authors of the methodological paper (not definitive list):
Christian Kerbiriou, Yves Bas, Heather Wood, Ashton Butt, Pierre Mallet, Patrick Wright, Florence Matutini, Fabien Claireau, Tomáš Bartonička, Robin Brabant, Jérémy Froidevaux, Stuart Newson, Sándor Zsebők, Kevin Barré

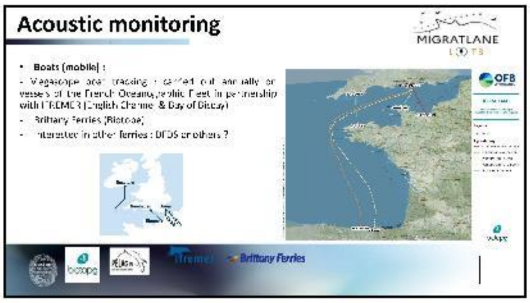

Thanks for your attention !
Wallonie environnement SPW
museum
Ecofirst
WWT
BTO
plecotus
BatLife

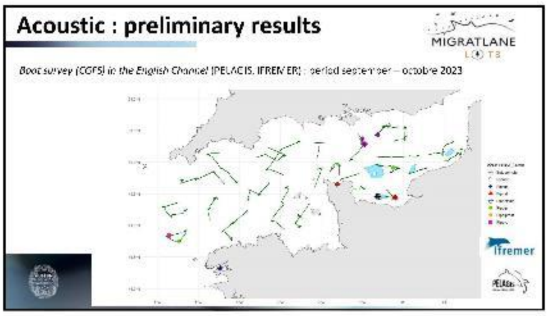

Methods
MIGRATLANE
LOT 3
• Radar (bird)
LOT 1
LOT 2
LOT 4
LOT 5
LOT 6


OFB
MUSÉUM
CESCO
MIGRATLANE
CHARACTERISE THE USE OF THE NORTH-EAST ATLANTIC ARC BY BIRDS AND BATS

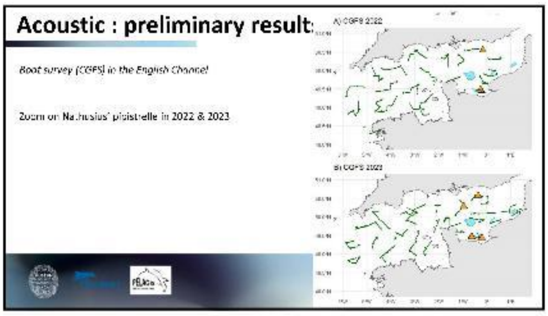

Acoustic monitoring
MIGRATLANE
Coast and islands
METEO FRANCE


Introduction
• Determine which species at sea

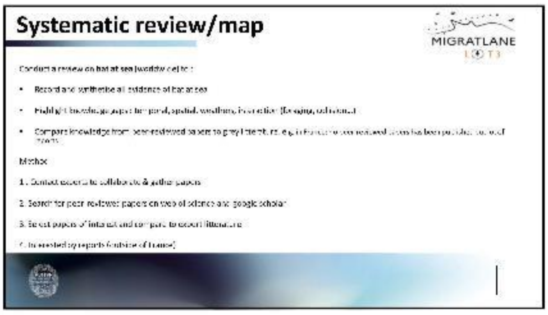

Acoustic monitoring
MIGRATLANE
• Boats (mobile) :
OFB
Brittany Ferries

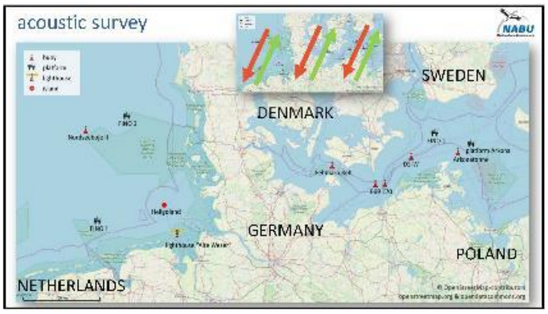

Acoustic : preliminary results
MIGRATLANE
Boat survey (CGFS) in the English Channel (PELAGIS, IFREMER) : period september – octobre 2023
Ifremer
PELAGIS


Thank you
MUSÉUM NATIONAL D'HISTOIRE NATURELLE
COBAN
METEO FRANCE
ideol
Ifremer
OPEN-C
Birding

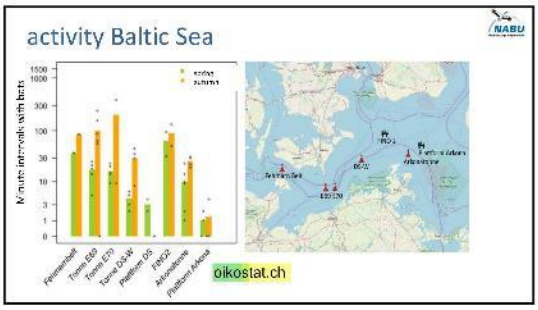

Acoustic : preliminary results
Boat survey (CGFS) in the English Channel
Zoom on Nathusius' pipistrelle in 2022 & 2023
A) CGFS 2022
B) CGFS 2023

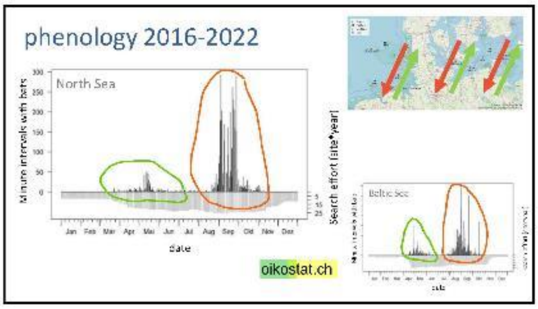

Lothar Bach, Petra Bach, Reinhold Hill, Matthias Göttsche, Michael Göttsche, Hinrich Matthes, Henrik Pommeranz, Sandra Vardeh, Christian Voigt, Antje Seebens-Hoyer
NABU
Mecklenburg-Vorpommern
Offshore wind and bats
Knowledge from Germany
Supported by the Federal Agency for Nature Conservation (BfN) with funds from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)

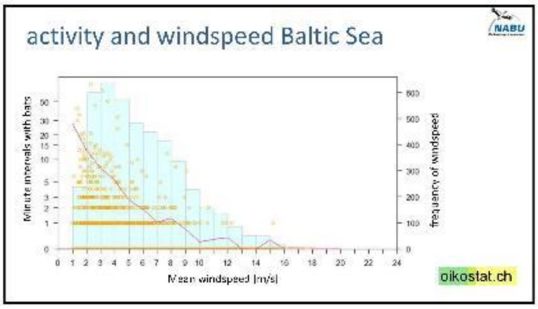

Systematic review/map
MIGRATLANE
Record and synthetise all evidence of bat at sea
Method

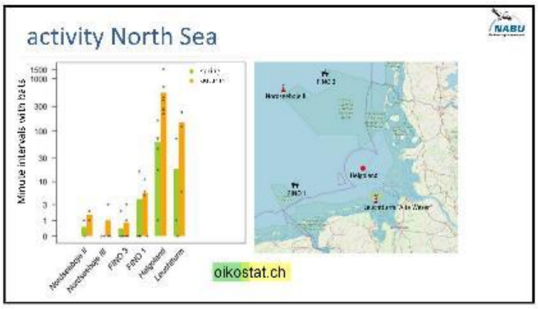

acoustic survey
NABU
SWEDEN
DENMARK
GERMANY
POLAND
NETHERLANDS

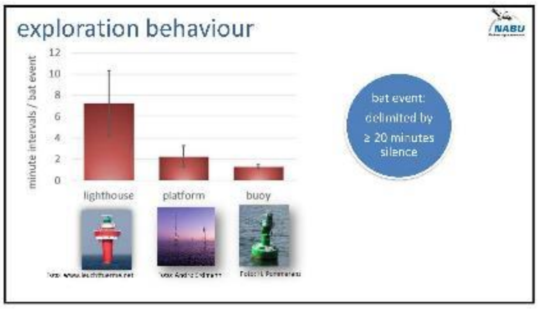

acoustic survey
NABU

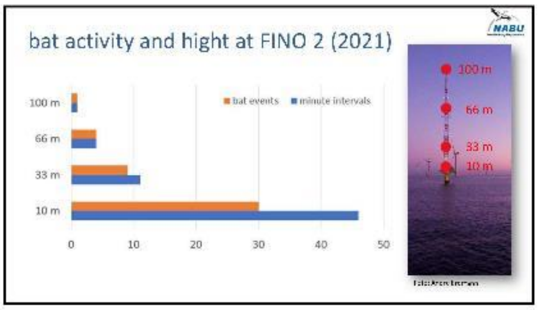

activity Baltic Sea
NABU
Minute intervals with bats
oikostat.ch

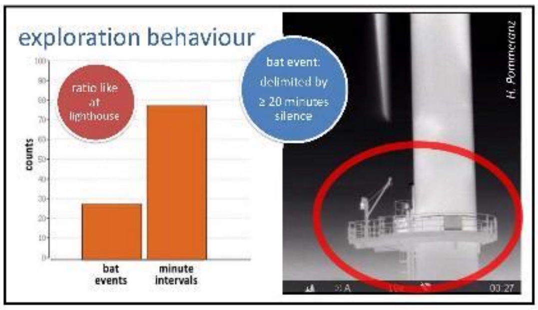

phenology 2016-2022
North Sea
Minute intervals with bats
Search effort [site*year]
Jan Feb Mar Apr Mai Jun Jul Aug Sep Okt Nov Dez
date
Baltic Sea
oikostat.ch


activity and windspeed Baltic Sea
NABU
Minute intervals with bats
frequency of windspeed
Mean windspeed [m/s]
oikostat.ch

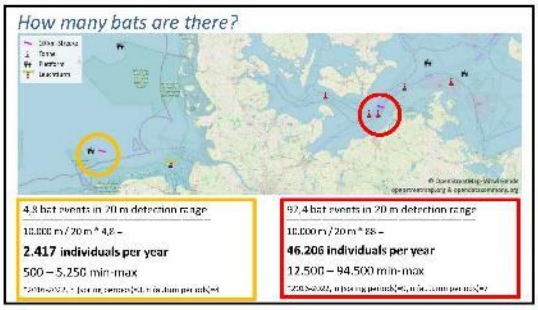

activity North Sea
NABU
Minute intervals with bats
oikostat.ch

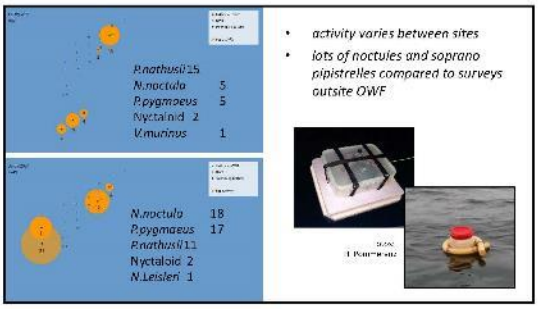

exploration behaviour
NABU
minute intervals / bat event
lighthouse
platform
buoy
bat event:
delimited by
≥ 20 minutes
silence

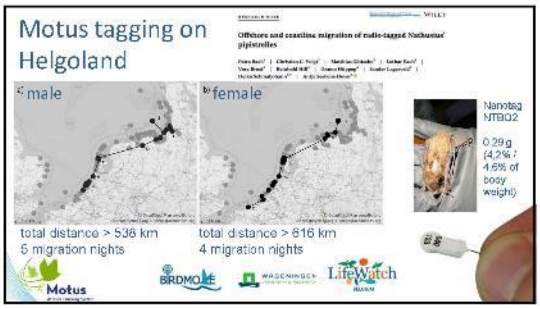

bat activity and hight at FINO 2 (2021)
NABU
bat events
minute intervals
100 m
66 m
33 m
10 m
0
10
20
30
40
50


exploration behaviour
ratio like at lighthouse
bat event: delimited by ≥ 20 minutes silence
counts
bat events
minute intervals
H. Pommeranz

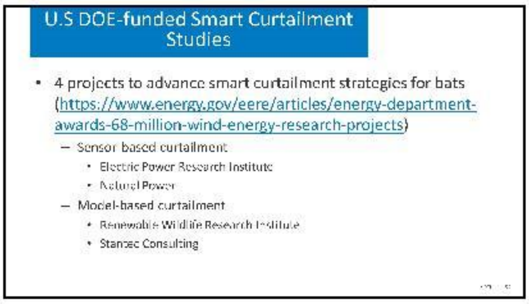

bat activity in the OWF Baltic 1
NABU
Henrik Pommeranz


How many bats are there?
4,8 bat events in 20 m detection range
10.000 m / 20 m * 4,8 =
2.417 individuals per year
500 – 5.250 min-max
97,4 bat events in 20 m detection range
10.000 m / 20 m * 88 =
46.206 individuals per year
12.500 – 94.500 min-max

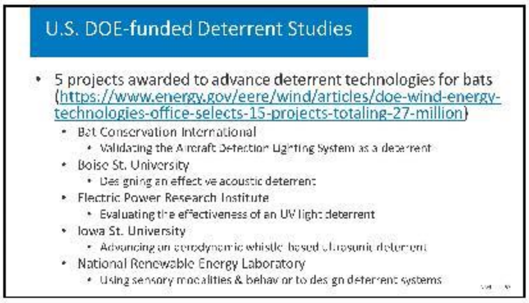

P.nathusii 15
N.noctula 5
P.pygmaeus 5
Nyctaloid 2
V.murinus 1
N.noctula 18
P.pygmaeus 17
P.nathusii 11
Nyctaloid 2
N.Leisleri 1
activity varies between sites
lots of noctules and soprano pipistrelles compared to surveys outsite OWF

