

Inventory of bats at Nordens Ark

Liliana S. Ferreira^{1*}

¹Centre for Ecology, Evolution and Environmental Changes & CHANGE - Global Change and Sustainability Institute, Department of Biology, Faculty of Sciences, University of Lisbon, 1749-016, Lisbon, Portugal
Bolin Centre for Climate Research, Department of Physical Geography, Faculty of Science, Stockholm University, SE-106 91 Stockholm, Sweden.

*Corresponding author. E-mail: liliana.ferreira@natgeo.su.se

Summary

This study summarises an acoustic inventory of bats at Nordens Ark, Sweden, and assesses their activity across different habitats. Passive acoustic monitoring was conducted at 13 sampling points in the wildlife zoo and Ecopark over three nights in July 2026. A total of 3592 bat passes were recorded, confirming the presence of at least seven species: *Eptesicus nilssonii*, *Myotis daubentonii*, *Myotis brandtii/mystacinus*, *Nyctalus noctula*, *Pipistrellus pygmaeus*, *Plecotus auritus*, and *Vespertilio murinus*. Bat activity was detected at all sampling points, with the highest activity and species richness recorded at forest edges. Compared with an inventory conducted in 2013, this study recorded higher bat activity and detected *P. pygmaeus* for the first time at Nordens Ark. The results indicate that Nordens Ark supports a relatively rich bat community and provides valuable habitats for bats.

Introduction

Bats are ecologically very important mammals. The species present in Europe feed on insects and other arthropods, helping to regulate insect populations and acting as top predators within their food chains (Augusto et al., 2024; Ramírez-Fráncel et al., 2022). They are also considered good indicators of ecosystem conservation status because of their high sensitivity to landscape and climate change (Jones et al., 2009). This sensitivity to environmental change is one of

the main reasons why many species are threatened in Europe. In mainland Sweden, up to 19 bat species are present, 14 of which may potentially occur in the study area (de Jong et al., 2020; Russo, 2023).

Bats have low reproductive rates, with females generally producing only one offspring per year, and only a few species may produce two. Together with the late sexual maturity of most species, typically between two and four years, this makes bats particularly vulnerable. As a result, bats and their roost sites are protected in Europe by national legislations and an agreement of

European countries (Agreement on the conservation of bats in Europe, EUROBATS, 1991).

Nordens Ark comprises a wildlife zoo focused on endangered animals and an Ecopark situated in a fjord landscape centred at 58.4°N and 11.4°E. The Ecopark is one of Nordens Ark's largest conservation projects, covering approximately 3 km² of land undergoing restoration, including diverse forest areas and meadows. The project, which began in January 2011, aims to recreate the open, species-rich landscapes of the 18th and 19th centuries, with livestock grazing as one of the key restoration processes. The overall goal is to benefit endangered species and enhance local biodiversity.

Bats are of particular interest in this context, and up-to-date knowledge of the species using this landscape is of great importance. Nordens Ark Ecopark provides potentially valuable habitats for bats, with forest patches, meadows, and water bodies offering suitable foraging areas. Old trees with cavities, loose bark, and rock fissures may also provide roosting opportunities for several species, as indicated by a previous inventory in the area, conducted in 2013 (Boham, 2015).

This study aims to update the acoustic inventory of bat species at Nordens Ark and to elucidate the importance of the different habitats present for these species. The study objectives are to (i) compile an inventory of the bat species present at Nordens Ark, (ii) map their activity and distribution, and to (iii) compare the findings with the results of the previous inventory.

Material & methods

Bat acoustic activity was sampled during the summer, from 12 to 19 July 2026, at 13 points distributed throughout Nordens Ark wildlife

zoo and Ecopark (Fig. 1). The sampling points corresponded approximately to the locations selected for a previous inventory conducted in the summer of 2013 (Boham, 2015), covering all representative habitat types in the area: forest interiors, forest edges near meadows, forest edges near water bodies, and open areas. Each sampling point was located at least 100 m from the other points, reducing the probability of detecting the same individual simultaneously on two recorders (Barataud, 2020).

Passive acoustic methods were used for the inventory, with bat calls recorded using stationary AudioMoth acoustic recording devices (Open Acoustic Devices). The recorders were mounted on natural elements in the landscape, such as tree branches, tree trunks, and shrubs (Fig. 2). They were placed approximately 2 m above the ground, with the microphone directed towards the habitat being sampled. Recorders deployed within forests were placed in uncluttered sites where the canopy was sufficiently open to allow bats to fly between the trees. At forest edges, the recorders were aligned perpendicularly to the edge, so that the microphone field covered similar proportions of forest and open land.

Each site was sampled for three nights under favourable weather conditions: a minimum air temperature of 7 °C (Rydell, 1991), no precipitation, and wind speeds below 5 m/s (Froidevaux et al., 2014). Recorders were programmed to record from 30 minutes before sunset until 30 minutes after sunrise, ensuring that the activity period of all species was included. Recordings were made at a sampling rate of 250 kHz to capture the full frequency range used by the bat species occurring in Sweden. The gain was set to medium to reduce distortions. Recordings were made continuously in 59-minute

periods, with 1-minute intervals without recording, allowing the devices sufficient time to write data to the memory cards.

