

Directional variation and method-specific detection patterns in offshore bat migration

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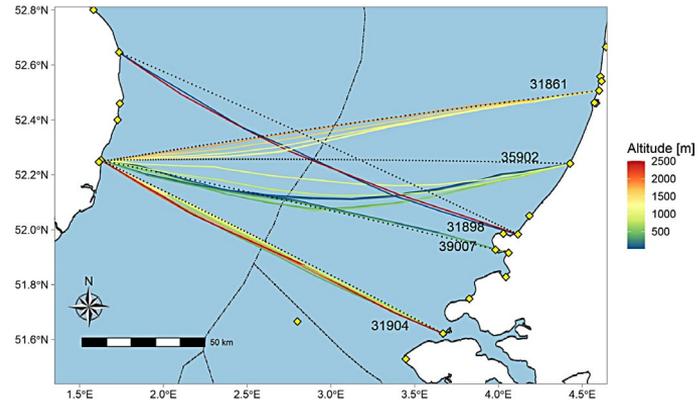


Bats & Wind Energy

- Mortality due to collisions, in some cases barotrauma
- Most fatalities concern migratory species and occur late summer/autumn
- In Germany 250.000 and in the U.S. 600.000 fatalities per year. In the Netherlands 5-10 per wind turbine per year on land and 0-1 (presumed) at sea.
- Reduction of the number of fatalities:
 - Spatial planning
 - Operational measures (curtailment)
 - Deterrents

Bats at sea

- Nathusius' pipistrelle is the most common migrant at the North Sea
- Migration likely occurs at altitudes of several hundred meters during moderate supportive winds, low-altitude migration occurs when wind conditions are less favourable (general low or high wind speeds, headwind or crosswind).
- Diurnal stopovers at offshore platforms and wind turbines regularly occur



Protection of bats at sea

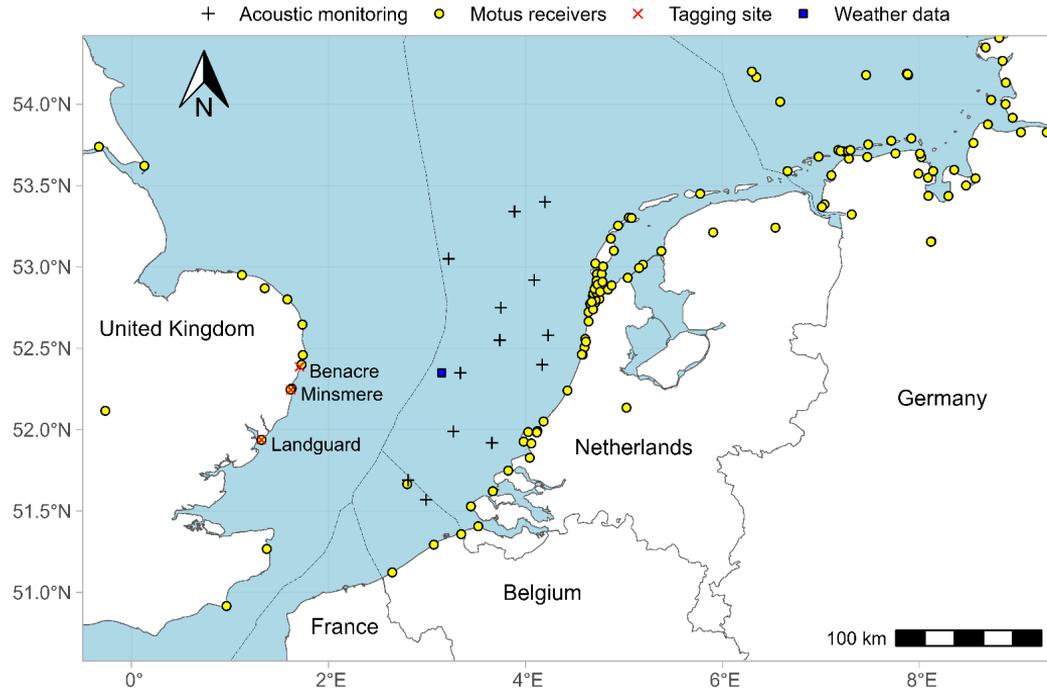
- Curtailment is currently the only feasible option
- Requires knowledge on the spatiotemporal occurrence and environmental predictors of migration over sea
- Available monitoring techniques:
 - acoustic monitoring
 - individual tracking
- However, seemingly contradictory insights into migration patterns