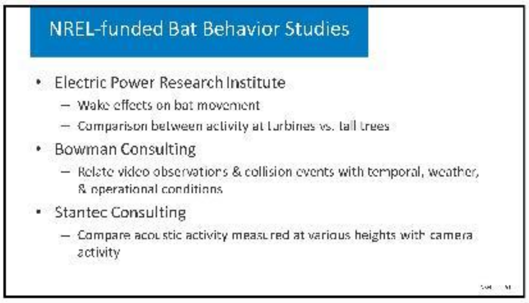

Motus tagging on Helgoland
Offshore and coastline migration of radio-tagged Nathusius' pipistrelles
male
female
total distance > 536 km
5 migration nights
total distance > 616 km
4 migration nights
Nanotag NTBO2
0.29 g (4,2% / 4,6% of body weight)
Motus
BIRDMOVE
WAGENINGEN
LifeWatch

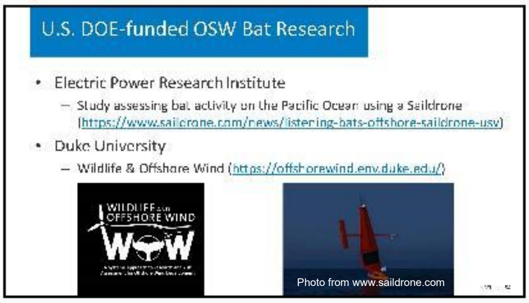

NABU
Mecklenburg-Vorpommern
BfN
Federal Agency for Nature Conservation
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
Thank you!
LifeWatch
WSV.de
BIRDMOVE
WAGENINGEN
UNIVERSITY & RESEARCH
NABU


U.S DOE-funded Smart Curtailment Studies
• 4 projects to advance smart curtailment strategies for bats (https://www.energy.gov/eere/articles/energy-department-awards-68-million-wind-energy-research-projects)
– Sensor based curtailment
• Electric Power Research Institute
• Natural Power
– Model-based curtailment
• Renewable Wildlife Research Institute
• Stantec Consulting


Bats & Wind Energy Studies in the U.S.
Cris Hein, Ph.D. – NREL
Bat Conservation Trust Workshop
15 February 2024

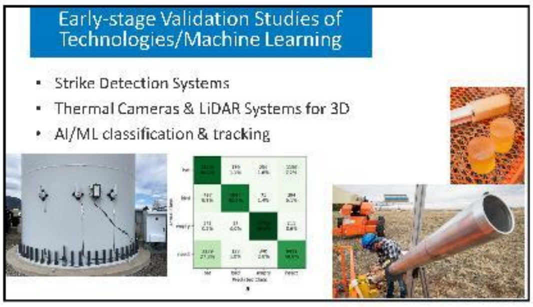

U.S. DOE-funded Deterrent Studies
• 5 projects awarded to advance deterrent technologies for bats (https://www.energy.gov/eere/wind/articles/doe-wind-energy-technologies-office-selects-15-projects-totaling-27-million)
• Bat Conservation International
• Validating the Aircraft Detection Lighting System as a deterrent
• Boise St. University
• Designing an effective acoustic deterrent
• Electric Power Research Institute
• Evaluating the effectiveness of an UV light deterrent
• Iowa St. University
• Advancing an aerodynamic whistle-based ultrasonic deterrent
• National Renewable Energy Laboratory
• Using sensory modalities & behavior to design deterrent systems

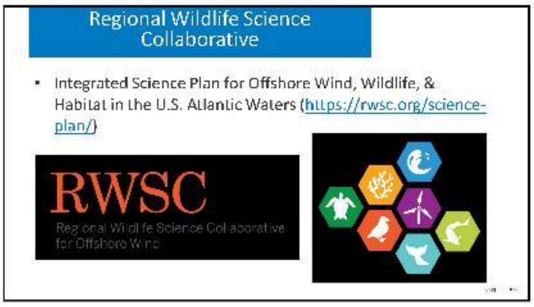

NREL-funded Bat Behavior Studies
• Electric Power Research Institute
– Wake effects on bat movement
– Comparison between activity at turbines vs. tall trees
• Bowman Consulting
– Relate video observations & collision events with temporal, weather, & operational conditions
• Stantec Consulting
– Compare acoustic activity measured at various heights with camera activity


U.S. DOE-funded OSW Bat Research
• Electric Power Research Institute
– Study assessing bat activity on the Pacific Ocean using a Saildrone (https://www.saildrone.com/news/listening-bats-offshore-saildrone-usv)
• Duke University
– Wildlife & Offshore Wind (https://offshorewind.env.duke.edu/)
WILDLIFE AND OFFSHORE WIND
WOW
Photo from www.saildrone.com


Tethys (https://tethys.pnnl.gov)
Atlantic & Pacific Research Recommendations Databases
Atlantic & Pacific Project Finders
Monitoring & Mitigation Technologies Tool
Offshore Wind Metadata
Knowledge Hub
– 6,600 publications & reports
Tethys Blasts
– Bi-weekly newsletter announcing new publications, webinars, etc.


U.S. DOE-funded Radar Buoy Development
U.S. Geological Survey & Pacific Northwest National Laboratory
– Developing a stabilization system for radars & other technologies on buoys
Graphic from PNNL/USGS project


Early-stage Validation Studies of Technologies/Machine Learning
Strike Detection Systems
Thermal Cameras & LiDAR Systems for 3D
AI/ML classification & tracking

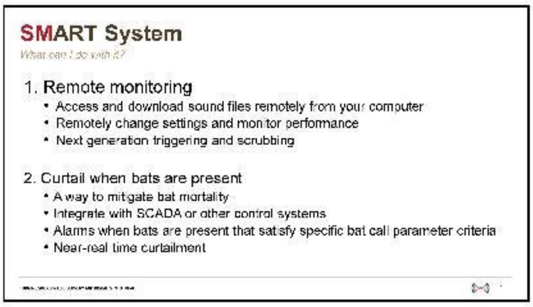

Regional Wildlife Science Collaborative
Integrated Science Plan for Offshore Wind, Wildlife, & Habitat in the U.S. Atlantic Waters (https://rwsc.org/science-plan/)
RWSC
Regional Wildlife Science Collaborative for Offshore Wind

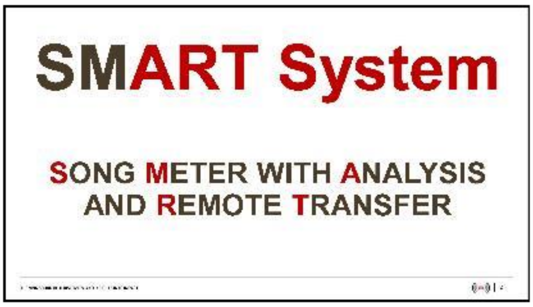

Integral
California Energy Commission-funded Integral Consulting, Inc.
– Integrated, real-time, multi-scale system for monitoring seabird & bat interactions with floating offshore wind technologies
Thermal Tracker camera system
DeTect 3d Radar
Velvetwire-Stickershock sensor
Photo by W. Slocum, NREL

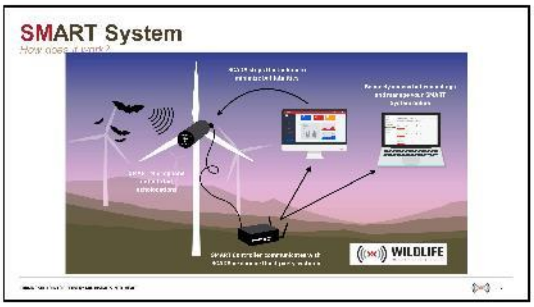

Thank you
www.nrel.gov
Cris Hein (cris.hein@nrel.gov)
NREL
Transforming ENERGY


ATOMic TIMR: A Multi-Sensor Approach for Bat-Turbine Interaction Monitoring and Mitigation
Eran Amichai, PhD
Normandeau Associates
eamichai@normandeau.com
NORMANDEAU ASSOCIATES


WILDLIFE
ACOUSTICS
BEING SMART ABOUT BATS AT WIND FARMS
INTRODUCING WILDLIFE ACOUSTIC'S SMART SYSTEM

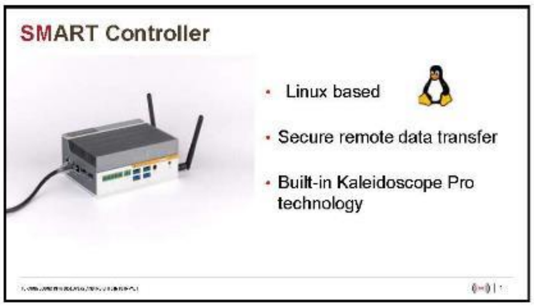

SMART System
What can I do with it?
1. Remote monitoring
• Access and download sound files remotely from your computer
• Remotely change settings and monitor performance
• Next generation triggering and scrubbing
2. Curtail when bats are present
• A way to mitigate bat mortality
• Integrate with SCADA or other control systems
• Alarms when bats are present that satisfy specific bat call parameter criteria
• Near-real time curtailment

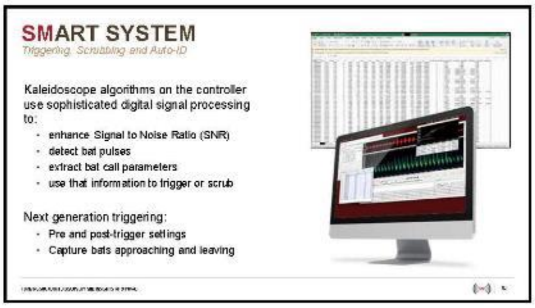

SMART System
SONG METER WITH ANALYSIS
AND REMOTE TRANSFER

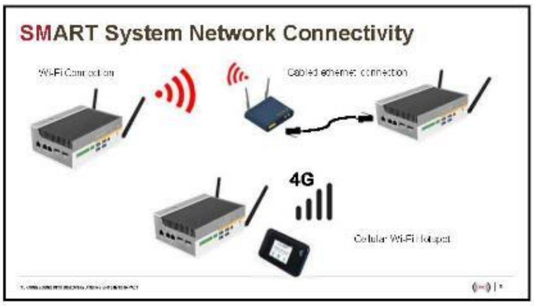

SMART System
How does it work?
WILDLIFE

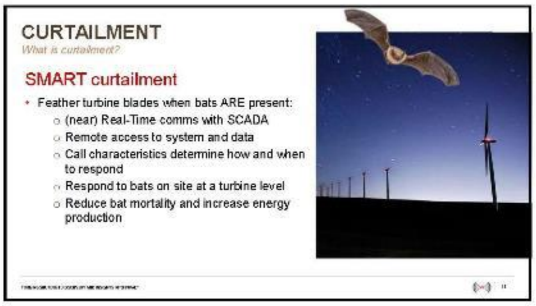

SMART System
SMART MIC-1

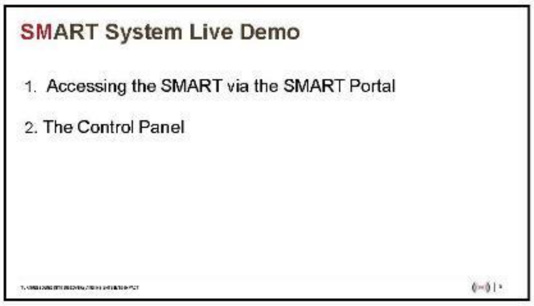

The SMART MIC-1
• Performs analogue to digital conversion
• Data output through Ethernet cable
• Rated IP67 salt-fog tested
Anodization with exposed metal grounding stripe
Dual ultrasonic sensor elements
Ultrasonic speaker
Heating element
Waterproof RJ45 CAT5/6 connection
SMART MIC-1

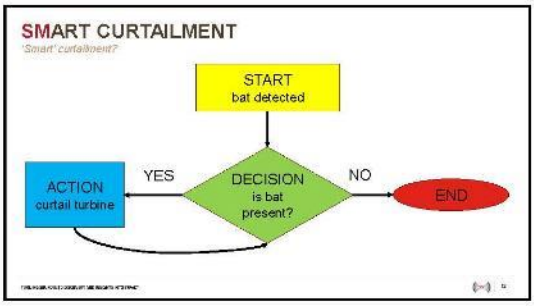

SMART Controller
Linux based
Secure remote data transfer
Built-in Kaleidoscope Pro technology


SMART SYSTEM
Triggering, Scrubbing and Auto-ID
Kaleidoscope algorithms on the controller use sophisticated digital signal processing to:
enhance Signal to Noise Ratio (SNR)
detect bat pulses
extract bat call parameters
use that information to trigger or scrub
Next generation triggering:
Pre and post-trigger settings
Capture bats approaching and leaving


SMART System Network Connectivity
Wi-Fi Connection
Cabled ethernet connection
4G
Cellular Wi-Fi hotspot

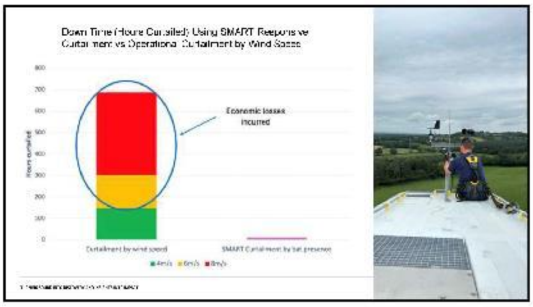

CURTAILMENT
What is curtailment?
SMART curtailment
Feather turbine blades when bats ARE present:
(near) Real-Time comms with SCADA
Remote access to system and data
Call characteristics determine how and when to respond
Respond to bats on site at a turbine level
Reduce bat mortality and increase energy production

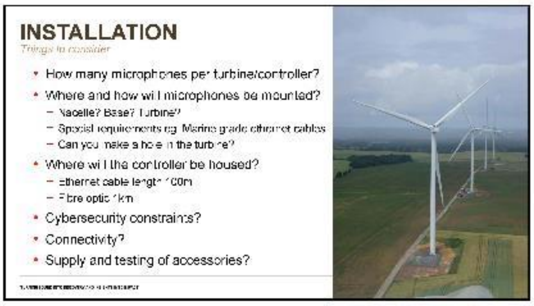

SMART System Live Demo
1. Accessing the SMART via the SMART Portal
2. The Control Panel


SMART CURTAILMENT
'Smart' curtailment?
START
bat detected
DECISION
is bat present?
YES
NO
ACTION
curtail turbine
END


SMART
SCADA tab


Thank you!
WILDLIFE
ACOUSTICS


800
700
600
500
400
300
200
100
0
Economic losses incurred
Curtailment by wind speed
SMART Curtailment by bat presence
4m/s
6m/s
8m/s


INSTALLATION
Things to consider
How many microphones per turbine/controller?
Where and how will microphones be mounted?
Nacelle? Base? Turbine?
Can you make a hole in the turbine?
Where will the controller be housed?
Cybersecurity constraints?
Connectivity?
Supply and testing of accessories?