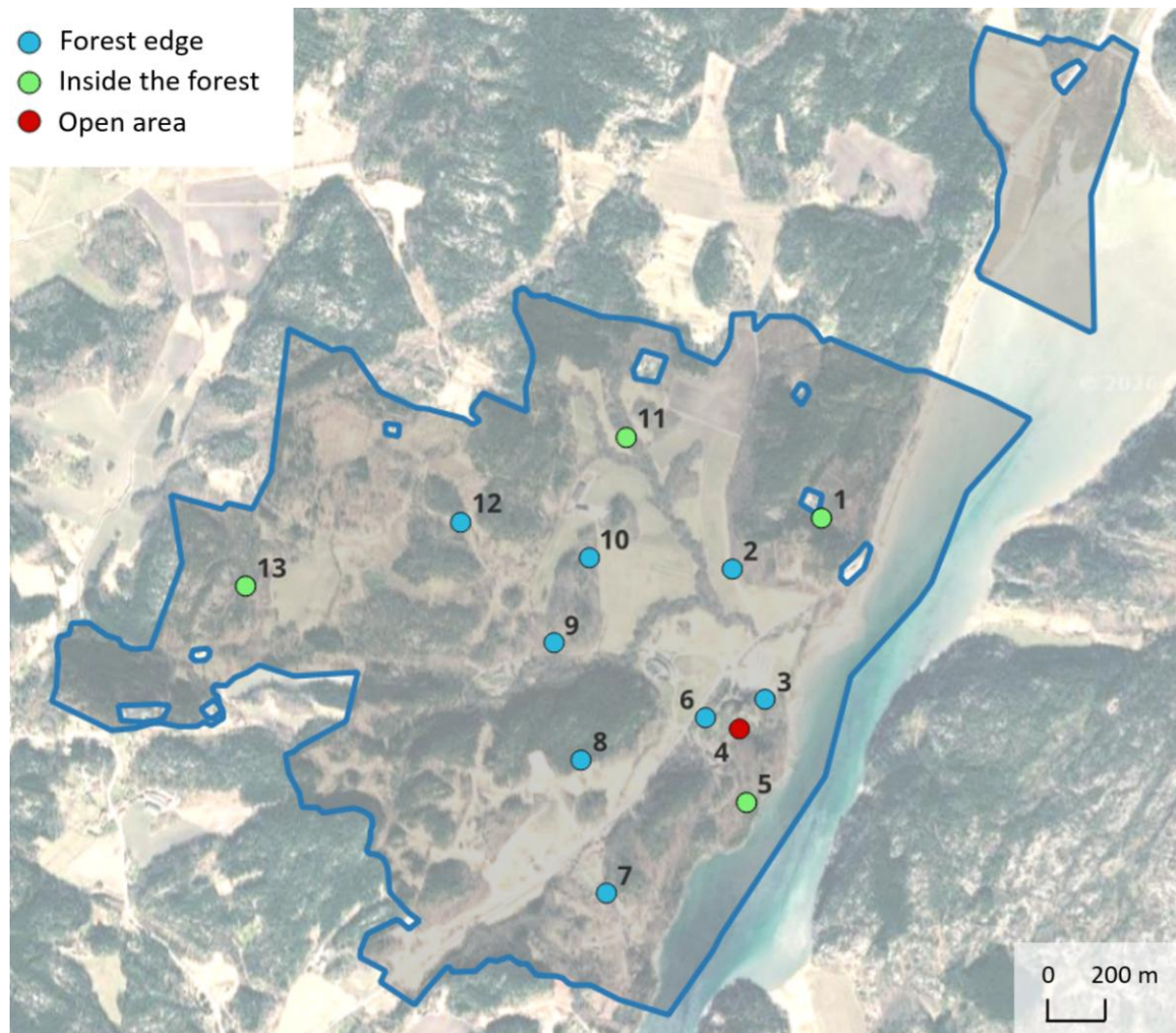


Figure 1. Distribution of points sampled for bats at Nordens Ark. The different colours correspond to different habitats: forest edge, inside the forest, and open area. The blue contour line delimits the Nordens Ark land boundary.

All recordings were analysed using Kaleidoscope Pro v5.3.9 software (Wildlife Acoustics, Inc.). The first step of the analysis was to split the 59-minute sound files obtained in the field into 5-second files. Files without recordings fulfilling the following four criteria were discarded, as they likely did not contain bat calls: pulses within the frequency range of 10-130 kHz; pulse lengths between 1.5 and 500 ms; a maximum interval between pulses of 500 ms; and a minimum of

two pulses. At the same time, the software performed automatic identification of files containing bat calls, using the Bats of Europe classifier version 5.2.1 for Sweden.