Aims current study

- Examine the species' spring occurrence throughout the season and the night
- Identify environmental conditions serving as migratory cues
- Compare patterns observed across monitoring methods to explain both differences and consistencies in detected occurrence
- Recommend mitigation strategies for offshore wind farms to reduce collision risk

Study area & effort



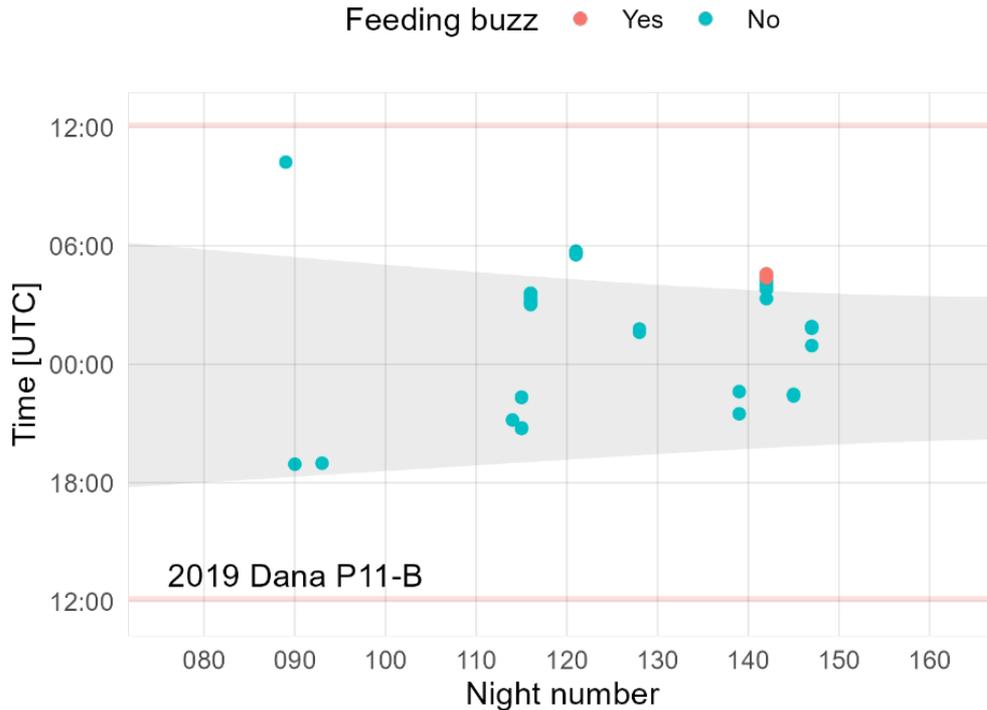
Acoustic monitoring:

- 13 locations
- 2018-2021
- 4309 monitoring nights in spring

Tracking:

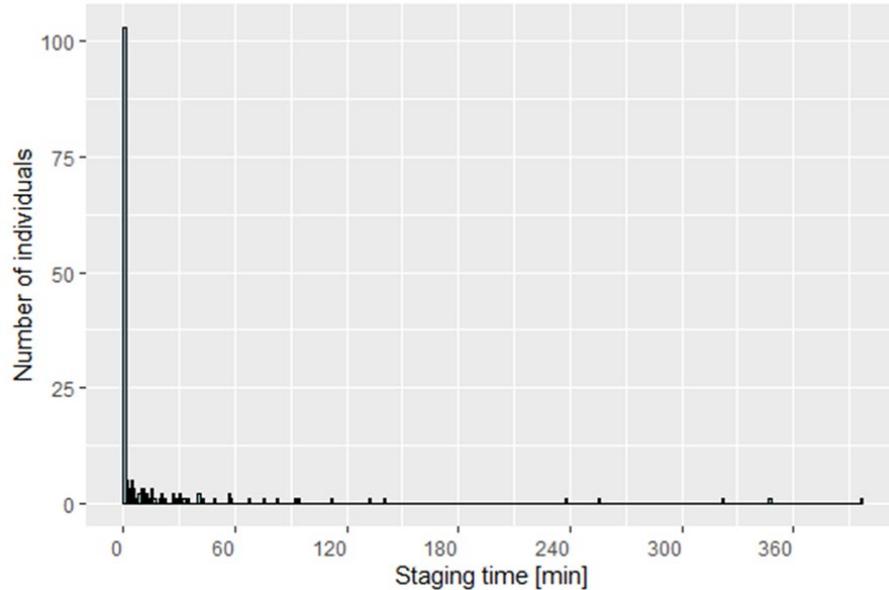
- East coast UK
- 2021-2023
- 123 bats tagged