Appendix E. Literature Results – Bat Migration within the British Isles and between the British Isles and Europe

Baltic Sea

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Appendix F. Literature Results – Bat Interaction with Offshore Wind Turbines

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Appendix G. National Nathusius' Pipistrelle Project: Summary Analysis

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1. Introduction

The National Nathusius' Pipistrelle Project (NNPP) is a citizen science project with the aims of:

- Determining the resident and breeding status of *Pipistrellus nathusii* (Nathusius' pipistrelle) in Great Britain.
- Determining the migratory origins of *P. nathusii* in Great Britain.
- Gathering further information on the distribution of *P. nathusii* in Great Britain and the Channel Islands.

It began in 2014 and combines acoustic surveys, capture surveys, ringing, radio tracking and stable isotope analysis. Surveys are undertaken by local bat groups coordinated by and under the guidance of Daniel Hargreaves and staff at the Bat Conservation Trust.

This report presents a summary of data from NNPP capture surveys and ringing recoveries.

2. Methods

2.1 Site selection

Capture surveys were undertaken in the vicinity of large waterbodies, at locations where the presence of *P. nathusii* had previously been confirmed by either acoustic surveys or bat box inspections, ideally in multiple consecutive years. Survey locations were selected by participating bat groups to maximise the chances of capturing *P. nathusii*, taking into consideration the habitat composition of the surrounding landscape (favouring locations with larger areas of water or wetlands with adjacent woodland) and topographic features that could create migratory corridors.

2.2 Survey methods

Surveys were undertaken each year from April to mid-June, and from mid-July to October. Surveys were suspended between approximately mid-June to mid-July each year to avoid capturing heavily pregnant or lactating females. The exact timing of the suspension was determined for each locality each year in discussion with surveyors, considering the progress of the breeding season and the body condition of bats caught in early June.

Each site was surveyed at least twice, once in the pre-breeding period and once in the post-breeding period. At each site at least two trap locations were identified. Trap locations were selected to be more than 200 m apart, as close to the water as possible, ideally with trees or vegetation to conceal the trap supports, and with suitable space for surveyors to operate with appropriate distancing for themselves and the bats. At each trap location either a harp trap or mist net was deployed in conjunction with an acoustic lure (Sussex Autobat, BAT AT100, Apodemus BatLure or Avisoft UltraSoundGate) playing a *P. nathusii* advertisement call. The lure was placed in the centre of the trap at approximately 1.5m height and ultrasound calls were broadcast from the acoustic lure as described in Lintott et al. (2014). Lures were switched on and traps were opened at sunset and were checked regularly, at least every 15 minutes, during the survey. Surveys continued for at least two hours, but longer where possible.

Temperature, cloud cover, rain, wind speed and moon phase were recorded at the start of the survey, and temperature was also recorded at the end of the survey. From 2021 onwards all reusable equipment including traps, nets, containers, bags and callipers that were in direct contact with bats were disinfected between use to avoid the transfer of SARS-CoV-2 from humans to bats, following the recommendations of the IUCN Bat Specialist Group (Kingston et al., 2021). All surveys were carried out under license from the relevant statutory nature conservation body.

2.3 Bat captures

For each captured bat the following information was recorded: time caught, species, age, reproductive status, and for *Pipistrellus* species, weight, forearm measurement and fifth finger length. Bats were aged as adults or juveniles according to the degree of ossification of the epiphyseal joints in the finger bones (Baagoe, 1977). A ratio of the fifth digit length to the forearm length of 1.25 or more was taken as indicative of *P. nathusii* (Stebbings 1970). In the initial two years of the survey a fur sample (approx. 1 mg) was taken from the lower dorsal area of captured *P. nathusii* and *Pipistrellus pygmaeus* to enable comparative stable isotope analysis, and *P. nathusii* were held in a clean bag for up to 15 minutes to collect droppings for genetic confirmation of species identification. Where participants were licensed to do so, captured *P. nathusii* were ringed with a 2.9 mm ring following standard bat ringing protocols. In areas where no previous *P. nathusii* maternity roosts were known, and where survey results suggested evidence of breeding, female *P. nathusii* caught in the pre-breeding season in good condition, of a suitable weight and not heavily pregnant were radio tagged and tracked back to their roost. Emergence surveys at located roosts were conducted over the breeding season to assess roost occupancy and confirm breeding where possible (data not reported here).

The survey instructions provided to surveyors are included in Annex A.

2.4 Data summary and analysis

Survey data were inspected for errors or inconsistencies, e.g. erroneous date-time stamps, bat capture times that preceded the start of a survey, or inconsistencies in sex/age between ring recoveries. All data errors were corrected, and all reported data were included in the analysis.

To account for variation in survey effort between and within years, months, bat groups, survey sites, and individual surveys we calculated a bat capture rate by dividing the number of bats caught by the total duration of survey effort per survey. Survey effort was calculated as the number of minutes (presented as hours in this report for clarity) between the start and end of a survey, multiplied by the number of traps deployed during that survey. This provided a consistent measure of total survey effort that also accounted for the 78 surveys where no bats were caught. For any surveys that had no, or incomplete, start and end time data (n = 228) we drew a pseudo-random sample of survey durations from our 1,206 complete survey durations. This sample was not drawn entirely at random; it was drawn in a way that exactly matched the distribution of our actual survey durations. In this way we were able to retain these 228 survey records without simply assigning them a mean duration.

To investigate body condition, we calculated a scaled body mass index (SBMI) rather than a standard body condition index (BCI). Body condition indices are commonly calculated from the linear relationship between body mass and a length measurement e.g., forearm length. However, a wide range of BCIs exist, many of which fail to account for body size (a vital requirement for condition indices, Peig & Green 2010). The SBMI corrects for variation in body size by scaling all individuals to the same length (the population average) and comparing each individual's true mass to the expected mass of an individual of average length. The resulting 'predicted mass' indicates where an individual lies (in terms of body mass) in relation to the average individual.

International and within-GB ring recovery data were investigated using the *geosphere* (Hijmans, 2022) and *circular* (Agostinelli & Lund, 2023) packages in R (R Core Team, 2023). Travel bearings were calculated from start and end locations using the *geosphere::bearings* functions and the uniformity of these bearings was tested for statistical significance (P = 0.05) using the *circular::rayleigh.test* function.

3. Results

3.1 Survey effort

Between 2014 and 2023, 29 bat groups conducted 1,434 surveys across 352 sites (Fig. 1), catching a total of 17,930 bats. These comprised 18 taxa identified to species level and two identified to genus level: unidentified *Pipistrellus* species and unidentified small *Myotis* species (Table 1). Of the total number of bats captured during the survey, 2,364 were ringed for the first time, and 111 were already ringed upon capture, either as part of the NNPP or elsewhere.

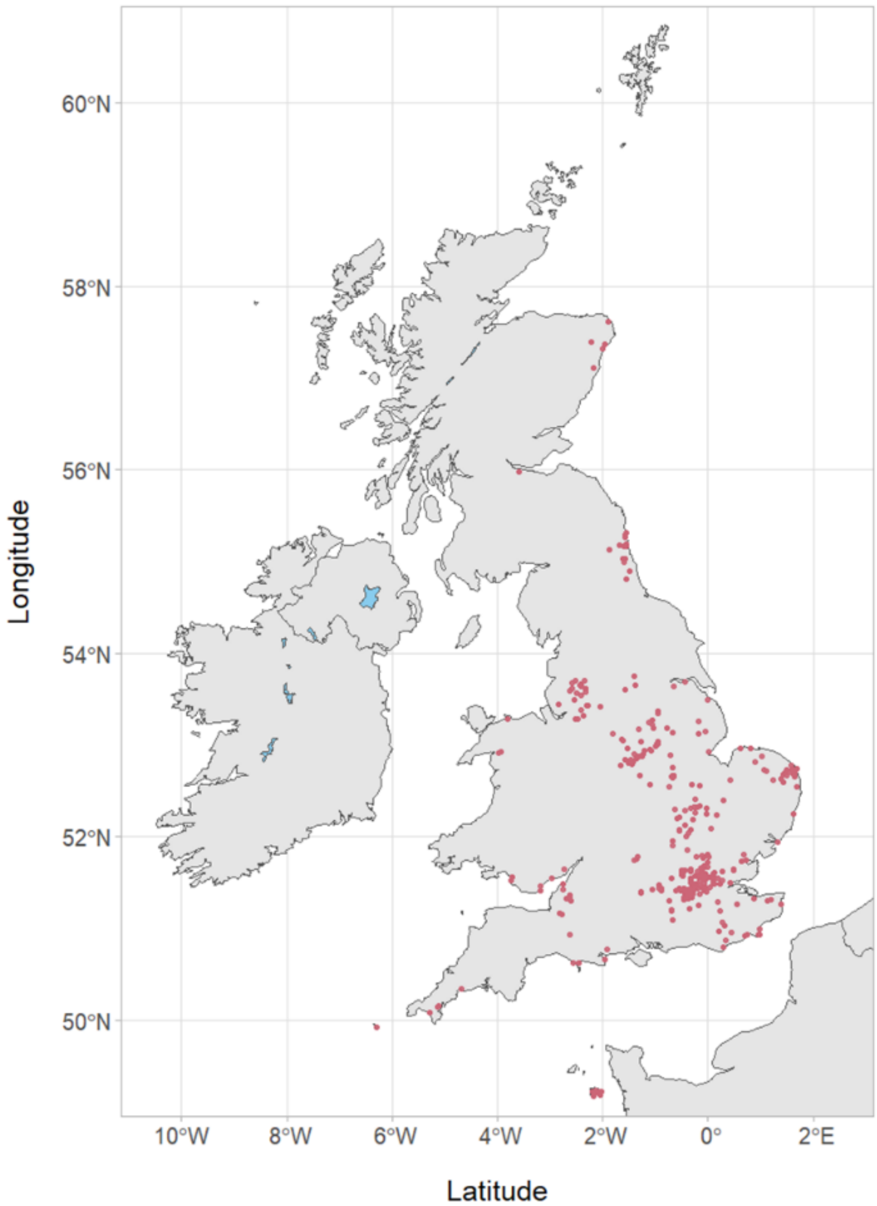

Figure 1. National Nathusius' Pipistrelle Project survey locations 2014-2023 (red circles)

Table 1. Bats captured during National Nathusius' Pipistrelle Project surveys (2014-2023)

Species	Number of captures	Proportion of total captures
Pipistrellus pygmaeus	9,160	0.5109
Pipistrellus nathusii	2,622	0.1462
Pipistrellus pipistrellus	2,377	0.1326
Myotis daubentonii	2,067	0.1153
Myotis mystacinus	561	0.0313
Myotis nattereri	306	0.0171
Nyctalus noctula	241	0.0134
Plecotus auritus	205	0.0114
Myotis brandtii	113	0.0063
Unidentified *Pipistrellus spp.*	54	0.0030
Barbastella barbastellus	30	0.0017
Rhinolophus hipposideros	28	0.0016
Nyctalus leisleri	27	0.0015
Unidentified small *Myotis spp.*	18	0.0010
Eptesicus serotinus	12	0.0007
Myotis alcathoe	12	0.0007
Rhinolophus ferrumequinum	5	0.0003
Myotis bechsteinii	4	0.0002
Plecotus austriacus	3	0.0002
Pipistrellus kuhlii	1	0.0001
Unidentified bat	84	0.0047

3.2 *Pipistrellus spp.* capture rates

3.2.1 *Pipistrellus spp.* capture rates by survey month

Capture rates (number of bats captured per trap, per hour) of *P. nathusii*, *P. pygmaeus*, and *Pipistrellus pipistrellus* varied throughout the annual trapping window (April through October, Figs. 2A & 2B). The capture rate of *P. nathusii* showed a marked U-shaped pattern; rates declined slowly from April until June, then rose sharply in August (Fig. 2A). *P. pygmaeus* capture rates were notably higher than those of *P. nathusii* and *P. pipistrellus* throughout most of the year, peaking in mid-July (Fig. 2B).

3.2.2 *P. nathusii* capture rates at coastal and inland survey sites

Capture rates differed between coastal locations (those within 10 km of the shore) and inland locations (those further than 10 km from the shore) over the course of the year and survey evening (Fig. 3). Capture rates were typically higher at coastal survey locations.