All automatic identifications of recorded bat calls were manually verified by observing call shapes on sonograms and measuring five acoustic parameters: frequency of maximum energy (kHz); maximum frequency (kHz); minimum frequency (kHz); call duration (ms); and inter-pulse interval (ms), for at least two

pulses in each bat pass. Identifications to species, genus or sonotype (defined as groups of possible species), were made by comparing measured acoustic parameters with those available in the literature (Barataud, 2020; Russ, 2021).

Species acoustic activity at each sampling site was quantified as the number of passes, defined as the number of times an animal passed through the space sampled by the recorder's microphone. Each 5-second file containing vocalizations was considered one bat pass. Activity at each point was measured as the total number of bat passes recorded over the three sampled nights.

Data analysis was performed using R Statistical Software (version 4.4.2) for the boxplots and QGIS (version 3.40.10-Bratislava) for the maps.



Figure 2. Acoustic recording device used in the inventory. AudioMoth recorders were placed inside protective cases and mounted on natural landscape elements.

Results

A total of 3592 5-second sound files contained bat passes, of which 2160 could be identified to species level or to possible species. In total, the occurrence of at least seven bat species was recorded: *Eptesicus nilssonii*, *Myotis daubentonii*, *Myotis brandtii*/*Myotis mystacinus*, *Nyctalus noctula*, *Pipistrellus pygmaeus*, *Plecotus auritus*, and *Vespertilio murinus* (Tab. 1). The remaining sound files could only be identified to genus level or sonotype: 20 as *Myotis* spp. and 1412 as *Eptesicus* spp. or *Vespertilio murinus*.

M. daubentonii was detected at 12 of the 13 sampled points (Fig. 3), only not recorded in the point sampled at an open area. *E. nilssonii* was detected at 11 points, with no recordings only at two of the points sampled inside the forest. *M. brandtii/mystacinus* was detected at 10 points, with no detections in the open area, one point inside the forest and one forest edge point. These species had the widest distribution across Nordens Ark. The remaining species appeared to be less frequent, although *P. pygmaeus* was also relatively widespread, being recorded at approximately half of the sampled points, seven in total.

Bat activity was recorded at all 13 sampled points, and both the level of activity and the number of detected species varied spatially (Fig. 4; 5). Of the total activity identified to species level, 76.9% corresponded to *E. nilssonii* and 16.1% to *M. daubentonii*. Together, these species accounted for 93% of all recorded passes identified to species during this study. *V. murinus* could only be identified with certainty at one sampled point, as its echolocation calls overlap with those of other bat species and can only be distinguished reliably when characteristic social calls are present (Zagmajster, 2003)