Acoustic monitoring (recordings)



- Bats were recorded at all monitoring locations, though not every year
- Regular arrivals in daylight hours
- 2777 recordings, including 152 (5.5%) with feeding buzzes
- From recordings to individuals using a two-hour interval without bat activity (n=172)

Acoustic monitoring (individuals)

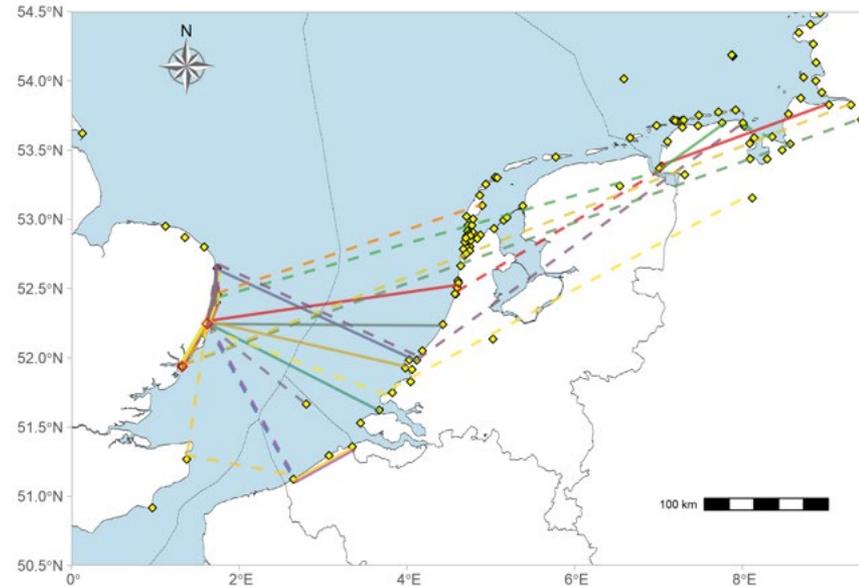


Generally briefly recorded:

- 60% less than 1 min
- 9% between 1 – 5 min
- 10% between 5-15 min

Tagging and tracking

- 123 bats: March (2), April (33), May (78)
- 27 individuals detected on European mainland
- Night of crossing known for 10 individuals (8 with known departure and arrival time)