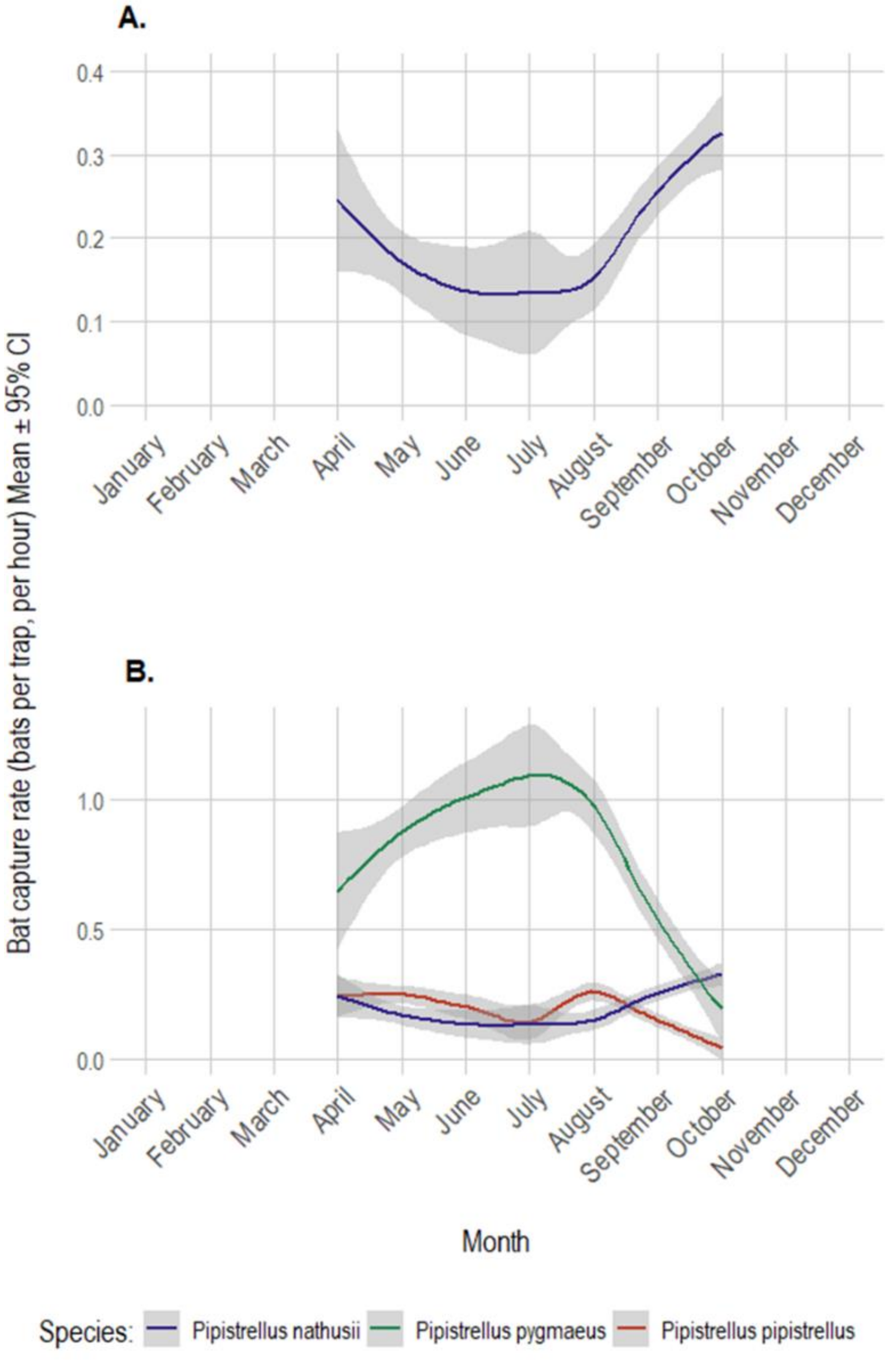

Figure 2. ***Pipistrellus spp.*** **capture rate by month. Panel A:** ***P. nathusii*****. Panel B:** ***P. nathusii, P. pygmaeus*****, and** ***P. pipistrellus*****.**

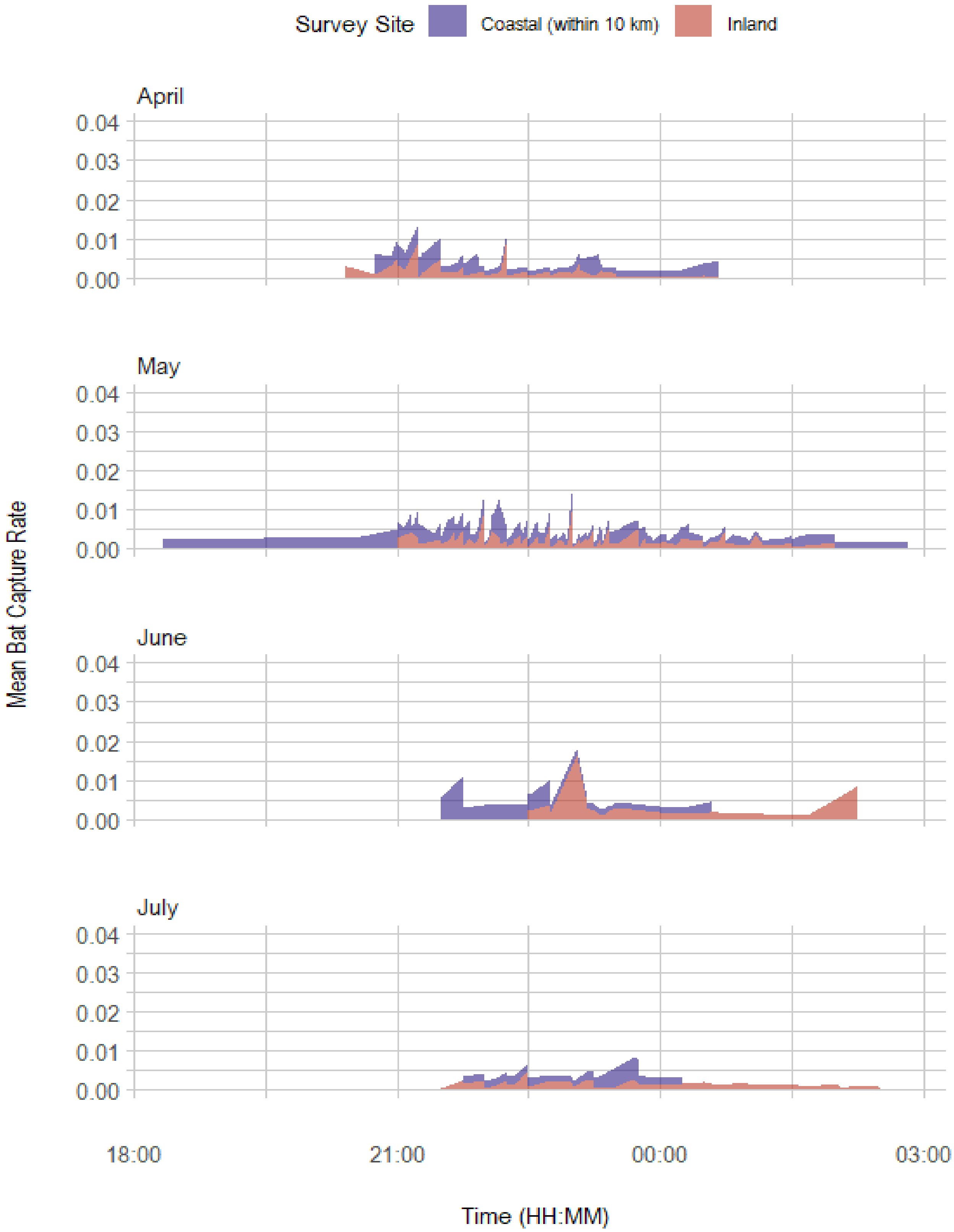

Figure 3. *P. nathusii* capture rates at coastal and inland survey sites, by month. Capture rates are binned into 15-minute intervals over the course of a typical survey evening.

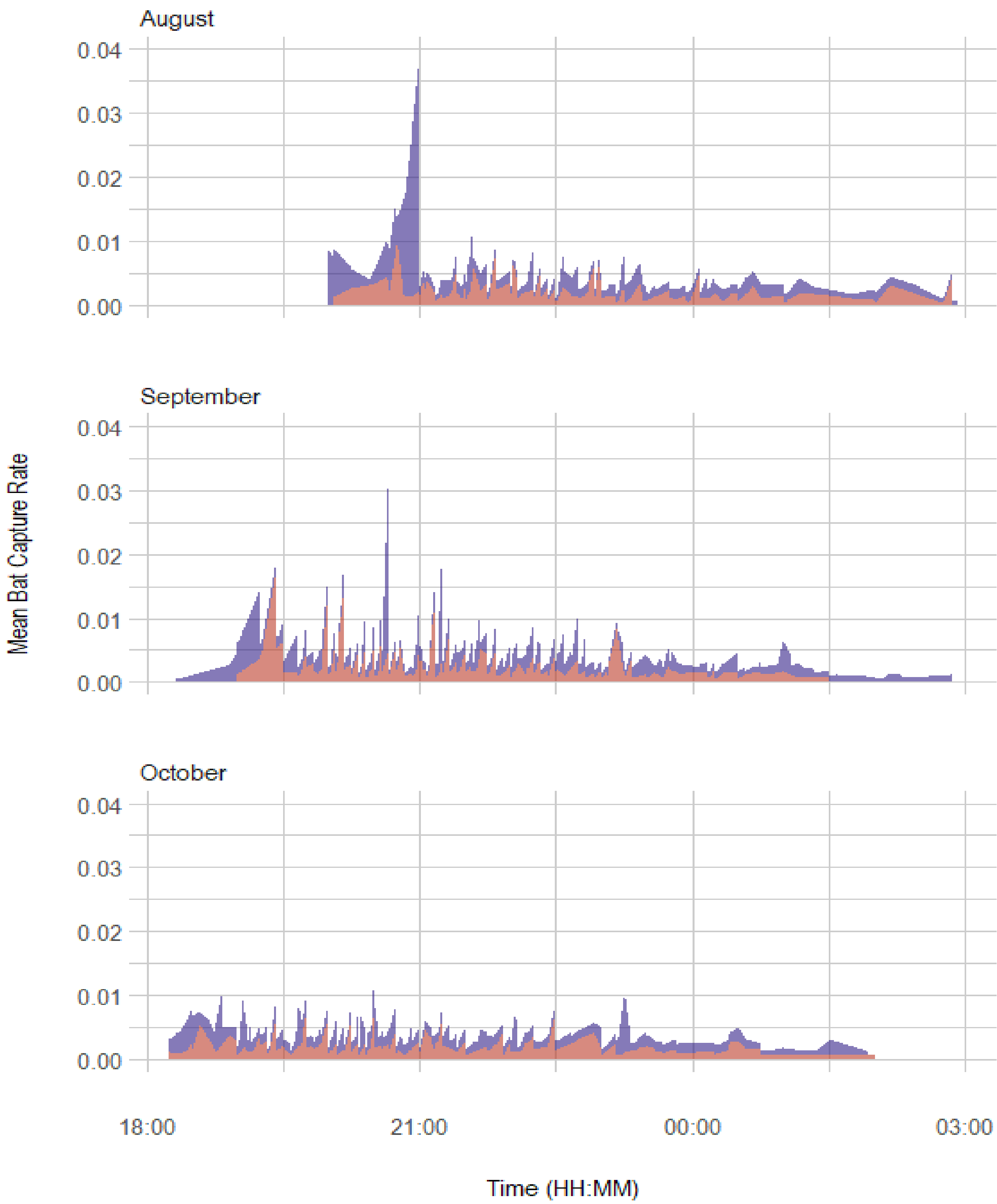

Figure 3. continued *P. nathusii* capture rates at coastal and inland survey sites, by month. Capture rates are binned into 15-minute intervals over the course of a typical survey evening.

3.2.3 *Pipistrellus spp.* capture rates by sex

The sex ratio of all captured bats of all species was approximately even over the survey, with 9,153 female (proportion of captures = 0.51) and 844 male (proportion of captures = 0.47) bats captured; 333 individuals could not be accurately sexed (proportion of captures = 0.02). The sex ratio of captured individuals varied between the *Pipistrellus spp.* (Table 2 and Fig. 4), with the majority of *P. nathusii* captures being of males.

Table 2. Summary of *Pipistrellus* spp. bats captured, by species and sex, during National Nathusius' Pipistrelle Project surveys (2014-2023)

Species	Sex	Number of captures	Proportion of total species captures
Pipistrellus nathusii	Female	628	0.240
	Male	1,992	0.760
	Unknown	2	0.001
Pipistrellus pygmaeus	Female	5,348	0.584
	Male	3,656	0.399
	Unknown	156	0.017
Pipistrellus pipistrellus	Female	1,353	0.569
	Male	1,011	0.425
	Unknown	13	0.005

P. nathusii males were captured at consistently higher rates than females in all months (Fig. 5). If we assume that capture rates are relative to abundance, that the mean capture rate by sex across June, July and August reflects the abundance of resident individuals, and that capture rate above this summer mean value represents the abundance of individuals that have migrated to GB, the sex ratio of the migratory population (female/male) in GB in October would be approximately 0.95.

Females of *P. pygmaeus* and *P. pipistrellus* were captured at higher rates than males between April and early August, after which capture rates of females and males converged.