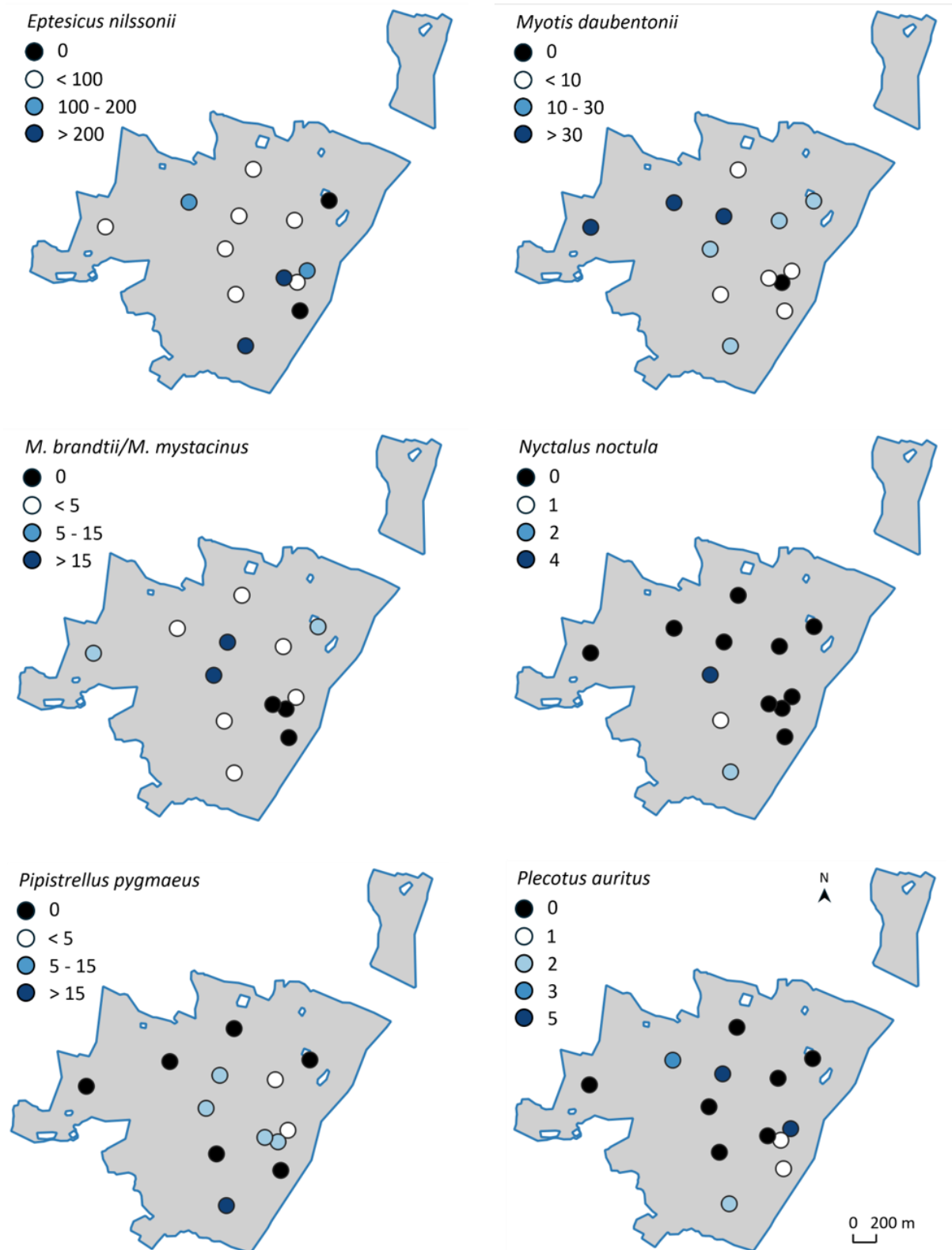


Figure 3. Bat sampling results by species and sampling point. Values indicated correspond to activity (total number of recorded bat passages) for each species or pair of species over the three nights sampled.

Table 1. List of bat species with confirmed occurrence at Nordens Ark during the inventory. Conservation status is defined according to the Swedish Red List 2025 (SLU Artdatabanken, 2026): NT – Near Threatened and LC – Least Concern.

Common name	Swedish name	Scientific name	Status	Habitat
Northern bat	Nordfladdermus	<i>Eptesicus nilssonii</i>	NT	Forest edge Inside the forest Open area
Daubenton's bat	Vattenfladdermus	<i>Myotis daubentonii</i>	LC	Forest edge Inside the forest
Whiskered bat/ Brandt's bat	Mustaschfladdermus/ tajgafladdermus	<i>Myotis mystacinus</i> / <i>Myotis brandtii</i>	LC/LC	Forest edge Inside the forest
Common noctule	Större brunfladdermus	<i>Nyctalus noctula</i>	LC	Forest edge
Soprano pipistrelle	Dvärgpipistrell	<i>Pipistrellus pygmaeus</i>	LC	Forest edge Open area
Brown long-eared bat	Brunlångöra	<i>Plecotus auritus</i>	NT	Forest edge Inside the forest Open area
Parti-coloured bat	Gråskimlig fladdermus	<i>Vespertilio murinus</i>	LC	Forest edge

Discussion and recommendations

This study provides up-to-date information on the bat species occurring at Nordens Ark. In terms of species richness, at least eight different species were recorded in the previous bat inventory conducted in the summer of 2013: *Barbastella barbastellus*, *E. nilssonii*, *M. daubentonii*, *M. brandtii*, *mystacinus*, *Myotis nattereri*, *N. noctula*, *P. auritus*, and *V. murinus*. In the present inventory, at least seven bat species were recorded. One species, *P. pygmaeus*, was detected during the current study but was not recorded in the previous inventory. However, no detections were made of *B. barbastellus* or *M. nattereri*. *B. barbastellus* is at the northern limit of its known distribution in Sweden, and its highly characteristic alternating calls must be recorded to identify the species reliably using acoustic methods. *M. nattereri* emits calls that span from very high to very low frequencies and are easily attenuated by vegetation clutter (Barataud, 2020; Russ, 2021). As this species is known to occur further north in Sweden, it is likely to be

present also around Nordens Ark (de Jong et al, 2020; Russo, 2023).

In addition to the seven species with confirmed presence in the area, it is likely that a few more species remain to be confirmed (de Jong et al., 2020). A study by Ferreira et al. (2026), carried out in a 405 km² area in south-eastern Sweden at the same latitude, revealed the presence of nine different bat species. This highlights that Nordens Ark is relatively species-rich in bats considering its size. The area may also have increased in importance over the 13 years since the previous inventory, due to the Ecopark conservation project and ongoing land restoration, which have restored diverse forest areas and meadows while ensuring careful protection of the area.