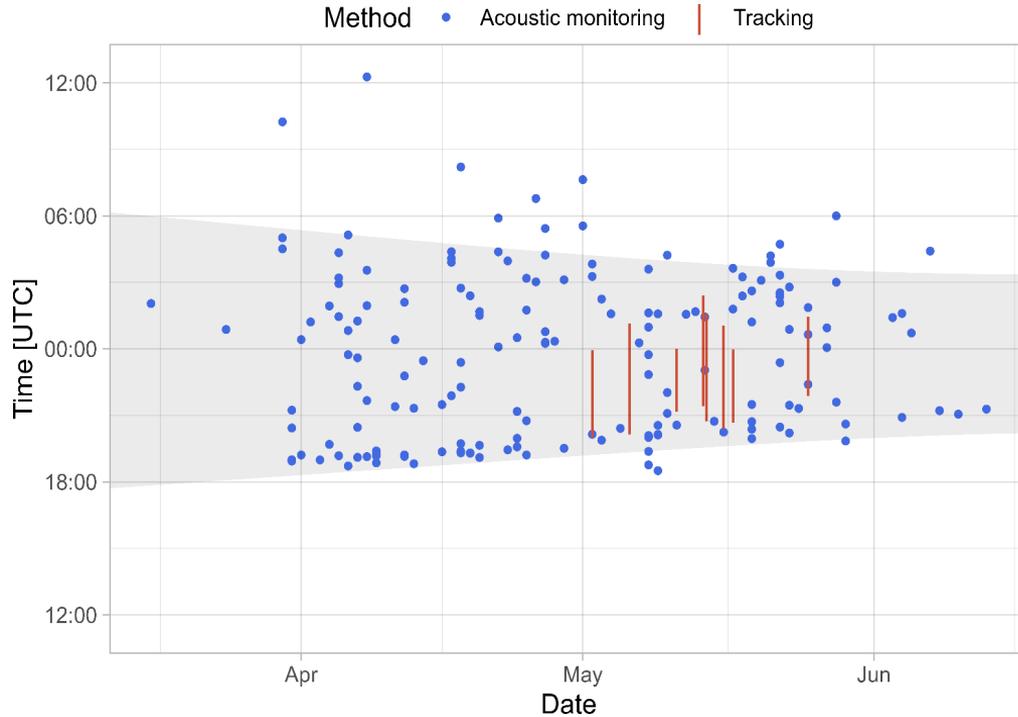


2021 & 2022 tracks (Lagerveld et al 2024)

Analysis

- Compare seasonal and nocturnal patterns of spring occurrence across monitoring methods
- Probability of migratory departure across nights in a capture-recapture model in state-space formulation to identify environmental conditions serving as migratory cues:
 - Acoustic model: night number, windspeed, wind direction, period, temperature, atmospheric pressure change, cloud cover, precipitation and lunar phase
 - Tracking model: night number, windspeed and wind direction
 - Wind data at 200 m above sea level

Seasonal and nocturnal bat occurrence



(Lagerveld et al 2026)

Acoustics:

- Occurrence mid-March-mid June, most bats in April (50%) and May (39%)
- Mainly around sunset (37%), around sunrise or later (40%)
- Arrival time does not depend on season and spatial location

Tracking:

- Crossings from early May until early June
- Median departure: 59 min after sunset
- Median arrival: 171 min before sunrise
- Median duration: 258 min

Environmental conditions

Simplified tracking model:

Probability of stay_{i,t} = $\text{logit}^{-1} (\beta_0 + b_i + \beta_1 \times \text{night}_t + \beta_2 \times \text{windspeed}_{i,t} + \beta_3 \times \text{windspeed}_{i,t}^2 + \beta_4 \times \cos(\theta_{i,t}) + \beta_5 \times \cos(\theta_{i,t}) \times \text{windspeed}_{i,t})$

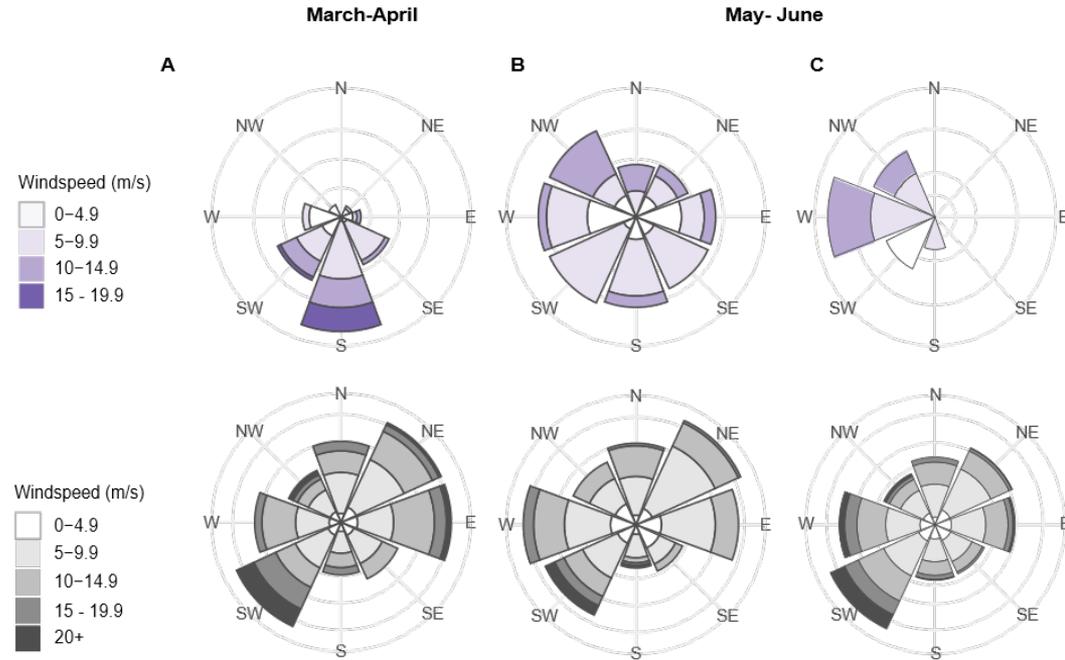
Simplified acoustic model:

Probability of stay_{i,t} = $\text{logit}^{-1} (\beta_0 + b_i + \beta_1 \times \text{night}_t + \beta_2 \times \text{windspeed}_{i,t} + \beta_3 \times \text{windspeed}_{i,t}^2 + \beta_4 \times \cos(\theta_{i,t}) + \beta_5 \times \sin(\theta_{i,t}) + \beta_6 \times \sin(2\theta_{i,t}) + \beta_7 \times \text{windspeed}_{i,t} \times \cos(\theta_{i,t}) + \beta_8 \times \text{windspeed}_{i,t} \times \sin(\theta_{i,t}) + \beta_9 \times \text{windspeed}_{i,t} \times \sin(2\theta_{i,t}) + \beta_{10} \times \text{periodI} + \beta_{11} \times \text{periodI} \times \sin(\theta_{i,t}))$

Lunar phase, cloud cover, precipitation, atmospheric pressure change and temperature not significant

Environmental predictors

- Early season acoustic bats in generally strong southerly winds (median 8.5 m/s; IQR 5.9–12.7 m/s)
- Late season tracked bats in moderate western or northwestern winds (median 7.0 m/s; IQR 5.4–11.2 m/s)
- Late season acoustic bats in lower westerly and northwesterly winds (median 6.6 m/s; IQR 3.0–9.9 m/s), in southern winds (median 5.9 m/s; IQR: 5.2–7.5 m/s) and from the east (median = 3.4 m/s; IQR 3.4–5.6 m/s).



Conclusions

- Seasonal timing and wind conditions are the key predictors of offshore spring migration.
- In March and April migration from the UK to the mainland appears to be rare or absent. Early season bats at the southern North Sea likely refer to wind-drifted bats from the mainland.
- In May–June, most bats migrated from the United Kingdom under westerly and northwesterly tailwinds. Tracked individuals flew in stronger supportive winds than acoustically recorded bats, which were also detected under crosswinds and headwinds.
- Acoustic detectors primarily recorded bats that landed on offshore platforms, likely because they were unable to cross the North Sea in a single flight due to less favorable wind conditions, or because they departed from more inland locations.

Conclusions

- Combining observation techniques improves our understanding of bat migration patterns
- Acoustic monitoring can capture migration from different geographic origins
- Current mitigation measures for offshore wind farms at the North Sea rely solely on acoustic data, likely overlooking the part of the population that crosses over sea with optimal wind support.
- Acoustic and tracking data are therefore complementary rather than contradictory, and both methods should be used together when developing mitigation measures.

Available as preprint

[https://www.biorxiv.org/content/
10.64898/2026.02.06.704313v1](https://www.biorxiv.org/content/10.64898/2026.02.06.704313v1)

1 **Directional variation and method-specific detection patterns in offshore bat**
2 **migration: implications for wind farm mitigation**

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16 **Abstract**

17 1. Curtailment of wind farms effectively reduces collision mortality in bats. Implementing this measure

18 in offshore wind farms requires knowledge on the spatiotemporal occurrence and environmental

19 predictors of migration over sea. In bats, such information can be obtained through acoustic

20 monitoring and individual tracking. However, these techniques provide seemingly contradictory

21 insights into migration patterns.

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