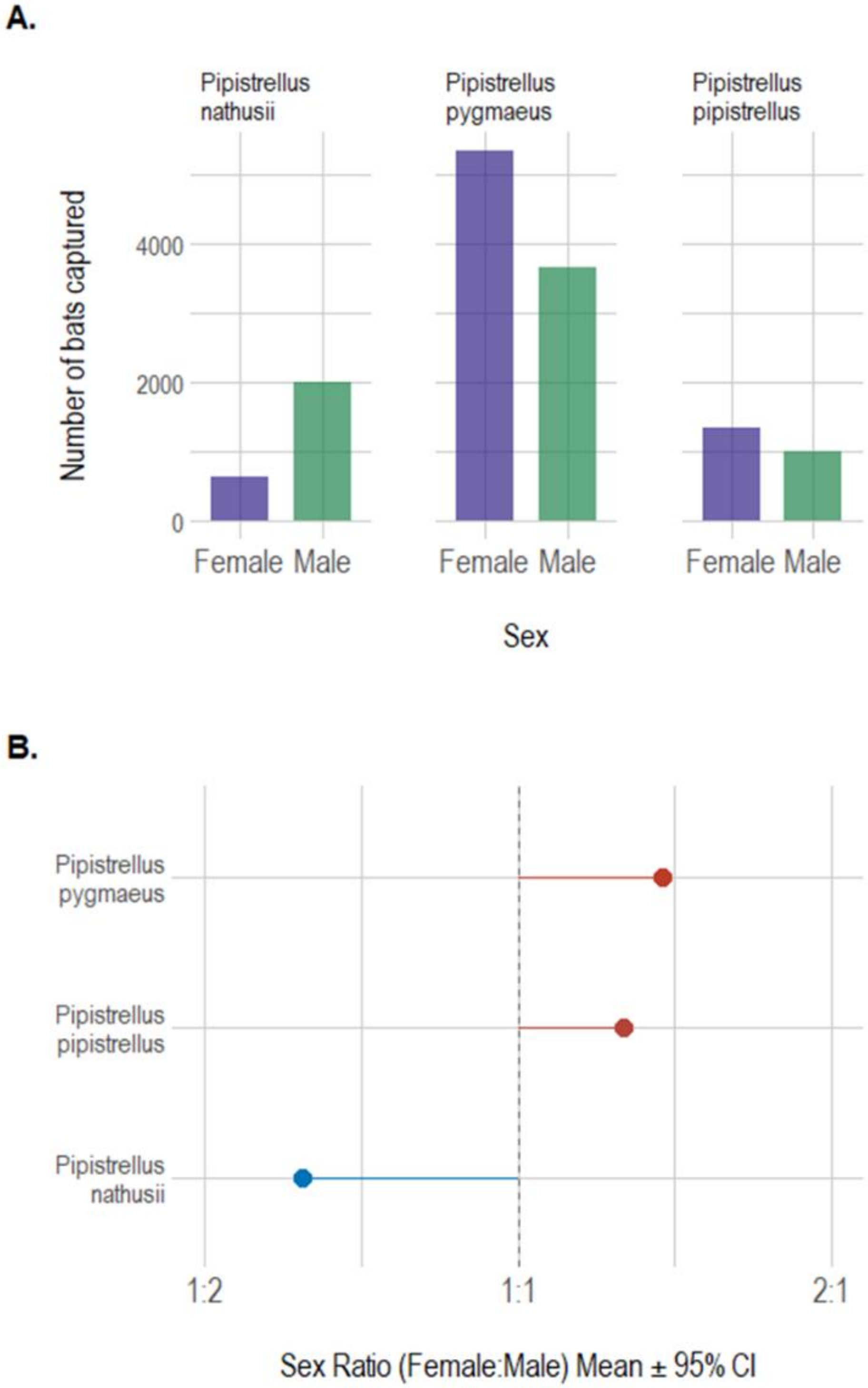

Figure 4. Panel A: Number of Pipistrellus spp. captured by sex. Panel B: Sex ratio (female:male) of Pipistrellus spp. captures.

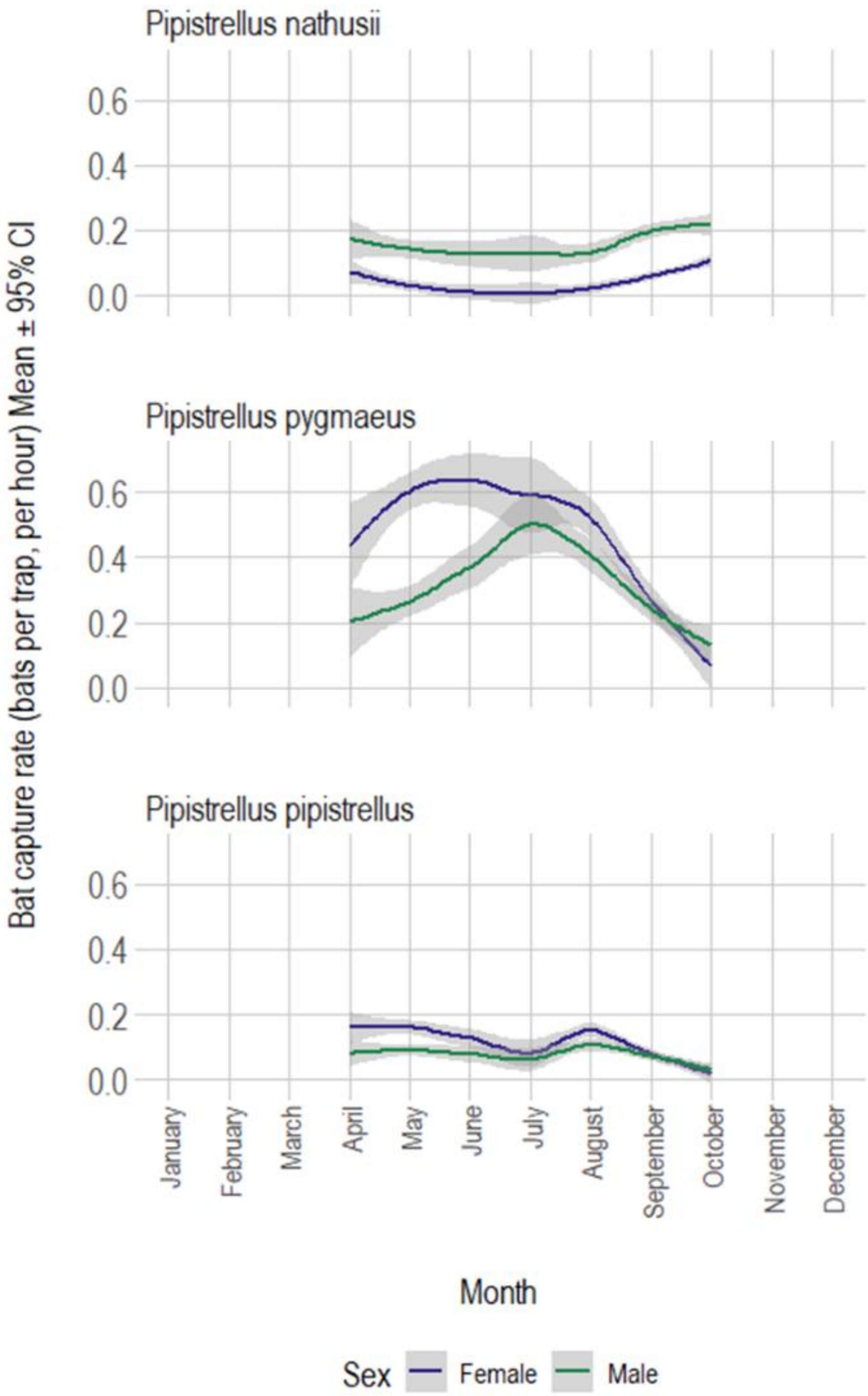

Figure 5. ***Pipistrellus*** **spp. capture rates throughout the year, by sex.**

3.2.4 *Pipistrellus spp.* sex ratios at coastal and inland sites

While more males than females were captured at both coastal and inland sites, the proportion of female *P. nathusii* captured was slightly higher at coastal survey sites than inland sites (Fig. 6). This was seen throughout the year, however it was only between August and October that the 95% confidence interval of these estimates did not overlap. There was little evidence that the sex ratio of captured *P. pygmaeus* differed between coastal and inland sites. The ratio of female to male *P. pipistrellus* captured at coastal sites increased substantially during June and July, however the 95% confidence interval surrounding this estimate is broad and should be interpreted with caution.

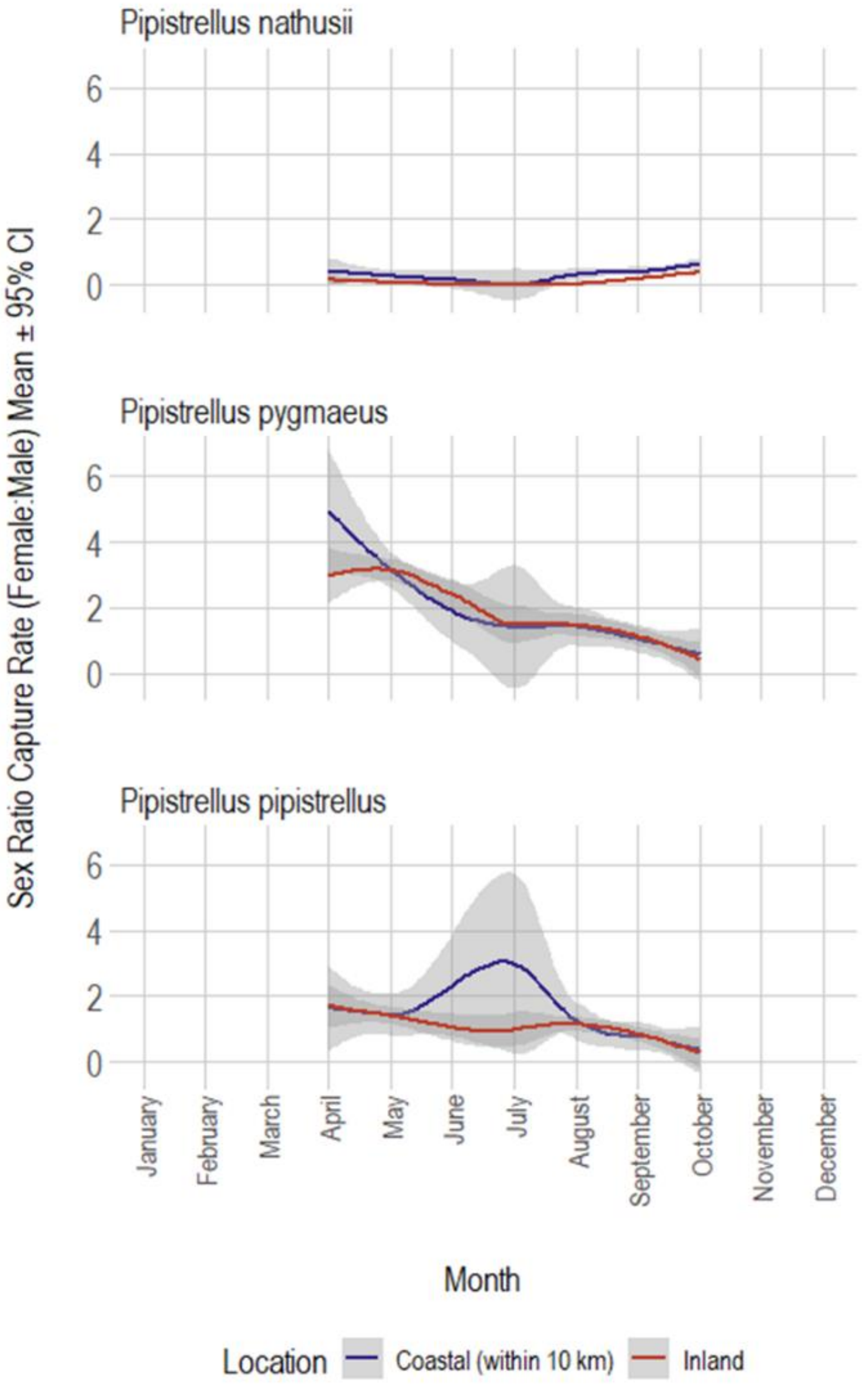

Figure 6. Sex ratio of captured Pipistrellus spp. at coastal and inland survey sites throughout the year.

3.2.5 *Pipistrellus spp.* capture rate by age class

Adult bats of all three *Pipistrellus* spp. were captured at higher rates than juveniles, with the exception of a temporary spike in the capture rate of juvenile *P. pygmaeus* and *P. pipistrellus* in July as the young of the year became volant (Fig. 7). Across the whole survey only 29 juvenile *P. nathusii* were captured between July and August, with juveniles of this species generally not captured until September.