Compared with the previous bat inventory (Boham, 2015), a higher number of bat recordings was collected during the present study, with almost 14 times more files containing bat calls: 260 in the previous study compared with 3592 in the present study. Both inventories were conducted for three sampling nights, but in the current study recordings were made throughout the

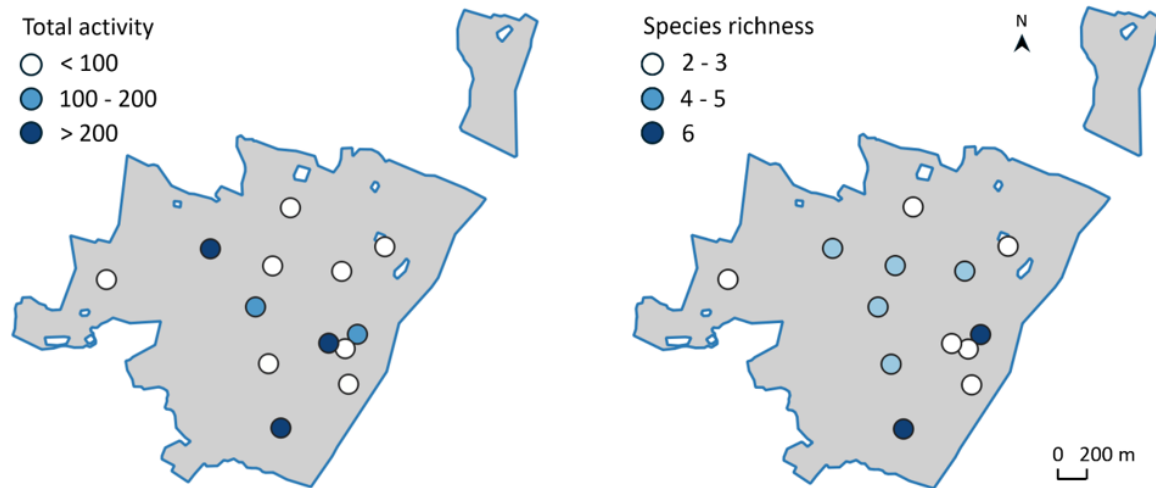


Figure 4. Overall bat sampling results by sampling point. Values correspond to total activity (total number of recorded bat passes) and species richness (minimum number of confirmed bat species) recorded in each sampled point.

entire night, from 30 minutes before sunset until 30 minutes after sunrise. In contrast, the previous study recorded only from sunset until between 01:00 and 02:30, with the duration differing between sampling nights. This difference in recording duration – recording the full night versus only part of the night – most likely contributed to the higher number of recordings collected in the present study.

Regarding the activity of different species in the different sampled habitats (Fig. 5; 6), open habitats were under-represented because only one sampling point was located in an open area, thus limiting comparisons of species activity between habitat types. However, the high activity of *E. nilssonii* in forest edge habitats is worth highlighting. This species is an open space forager, with wings adapted for flight in a range of open habitats, such as forest edges and meadows. It moves across the landscape and hunts mainly in more open environments (Norberg & Rayner, 1987; Rydell, 1992).

Bats were shown to use all existing habitats in the area, although certain habitat features are likely of greater importance. These include diverse forest areas and

flower-rich meadows, which provide food resources, and older trees, which offer potential roosting sites. Habitat type appears to influence both total bat activity and species richness (Fig. 5). According to the analysis, both total activity and richness were higher at forest edges, where the highest number of bat passes, 1599, and the highest number of

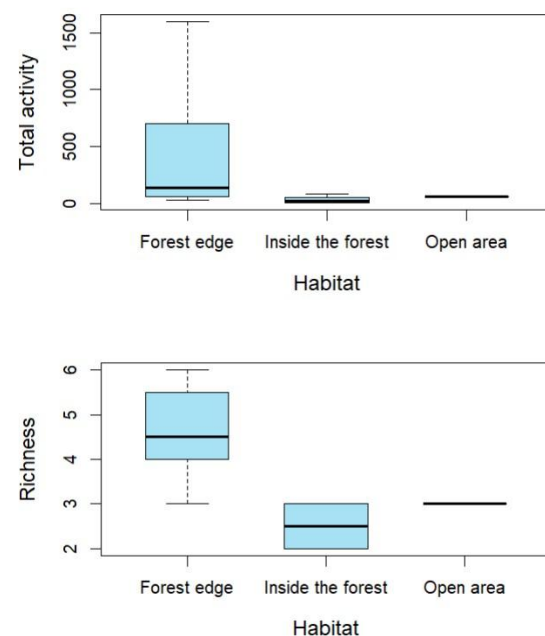


Figure 5. Overall bat sampling results by sampled habitat: total activity (total number of recorded bat passes) and species richness (minimum number of confirmed bat species).

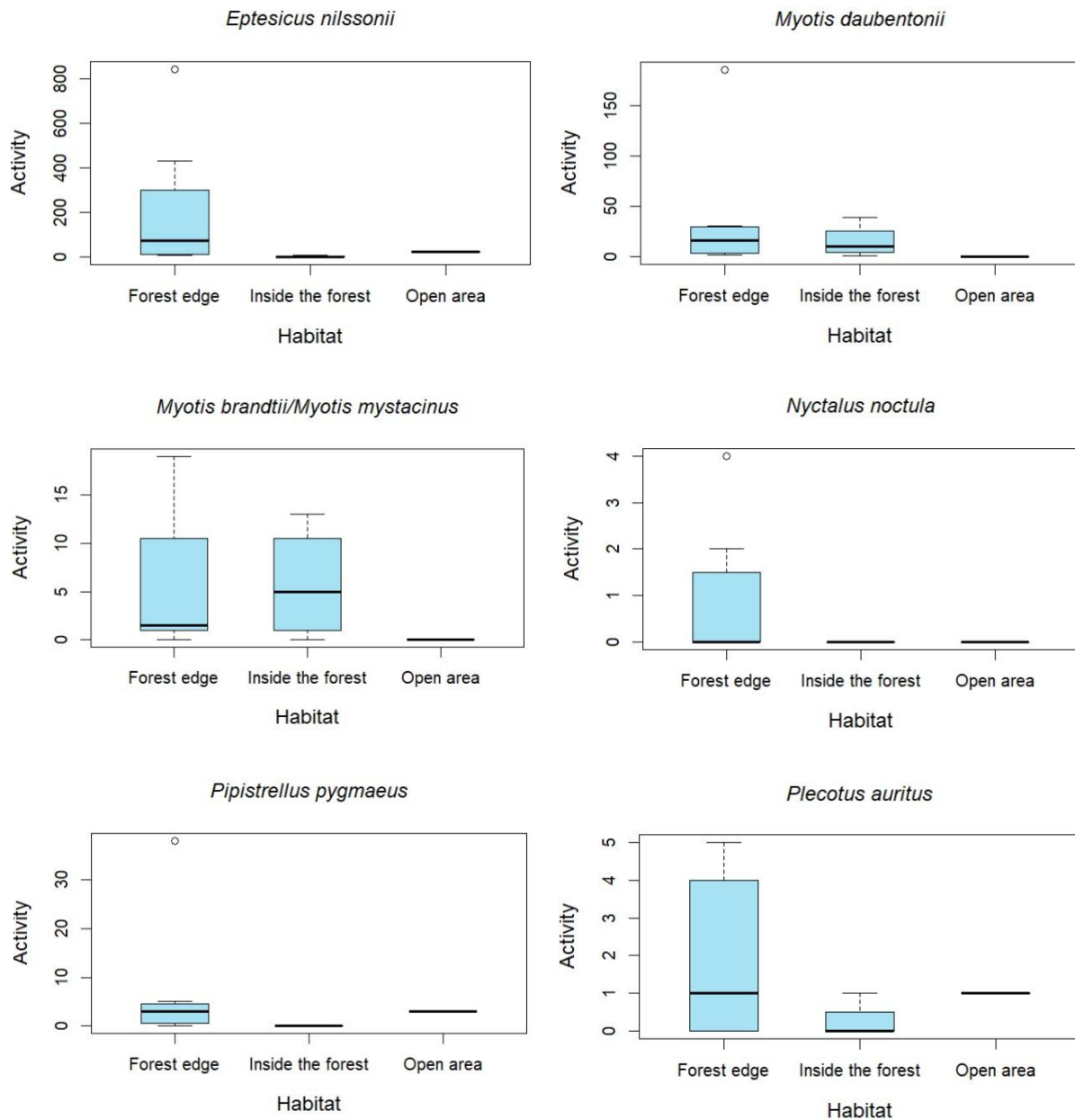


Figure 6. Bat total activity (total number of recorded bat passes) by species and sampled habitat.

different species, six, were recorded. This may partly be due to the microphone orientation, as recorders were aligned perpendicular to the edge, allowing them to record bats flying both within or above the forest interior and over open areas.

The use of acoustic methods for bat sampling is one of the most effective approaches, as it causes no disturbance to the sampled animals and allows large amounts of information on their presence and activity to be collected. However, despite

its clear advantages, this methodology has several limitations. Firstly, different species are not detected equally by the recorders. Species with low intensity vocalisations, such as *P. auritus*, or species with calls covering high frequencies, such as some *Myotis* species, including *M. nattereri*, are less frequently detected. Secondly, the distance at which each species can be detected varies depending on the frequency and intensity of the emitted calls. This means that direct comparisons of activity between different

species cannot be made due to differences in sampling effort. Thirdly, some species cannot be identified to species level using acoustic methods alone, and recordings must therefore be classified into groups of species (e.g. *Myotis brandtii/mystacinus*) (Barataud, 2020; Russ, 2021).

To support bat populations at Nordens Ark, the following conservation and management measures are recommended:

Roosts

- Maintain large trees, especially old trees with holes or cavities.
- Avoid pruning old and large trees during sensitive periods, particularly during the breeding and hibernation seasons.
- Inform technicians responsible for pruning about how to act if bats are found in trees. In such cases, pruning should only be carried out if strictly necessary.
- Protect known roosts.
- Closely monitor potential conflict situations when bats roost in spaces used by humans.

Feeding areas

- Maintain and restore species-rich forest areas.
- Protect and enhance wetlands.
- Promote the responsible use of pesticides.
- Allow understorey vegetation to develop in forest and woodland areas and promote the planting and maintenance of flowers and shrubs that support insect populations.