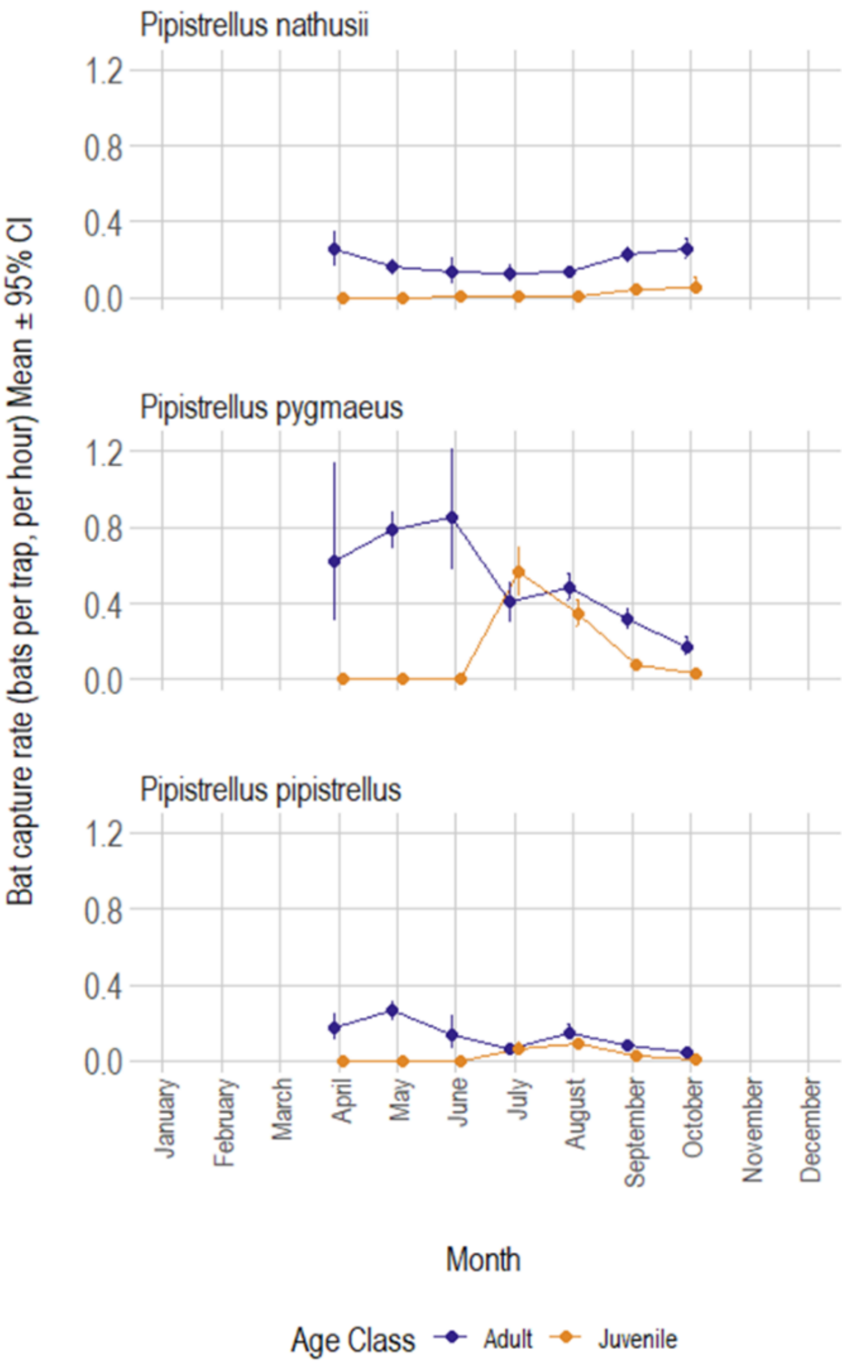

Figure 7. Capture rates of adult and juvenile *Pipistrellus spp.* throughout the year.

3.2.6 *Pipistrellus spp.* scaled body mass index by sex

In this study we use a scaled body mass index (SBMI) to account for the changing relationship between body mass and forearm length across juveniles and adults, as body size changes and growth occurs. The SBMI of all three *Pipistrellus* species fluctuated predictably throughout the year (Fig. 8). The SBMI of both sexes rose sharply post-hibernation/torpor, starting in April (first month of the year for which data were routinely available). Females of all *Pipistrellus spp.* species saw a steep drop in SBMI during the breeding season (June/July), followed by a steady post-partum increase for the rest of the year. The seasonal pattern of male *P. nathusii* SBMI diverges markedly from female *P. nathusii,* and to the other *Pipistrellus* species of both sexes; it increases rapidly to a peak in August before declining in September.

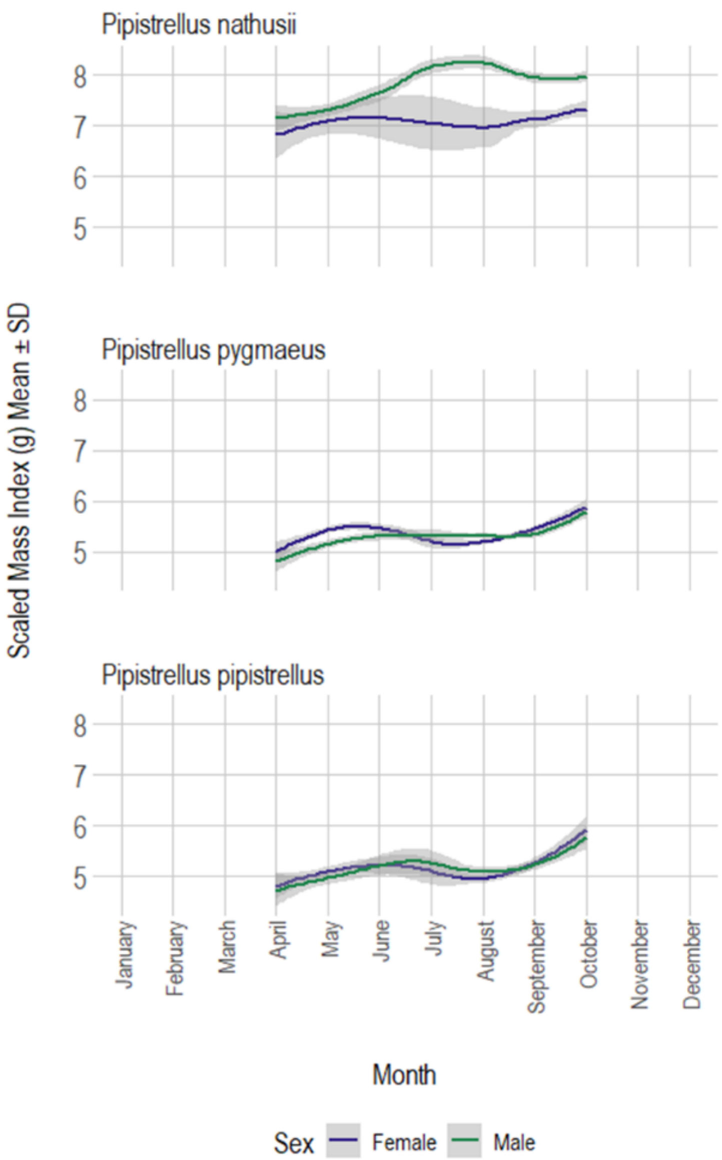

Figure 8. Scaled Body Mass Indices (SBMI) of captured female and male P*ipistrellus spp.* throughout the year.

3.3 International ring recoveries of *P. nathusii*

Between October 2012 and September 2019, six ringed P. nathusii were recovered that had been ringed outside the UK, whilst four individuals ringed in the UK were recovered elsewhere in Europe (Table 3 & Fig. 9). The ringing locations of those individuals ringed outside GB were Latvia (n = 4) and Lithuania (n = 2). The four individuals originally ringed in the GB were subsequently recovered in the Netherlands (n = 1), Belgium (n = 1), Poland (n = 1), and Russia (n = 1). The farthest distance travelled (between ring recovery locations) was 2,018 km from Bedfont Lakes near Heathrow airport in London, UK to Pskov in Russia, undertaken by a female *P. nathusii*. The fastest rate of travel recorded was by a male P. nathusii between Lithuania and Stodmarsh (near Canterbury, UK) at approximately 37.8 km per day over 37 days. Eight of the recaptured individuals were recovered at least six months after their initial ringing.

Table 3. ***P. nathusii*** **international ring recoveries**

Ring number	Sex	Ringing date	Recovery date	Distance (km)	Days	Note
A4030	Male	2012-10-14	2013-12-23	594	435	Blagdon Lake to Holland
SA4722	Male	2015-08-21	2015-10-10	1,454	50	Latvia to Rye Sussex
JJ00424	Male	2015-09-02	2016-08-06	1,415	339	Lithuania to Oare
H8629	Female	2015-09-27	2018-09-01	213	1,070	Castle Water Sussex to Heusden Belgium
SA3908	Male	2016-08-22	2017-08-25	1,430	368	Latvia to Stockers Lake Herts
SA5963	Female	2016-08-23	2017-09-08	1,447	381	Latvia to Kempton Park Reservoir
SA6515	Male	2016-08-23	2017-09-01	1,410	374	Latvia to Chigborough Lakes Maldon

Ring number	Sex	Ringing date	Recovery date	Distance (km)	Days	Note
JJ21406	Male	2016-08-31	2016-10-07	1,397	37	Lithuania to Stodmarsh
H5223	Female	2016-10-16	2012-07-30	2,018	1,748	Bedfont Lakes to Pskov Russia
H8829	Female	2017-04-20	2019-05-10	1,189	750	Druridge Bay Northumberland to Poland

Analysis of the bearings between ringing recovery locations (assuming a straight-line travel trajectory) indicated a statistically significantly uniform distribution of bearings, i.e., the probability of these bearings being so similar, merely by chance, is highly unlikely (Rayleigh-test, *R* = 0.5971, *P* = 0.024, n = 8; Fig. 10).

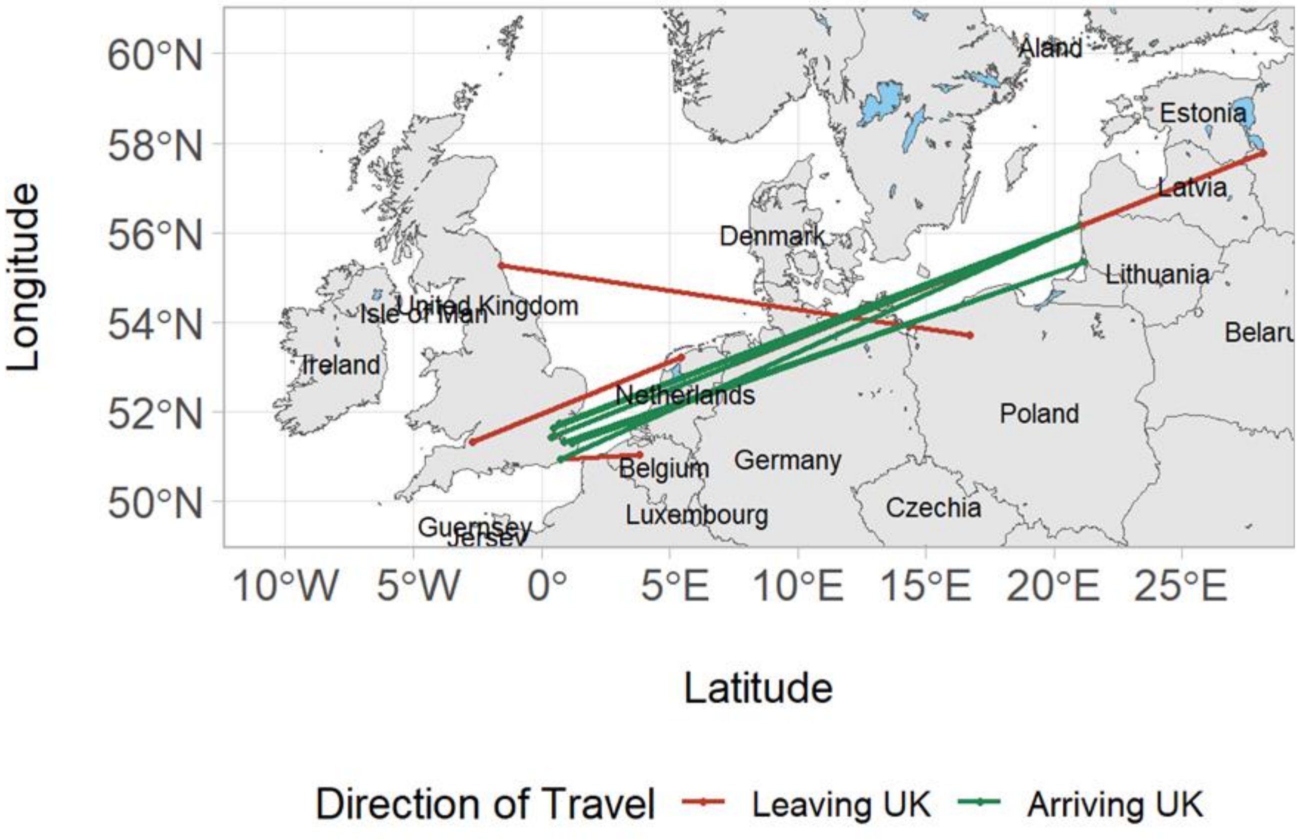

Figure 9. Map of *P. nathusii* international ring recovery locations and straight-line travel trajectories

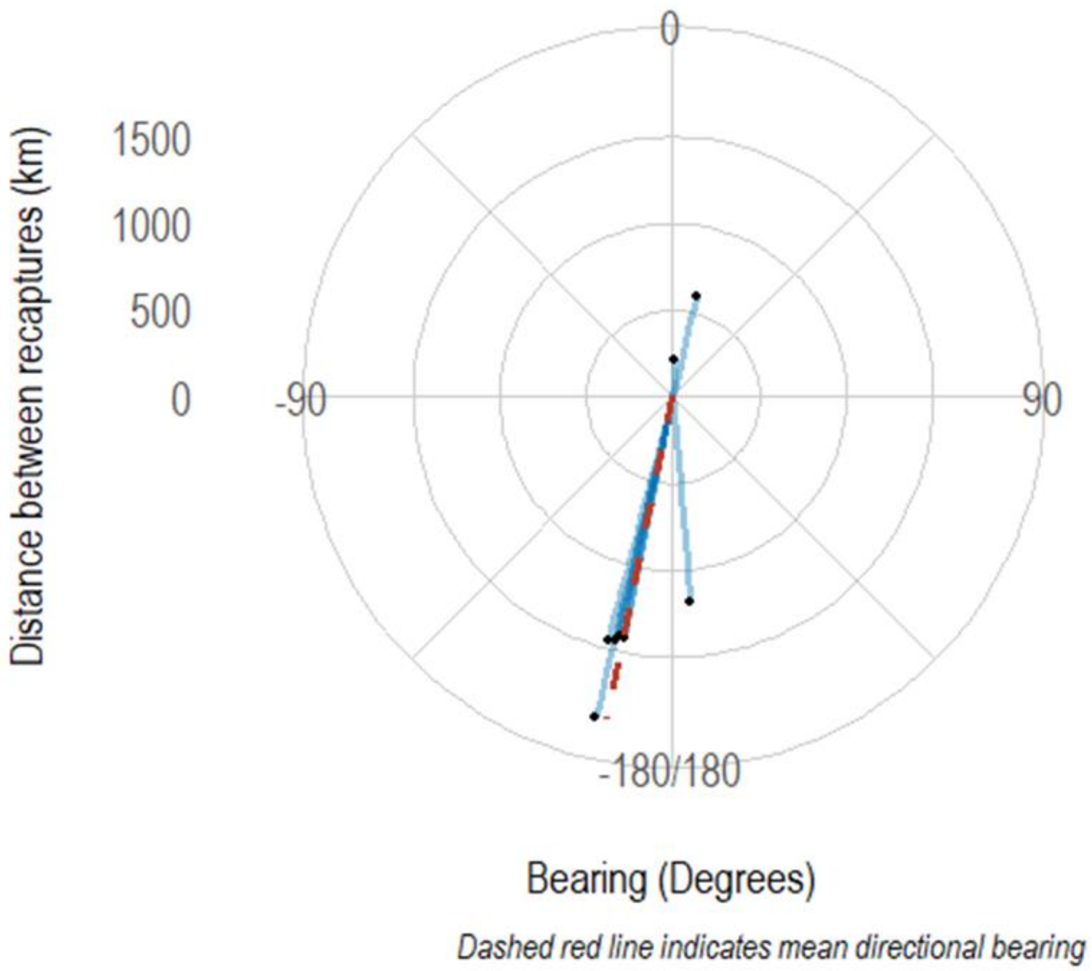

Figure 10. ***P. nathusii*** **international ring recovery bearings**

3.4 Within-GB ring recoveries of *P. nathusii*

Between January 2013 and September 2023, 132 individual ringed *P. nathusii* were recovered in the GB that had been ringed within GB. Of these the majority (n = 117) were recovered within 3 km of their original position. The remaining 15 ring recoveries exceeded this 3 km radius (Fig. 11); the median distance between these recoveries was approximately 11 km, however five individuals made substantially longer journeys of approximately 113 km, 80 km, 60 km, 35 and 34 km. The majority of recoveries in excess of 3 km were of adult male *P. nathusii*.