Movement

- Promote the continuity of green corridors, such as tree lines, and foster the creation of linear landscape structures in nearby urbanised areas.

These features help guide bats during commuting flights and keep them away from busy roads, reducing the risk of traffic-induced mortality during movements between roosts and foraging areas.

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Appendix

Brief description of species with confirmed presence at Nordens Ark

Northern bat (*Eptesicus nilssonii*)

National distribution and status – Classified as 'Near Threatened – NT', the northern bat is the most widely distributed species in Sweden, being the only bat species present almost as far north as the northernmost parts of the country. However, its population size in southern Sweden has been declining in the last decades (Rydell et al., 2020).

Biology - Medium-sized bat distinguishable from other bats by its long, dark fur with golden tips on the dorsal side, and a lighter ventral side (Rydell, 1993). It often roosts in heated buildings, under roofs warmed by the sun, and occasionally chooses abandoned buildings, bat boxes, or tree crevices (Dietz & Kiefer, 2016; Rydell, 1993). The northern bat utilises different habitats opportunistically and may shift from one habitat to another during the season (de Jong & Ahlén, 1991), with open canopy forests being important in northern Europe (de Jong 1994; de Jong and Ahlén, 1991). It is considered a generalist species in terms of insects consumed (Rydell 1986; Vesterinen et al., 2018).

Abundance and distribution at Nordens Ark – Detected at 11 of the 13 sampled sites, and with previous records confirming its presence at Nordens Ark (Boham, 2015), it was the most frequently detected species.

Conservation and management measures – Recent declines in population size in Sweden (Rydell et al. 2020) suggest that the status of the species needs to be carefully monitored and frequently re-evaluated across the northern parts of its range. Essential to the conservation of the species is the availability of well-managed deciduous forests, water bodies and beaver flowages with high insect

productivity (de Jong, 1994; de Jong & Ahlén, 1991). Although feeding near streetlights is common for this species (Rydell, 1992), the maintenance of natural forest and grassland habitats remains essential for its survival, as urban areas may not provide sufficient food sources following the removal of insect-attracting mercury-vapour lighting (Rydell et al., 2020).

Daubenton's bat (*Myotis daubentonii*)

National distribution and status – Classified as 'Least Concern – LC', this species is found as far north as the eastern areas of northern Sweden, though only in a few locations and predominantly along the coast.

Biology - Bat of small size that can be confused with other species of the same genus but is distinguishable by its comparatively shorter ears within the genus *Myotis*. Echolocation pulses are also similar across species of this genus, making acoustic identification difficult. Only the presence of characteristic pulses allows for accurate identification, and even then, identification errors can occur (Barataud, 2020; Russ, 2021). It uses various types of roosts, such as tree cavities, including natural cavities and woodpecker holes, buildings, cellars, and caves. It also uses diverse habitats for foraging, with a preference for forests and areas with water, particularly areas of standing water (Encarnação, 2012; Jones & Rayner, 1988).

Abundance and distribution at Nordens Ark – Detected at nearly all sampling points and in all habitats present, with the exception of the open area, this species had already been confirmed at Nordens Ark in a previous inventory (Boham, 2015).

Conservation and management measures – As it roosts in tree cavities, its conservation involves maintaining and preserving older,

large trees with cavities. Given the importance of aquatic habitats, preserving water bodies and wetlands is essential. Pesticide use may also be a threat to this species.

Whiskered bat/Brandt's bat (*Myotis mystacinus*/*Myotis brandtii*)

National distribution and status – Both species in this group are classified as 'Least Concern – LC', with *M. mystacinus* mostly found in southern Sweden and *M. brandtii* also present in central Sweden. However, the exact distribution of both species is still uncertain due to their very similar appearance, calls and habitat preferences.

Biology - Bat of small size, mostly overlapping in appearance, size and weight. The fur colour is similar in both species, usually very dark, ranging from dark brown to black, and slightly paler on the ventral side than on the dorsum. Detailed inspection of the dentition is needed to distinguish between the two species. Both species can occur in various habitats, including mixed, coniferous, and broadleaved deciduous forests, and are strongly associated with aquatic habitats. They can be found roosting in tree holes, trunk crevices, or in spaces behind loose bark. Both species may also roost in buildings, house attics, or empty cavities within roofs. *M. brandtii* mostly forages in the same locations as *M. mystacinus*, such as water bodies, but is slightly more dependent on forest habitats (Budinski & López-Baucells, 2023).

Abundance and distribution at Nordens Ark – Detected at nearly half of the sampled points and in all habitats present, with the exception of the open area, this species complex had already been confirmed at Nordens Ark in a previous inventory (Boham, 2015).

Conservation and management measures – *M. brandtii* is highly sensitive to landscape fragmentation in foraging areas and to habitat loss (Ekman & de Jong, 1996). It is therefore essential to preserve or improve foraging habitat quality, structure, and complexity, including the preservation of water bodies, and to retain old trees for shelter.

Common noctule (*Nyctalus noctula*)

National distribution and status – Classified as 'Least Concern – LC', this species is mostly found in southern Sweden.

Biology – The largest bat species present in Sweden, it is easily recognised by its size, rounded ears, mushroom-shaped tragus, and light brown fur. It can also be reliably distinguished acoustically, as it emits very low frequency calls compared to the other bat species occurring in Sweden. It roosts in tree cavities, utilizing both natural hollows and holes excavated by woodpeckers (Boonman, 2000). It typically flies in open spaces and can fly above forest canopies (Norberg & Rayner, 1987).

Abundance and distribution at Nordens Ark – Recorded at three sampling points, and previously confirmed at Nordens Ark (Boham, 2015).

Conservation and management measures – As it relies on tree cavities as roosts, its conservation requires maintaining and preserving older, large trees with cavities. The use of pesticides, leading to a decrease in insect populations, may be a threat to this species.

Soprano pipistrelle (*Pipistrellus pygmaeus*)

National distribution and status – Classified as 'Least Concern – LC', this species is widely distributed throughout southern Sweden.

Biology – One of the smallest bat species present in Sweden. It forms colonies mainly in buildings but also uses cavities and crevices in trees and rocks, as well as bat boxes. It seems to prefer feeding over water surfaces, but it can also use other habitats. When foraging along lakes and low salinity fjords, activity is highest close to shores at northern latitudes (Michaelsen, 2017). Topography appears to have a strong influence on habitat use at its northern range limits; individuals prefer areas with steep mountains that provide shade at sunset and sunrise, potentially extending foraging time during the short summer nights compared to flat landscapes (Michaelsen et al., 2011).

Abundance and distribution at Nordens Ark – Detected at roughly half of the sampled sites, confirming its presence at Nordens Ark, although it was not detected during the previous inventory (Boham, 2015).

Conservation and management measures – Maintaining the populations that use Nordens Ark requires preserving the quality of the diverse habitats present. Raising awareness among local authorities and the public about the preservation of existing roosts in the area surrounding Nordens Ark and nearby towns, by following the legal requirements for bat protection in buildings during the renovation of older structures, and the installation of artificial roosts in areas with limited roost availability, are key measures to be considered. The use of pesticides, including pest control in urban areas, may be a threat to this species through the reduction of food sources and the contamination of soil and water, affecting prey abundance in feeding areas.

Brown long-eared bat (*Plecotus auritus*)

National distribution and status – Classified as 'Near Threatened – NT', *P. auritus* is

present throughout southern and central Sweden.

Biology – Species of the genus *Plecotus* are distinguished from other bat species by their very long ears. The two species present in Sweden, *P. auritus* and *P. austriacus*, are visually similar, with the brown long-eared bat having slightly brownish fur. However, definitive identification to species level requires genetic confirmation. In Sweden the majority of long-eared bats present are brown long-eared bats, as the grey long-eared bat is restricted to a few isolated locations in the extreme south. These two species are considered whispering bats, emitting low-intensity vocalisations that make them difficult to detect using acoustic methods. Nonetheless, their echolocation pulses are highly characteristic, with two harmonics. *P. auritus* is a forest species, mostly roosting in tree cavities or under loose bark, though it also utilizes houses, barns, and church lofts (Rydell et al., 2017). It feeds predominantly on large arthropods such as moths, and in Sweden, caddisflies (Trichoptera) comprise a major part of its diet (Rydell, 1989).

Abundance and distribution at Nordens Ark – Recorded at half of the sampled points and present in all habitats.

Conservation and management measures – As it uses forest edges and roosts in tree cavities, its conservation relies on the retention and preservation of old, large trees with cavities. The use of pesticides, which leads to reductions in insect prey populations, represents a potential threat to this species.

Parti-coloured (*Vespertilio murinus*)

National distribution and status – Classified as 'Least Concern – LC', *V. murinus* is present in southern and parts of central Sweden.

Biology – This species is somewhat similar in appearance to the northern bat, with dark small ears, a rounded tragus and dark brown fur. However, its fur is bicoloured, with white hair tips instead of yellow, and a black base, giving the bat a ‘frosty’ appearance. Its calls overlap with those of bat species of the genera *Nyctalus* and *Eptesicus*, making acoustic identification possible only when distinct social calls are present (Zagmajster, 2003). Colonies seem to be mostly found in houses and other buildings. It forages in open or semi-open environments, and in Sweden it has been found foraging around street lamps in the vicinity of cities and villages (Rydell et al., 2010; Rydell & Baagøe, 1994).

Abundance and distribution at Nordens Ark – Its presence was confirmed at only one of the sampled points, where social calls were recorded.

Conservation and management measures – As this species mostly uses human structures to roost, ensuring that known roost sites, particularly maternity colonies, are identified and protected is necessary. Due to its extensive use of open and semi-open habitats, *V. murinus* may be affected by land use change and the degradation of water bodies, making