As with the international ring recovery bearings, analysis of the bearings between GB capture locations (assuming a straight-line travel trajectory) indicated a significantly uniform distribution of bearings (Rayleigh-test, R = 0.445, P = 0.002, n = 15; Fig. 12).

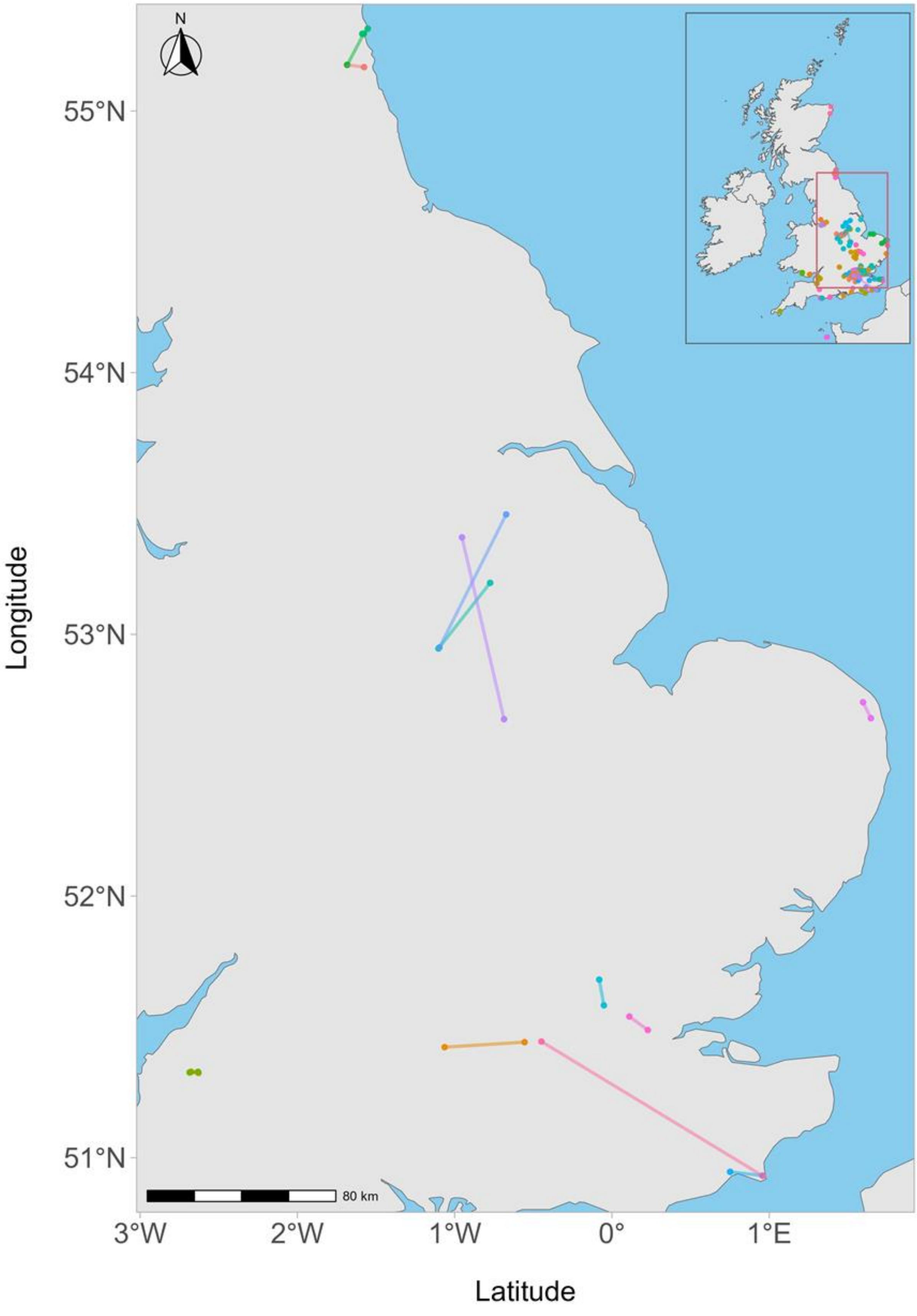

Figure 11. Map of *P. nathusii* GB ring recovery locations and straight-line travel trajectories

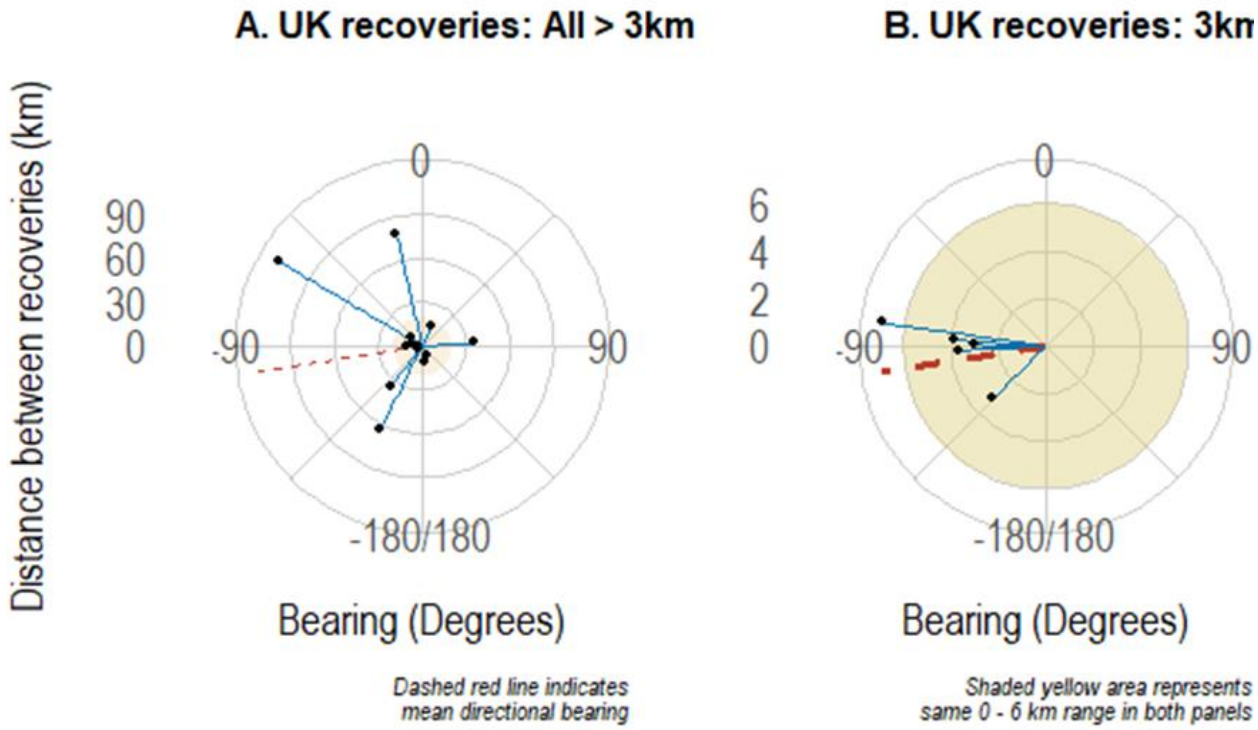

Figure 12. ***P. nathusii*** **within-GB ring recovery bearings. Panel A shows all recapture distances that exceeded the estimated 3 km core sustenance zone (CSV) of** ***P. nathusii.*** **However, this scale makes it difficult to appreciate the unimodal distribution of bearings; as such, panel B highlights the uniformity of bearings within a 6 km recapture distance. The shaded yellow areas represent the same geographical radius in both panels.**

4. Discussion

The most frequently caught bat species in this study was *P. pygmaeus,* which reflects the location of capture points adjacent to waterbodies, features with which *P. pygmaeus* are strongly positively associated (Vaughan, Jones & Harris 1997). However, the success of the survey methodology in capturing *P. nathusii* is demonstrated by the fact that they were the second most frequently caught species, despite being rare in Great Britain (Mathews et al., 2018). *P. nathusii* were captured during all months of the survey, confirming this species is present in GB year-round. However, what is not clear from this study is how long individual *P. nathusii* remain resident.

Capture rates of *P. nathusii* were highest at the start of the survey period in early April and again at the end of the survey period in late October. This corresponds with the periods during which migratory individuals are anticipated to be present in GB, having arrived in late summer and early autumn, and departed again in the spring. Seasonal differences in capture rates suggest that more than half the GB population of *P. nathusii* is migratory, and that in October the proportion of individuals that have migrated to the UK is approximately 50:50 female to male. However, this assumes that capture rates are proportional to abundance, which may not be the case, and does not reflect how the sex ratio of the *P. nathusii* population in GB may continue to change after October.

P. nathusii capture rates were higher during the autumn months than in spring. However, the two periods are not directly comparable as in neither period do capture rates show signs of having reached a peak. This suggests that there may be considerable migratory activity beyond the survey period, and that the spring peak of activity may occur in March, before most of the capture surveys undertaken in this study. In future studies we recommend surveying earlier than April and later than October to capture the likely peaks of *P. nathusii* activity in GB.

The seasonal changes in capture rates observed for *P. nathusii* contrast with those observed for *P. pygmaeus* and *P. pipistrellus*, both species with large breeding populations in GB, providing further support for the presence of migration in the GB population of *P. nathusii*. *P. pygmaeus* and *P. pipistrellus* were captured at highest rates during the summer months, corresponding with the period during which females in particular are most active as they raise young. Capture rates were lowest in October as bat activity reduced with falling overnight temperatures.

Capture rates of *P. pipistrellus* showed a notable decline in July, followed by a recovery in August. It is not clear what caused this decline; however, it corresponds with the peak capture rates for *P. pygmaeus*. *P. pipistrellus* is relatively plastic in its foraging habitat preferences (Vaughan, Jones, and Harris 1997), whereas *P. pygmaeus* has much narrower foraging preferences, so it may be that competition with *P. pygmaeus* results in more *P. pipistrellus* choosing to forage away from waterbodies during the peak of the breeding season.

Almost three and a half times more male than female *P. nathusii* were caught during the survey. This contrasts with *P. pygmaeus* and *P. pipistrellus*, for which more females were caught than males. It is possible that the use of an acoustic lure can bias the sex ratio of captured bats if the sexes respond differently to the acoustic stimuli, in this case a *P. nathusii* advertisement call. However, if the higher capture rate of male *P. nathusii* seen in this study was due to an increased likelihood of being attracted to the acoustic lure, we would expect male capture rate to change at a greater rate than female capture rate (as, for example, an increase in the abundance of male *P. nathusii* would result in a proportionally greater increase in the capture rate of males). However, in this study the capture rate of male and female bats changed at similar rates over the survey period, suggesting that the relative numbers of male and female *P. nathusii* caught in this study reflect an actual difference in the population of this species.

Capture rates suggest that while almost all of the female *P. nathusii* present over winter leave GB in the spring, a proportion of males do not. This supports the hypothesis that male *P. nathusii* are more likely to remain in GB over the summer as they do not have to migrate to breeding grounds and raise young, having already mated with females in the autumn.

More male than female *P. nathusii* were captured at both coastal and inland locations, however, on average, a higher proportion of female *P. nathusii* were captured at coastal sites than at inland sites. This was the case throughout the year, although the 95% confidence interval of these estimates overlapped between April-August. A separate trapping study at a location immediately on the coast in Suffolk, following similar methodology to the NNPP, captured more female than male *P. nathusii* in spring (J. Harris, pers. comm., 25th March 2023). Together, these observations suggest that female *P. nathusii* have a greater tendency to be found in coastal areas, whereas males are more likely than females to travel and remain inland.

The sex ratio of *P. pygmaeus* and *P. pipistrellus* captured across the survey period differed markedly to *P. nathusii*. Whereas more females than males were caught between April and September, the difference narrowed and eventually reversed, with slightly more males than females caught in October. This corresponds with the greater energy demands experienced by females during the summer breeding season, and greater activity by males in the autumn mating season. There was also no evidence that the sex ratio of *P. pygmaeus* or *P. pipistrellus* differs between coastal and inland sites.

The capture rate of juvenile *P. Nathusii* also differed from that of juvenile *P. pipistrellus* and *P. pygmaeus*. In this study, juveniles were identified using the degree of ossification of the epiphyseal joints in the finger bones. These joints will normally be fully ossified around 12 weeks after birth, so this technique can only distinguish juvenile bats in the summer and autumn months. As such, no juveniles of any species were reported during surveys in the pre-breeding period. The first juvenile *P. pygmaeus* and *P. pipistrellus* were caught in July, and capture rates peak in July (for *P. pygmaeus*) or August (for *P. pipistrellus*). The juvenile capture rate of these two species then declines over September and October, mirroring a similar decline in adult capture rates as bats reduce foraging activity as temperatures cool. The reverse pattern is seen for juvenile *P. nathusii*. A very small number of juvenile *P. nathusii* were caught across the whole survey in July and August, when it is more likely that juvenile bats will have been born locally, rather than having migrated from breeding locations outside GB. This provides evidence that *P. nathusii* do breed in GB, however the extremely low numbers of juveniles caught during the breeding season suggest breeding attempts may be infrequent and sporadic. Juvenile *P. nathusii* capture rates increased over autumn and were highest in October. This follows a similar pattern to the capture rates of adult *P. nathusii* in the post-breeding period and suggests that the majority of juvenile *P. nathusii* captured in GB have likely migrated from elsewhere.

Seasonal patterns in body condition also vary between *P. nathusii* and the two resident *Pipistrellus* species. Body condition of *P. pygmaeus* and *P. pipistrellus* follow a similar pattern over the year, being lowest in the period post-hibernation, recovering over spring and early summer, plateauing or dropping during the period when females are giving birth and lactating, then increasing again over autumn, reaching a peak as hibernation approaches. There is little difference in body condition or trends in body condition by sex. The body condition of female *P. nathusii* follows a similar pattern to that observed in *P. pipistrellus* and *P. pygmaeus*, although the large confidence intervals around the trend reduce certainty. The pattern of body condition in male *P. nathusii* is markedly different to female *P. nathusii*, and to the other *Pipistrellus* species of both sexes. As with the other *Pipistrellus* species it is at its lowest post-hibernation, but then increases rapidly to a peak in August before declining slightly in autumn. This may reflect the poorer body condition of individuals arriving in GB from continental Europe, or a strategy by which male *P. nathusii* build body condition in preparation for the mating season, then lose condition while advertising for females. It does not show a plateau or decline during the breeding season, as seen in female *P. nathusii* and in other *Pipistrellus* species of both sexes. In this study we estimated body condition using a combination of body weight and forearm length, so giving birth and the demands of lactation will result in a significant reduction in body condition for female bats. Interestingly body condition also plateaus or declines over this same period for male *P. pipistrellus* and *P. pygmaeus*. Previous studies suggest that male bats may be displaced to less suitable habitat by females (Lintott et al., 2014; Senior, Butlin, & Altringham, 2005). Competition with female conspecifics may therefore result in lowered body condition in males over the summer months. This may also explain why a similar impact on body condition is not observed for male *P. nathusii*. This study suggests that the population of *P. nathusii* in GB over the summer months is almost entirely male, and so it may be that males present in GB over the summer avoid the impacts of competition they face in areas with a higher population of females. In this way they may escape the competitive pressures that prevent body condition in male *P. pygmaeus* and *P. pipistrellus* from increasing in a similar fashion.

Four *P. nathusii* ringed in GB were recovered in central or eastern Europe or Russia, and six *P. nathusii* ringed in Latvia or Lithuania were recovered in GB. This represents the first direct evidence of long-distance movements of *P. nathusii* from central and eastern Europe to GB. The timing and uniformity of bearing of recoveries correspond with the known migratory movements of this species within Europe and confirm the migration of this species into and out of GB. However, these recoveries represent only part of the species' migratory pathway, which may extend further east and west of the locations recorded here. It is also not clear from the recovery data which routes the bats followed between capture locations, and in particular which route they took to cross the sea when entering or leaving GB.

Most recaptures of ringed *P. nathusii* were over comparatively short distances and time periods. This reflects the fact that trapping effort was concentrated around particular waterbodies and indicates that a proportion of *P. nathusii* remained in or near the site where they were first captured for a period afterwards. Although trapping effort was minimal outside of survey sites, there were 15 recaptures of ringed individuals beyond the typical mean-maximum foraging radius of *P. nathusii* (3 km), and five recoveries further than 30 km from their ringing location. Movements across these distances are more likely to represent dispersal, and uniformity of bearing analysis showed they were significantly more likely to be in a westerly direction, so may represent the continuation of migration within GB.

5. Acknowledgements

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Annex A. Surveyor documents: National Nathusius' Pipistrelle Project 2022 Survey Methods

A.1 Aims of trapping surveys

Our aim with these surveys is to provide evidence to confirm the resident and breeding status of Nathusius' pipistrelle in Great Britain, to identify the migratory pathways of this species and to gather further information on the distribution of Nathusius' pipistrelle in Great Britain and the Channel Islands.

A.2 Objective of trapping surveys

The objectives of the trapping surveys vary depending on the time of year:

- Pre-breeding season (April – approx. mid-June): To capture female Nathusius pipistrelles and, if resources are available, track them back to their roost.

- Post-breeding season (Approx. mid-July – early August): To capture post lactating females and /or recently volant juveniles which are unlikely to have migrated to the site and likely to have been born locally.
- During the migration season (August – October): To recapture migrating Nathusius pipistrelles that have been ringed outside of the British Islands. We aim to concentrate trapping effort during the migrating season at key sites to maximise coverage, as advised by the project co-ordinators.

A.3 Site selection

Each group should select their own sites for survey.

To make most efficient use of resources trapping should be undertaken at sites where the presence of Nathusius' pipistrelle has previously been confirmed using acoustic surveys within the last few years. Ideally this should be represented by multiple individuals in consecutive years.

If the site has been trapped previously and Nathusius' pipistrelles were caught it is a priority to repeat these sites to see if ringed bats are recaptured. However, after multiple years do consider whether there is more to be gained at that site in line with project aims.

Nathusius' pipistrelle is generally associated with woodland (deciduous and mixed) and waterbodies, and also wetlands such as reedbeds in some areas (this is possibly more relevant to Mediterranean areas). It forages on small Diptera, particularly midges (mainly Chironomidae) and also mosquitoes.

Modelling of UK records of Nathusius' pipistrelle has shown that the following are important factors in affecting presence of this species (Lundy et al. 2010):

- the area of the waterbody;
- the area of woodland;
- and presence of small areas of urbanization.

Areas of heathland/ peat appear to be avoided. This is based mainly on records of migrating bats and peaks in occurrence appear to occur in spring and autumn. In selecting sites for this project the following should be taken into account:

- Look for larger waterbodies such as lakes and reservoirs.
- Freshwater coastal sites and large rivers on migratory paths.
- Presence of woodland near waterbodies is ideal – and important for selecting trap locations.
- Select waterbodies with existing records (e.g. from bat boxes, bat detector records including NBMP Nathusius' pipistrelle Survey) to maximise chances of catching this species.

- Suitable access to the site for trapping is important as well as landowner permissions.

How to look for sites:

- Use Google Earth and OS maps to search for large waterbodies.
- Look at water company websites to find locations of lakes and reservoirs.
- Look at existing Nathusius' pipistrelle records, for example on the NBN Atlas.
- At sites where Nathusius' pipistrelle has not been confirmed within the last few years, carry out acoustic surveys in spring during April and May and/or in the Autumn (recordings need to be made and verified to confirm presence of Nathusius' pipistrelle) before trapping begins, to help ensure this invasive technique is targeted at sites where this species is known to occur.
- Check on landownership for access information, for example via the local council or land registry office, there may be small fees involved.
- Visit potential sites for a daytime recce to assess habitat and potential trapping locations (see below). Ensure daytime visits are carried out with landowner permission if it is necessary to visit areas that do not have public access.

It would be useful to have additional sites lined up as back up sites in case of any problems with the selected sites.

A.4 Survey timing

Ideally each site should be surveyed twice, once in the pre-breeding period and once in the post-breeding period. However, surveying in one of those periods alone can still produce useful data.

Please consider local factors for deciding when trapping can begin, when it should be suspended to avoid disturbing bats in the latter stages of pregnancy and birth, and when it can be resumed again following breeding (for example, spring weather/temperatures can influence the timing of pregnancy and birth).

Stop trapping for that period if a pregnant bat of any species is caught.

A.5 Trap site selection

For each site to be surveyed, at least two trap locations should be identified. It is best to do this during daylight hours prior to the first survey visit to assess optimal trap locations and complete risk assessments. The following should be considered when selecting trapping sites:

- The two sites should be ideally more than 200m apart.
- It is preferable that the traps are as close to the water as possible.

- Traps need to be hidden in vegetation, with ideally a tree either side of the supports.
- Where there are no trees, place the trap in tall vegetation that box the trap in.
- On colder nights concentrate more in woodland surrounding water bodies.
- The surrounding area provides ample space for volunteers to operate with appropriate distancing for themselves and the bats.

A.6 Surveys

At least one bat group coordinator named on the licence needs to be present for each evening survey, two if possible. Ideally 4-6 surveyors are needed for each survey visit. You can find more details on survey protocol in the Bat Surveys for Professional Ecologists: Good Practice Guidelines, downloadable here: https://www.bats.org.uk/resources/guidance-for-professionals.

Use the National Nathusius' Pipistrelle Project 2022 Recording Sheet to record information about the site and bats trapped.

Equipment needed for survey:

- 2x harp traps
- One acoustic lure for each harp trap
- 2x 2-way radios
- Clean holding bags
- Bat rings and circlips if ringing
- Processing kit with callipers, plastic wing ruler and scales
- Personal Protective Equipment (PPE) including additional gloves and masks
- Clipboard and recording sheets
- Camera
- Detector to check lure output
- Folding table and chairs
- Weatherproof boxes to store equipment

Setting up the equipment:

1. Find each selected trap location and put up traps. On the recording sheet note the OS grid reference of each trap location (to 1m resolution if possible-two letters and ten digits). This can be done in the field using a GPS or afterwards using the website. http://www.gridreferencefinder.com, which allows you to click on an aerial photo and will provide the ten figure grid reference. Please also note the equipment used including lure and call, the predominant habitat at the trap site using the categories given on the recording sheet and a short description of the trap placement.

2. Follow the instructions from the lure on placement on the trap. Correct placement is very important in its effectiveness. Generally keep it closer to the catch bag.
3. If suitable use the supplied WAV. File “Nathusius Advertisement call”.

The survey:

1. Pick a site away from the traps to set up your processing station.
2. Start surveys at sunset by connecting speakers and switching on lures (see above).
3. Record date, site name, grid reference (general reference for waterbody), name of survey organiser and names of other surveyors on the Recording Sheet.
4. Record temperature and weather conditions at the start of the survey.
5. Cloud: Clear (0-1/3 cover), Partly cloudy (1/3-2/3 cover) or Full (2/3 to complete cover).
6. Moon phase: New, quarter, half, three quarters, full.
7. Wind: Calm, Light breeze, Blustery, Strong.
8. Rain: None, light, constant drizzle. Note: Surveys can continue in light rain but if rain becomes heavy, or begins to wet the trap and/or pose a threat to the bats and the equipment, stop the survey. If it clears later, you may start again.
9. Check traps regularly (at least every 15 mins).
10. Surveys last at least 2 hrs, longer if possible. Surveys can be extended for as long as you like or as long as the lure battery will allow if you wish to stay out longer. When trapping during migration, consider where the bats will be travelling from and how long it might take them to reach your location.
11. Record temperature at the end of the survey.
12. Add any additional comments about the site or survey in the comments box on the Recording Sheet.

Processing bats:

For each bat caught enter the following information on the recording sheet (a-d should be ascertained in the hand):

a. Time caught
b. Species
c. Age: adult or juvenile
d. Reproductive status:
    i. ♀ = Parous, Non parous, Lactating, Pregnant
    ii. ♂ = Testes size (small, medium or large) and Epididymis colour (Pale, dark, patchy).
e. Only for target species (if unsure of species ID take measurements):
    i. Forearm measurement
    ii. Fifth finger measurement
    iii. Weight of bat
    iv. If licensed to do so, follow ringing protocol and ring the bat.

If you capture a female Nathusius' pipistrelle in the pre-breeding season:

Ideally any females caught in the pre-breeding season that are in good health, of a suitable weight and not heavily pregnant should be radio-tagged and tracked back to their roost. Emergence surveys at any roosts identified should be undertaken throughout the breeding season to identify the number of Nathusius' pipistrelle occupying the roost and, where possible, confirm breeding. If you would like more advice on this, please contact the project coordinators.

After each survey:

1. Traps should be checked to ensure they were not put away wet etc. Please also check the strings and replace as necessary.
2. All reusable equipment including traps, nets, containers, bags or callipers that have been in direct contact with bats should be disinfected between uses to promote good field hygiene. For more advice on read box 1 (field hygiene) and 3 (disinfectants) in the IUCN's Recommended Strategy for Researchers to Reduce the Risk of Transmission of SARS-CoV-2 from Humans to Bats AMP: Assess, Modify, Protect. Found under 'Bat Researchers' on this webpage: https://www.iucnbsg.org/bsg-publications.html.
3. Both the lures and spinner batteries need to be charged after each survey in accordance with manufacturer's instructions.

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