The bat fauna of the Erlenbusch (Frechen, North Rhine-Westphalia, Germany): preliminary results.

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Myotis emarginatus
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Abstract

Numerous acoustic surveys (3453 nights or evenings) of bats living in the Erlenbusch (or Buschbeller) forest (Western Germany) were carried out in all seasons between September 2014 and July 2021. The Erlenbusch is an old-growth, predominantly deciduous lowland forest, designated as a «biotope network area of exceptional importance». The species diversity of bats in relation to their types (hunting, transit, social) and their activity levels are described on the basis of numerous first analyses representative of annual, seasonal and spatial sampling. Sixteen bat species could be securely identified and two more as probable. The period of winter inactivity is shorter and more discontinuous than might be expected at this latitude. A first (but not unique: 46 acoustic contacts) record in Germany of *M. blythii* prompts a search for roosts of this species in the region. *M. alcathoe* and *M. emarginatus* are present and

actively hunting, giving this forest a rare status. The data show that this forest is a refuge habitat and that it acts as a feeding, roosting and reproduction area for bats, especially for local populations of *M. daubentonii, M. myotis, N. leisleri* and *P. pipistrellus*. These first results confirm that the Erlenbusch is one of the most important areas for bats in Germany.

Résumé

De nombreux relevés acoustiques (3453 nuits ou soirées) des chauves-souris vivant dans la forêt d'Erlenbusch (ou forêt de Buschbell, ouest de l'Allemagne), ont été réalisés en toutes saisons entre septembre 2014 et juillet 2021. Erlenbusch est une forêt de plaine ancienne, principalement feuillue, désignée comme « zone de réseau de biotopes d'importance exceptionnelle ». La diversité en espèces de chauves-souris, en lien avec leurs types (chasse, transit, sociale) et leurs niveaux d'activités, sont décrits sur la base de nombreuses premières analyses représentatives de l'échantillonnage annuel, saisonnier et spatial. Seize espèces de chauves-souris ont pu être identifiées comme certaines et deux comme probables. La période d'inactivité hivernale est plus courte et discontinue que ce qui peut être suspecté à cette latitude. Une première (mais non unique : 46 contacts acoustiques) mention en Allemagne de *M. blythii* incite à une recherche de gîtes de cette espèce dans la région. *M. alcathoe* et *M. emarginatus* sont présents et chassent activement, ce qui donne un statut de rareté à cette forêt. Les données montrent que cette forêt est un habitat refuge et qu'elle joue le rôle de zone de chasse, de gîte et de reproduction pour les chauves-souris, notamment pour les populations locales de *M. daubentonii, M. myotis, N. leisleri* et *P. pipistrellus*. Ces premiers résultats confirment que Erlenbusch est l'une des zones les plus importantes pour les chauves-souris en Allemagne.

Introduction

Many bat species (almost two-thirds of the European bat species) find crucial roosting and foraging opportunities in European forests: they use tree cavities to roost in during part of their life cycle, and some of them rely on these roosts for reproduction and hibernation (Russo *et al.*, 2004). Such forests have historically been exploited by humans and are still influenced by harvesting. One of the consequences of this pressure is the loss of key habitat resources, often making forests inhospitable to bats.

Vertical structure and tree species composition, also the age structure of forests affects the habitat use of bats (Crampton & Barclay, 1998), as older stands more likely to provide the advantageous combination of both suitable commuting and foraging grounds and roosting sites (Lacki *et al.*, 2007).

Tree-dwelling bats are highly dependent on the presence of large, old, dying or dead trees, as these provide potential roosts like woodpecker holes, fissures, peeling tree bark or decay holes (Racey & Entwistle, 2003). The density, structure and quality of tree roosts affect thermoregulation, safety from predators and parasites, and the social behavior (Russo *et al.*, 2005).

Due to their sensitivity to environmental changes and to anthropogenic impact

upon habitat quality and landscape structure, some forest bats are currently regarded as good biological indicators of the quality and trophic structure of habitats; this is the case for some Noctules (*Nyctalus* spp.), Brown and Grey Long-eared Bats (*Plecotus auritus* and *P. austriacus*), Greater Mouse-eared Bat (*Myotis myotis*), Bechstein's Bat (*Myotis bechsteinii*), and Alcathoe Bat (*Myotis alcathoe*) (Barataud *et al.*, 2009; Bohnenstengel, 2012; Coronado *et al.*, 2017; Grindal & Brigham, 1999; Kusch & Idelberger, 2005; Lučan *et al.*, 2009; Starik, 2018; Subirachs *et al.*, 2009; Vaughan *et al.*, 1997).

The study aimed to characterize the Erlenbusch from the bat fauna perspective.

Materials and methods

The study area

The forest is biogeographically located in the Atlantic region of Western Germany (**Figure 1**), Central Europe, at a medium altitude of 116 meters (99 to 133 m a.s.l. – Erlenbusch, Frechen, Germany, 50.925227° N, 6.772446° E). The average monthly daily temperatures fluctuate from 6 °C in January to 25 °C in July. The average annual rainfall is just under 600 mm, with a maximum in July and August (25.6% of the annual rainfall). The old forest area is isolated from other forest areas: In the north it is bounded by the A4 motorway, in the south by an open-cast mine. In the west, agricultural areas border the forest area; in the east, in addition to smaller agricultural areas, commercial areas and residential areas.

The forest is fully designated as "biotope network area of outstanding importance" (Landesamt für Natur, 2017). The lack of forests prevailing today within a radius of 30 km around the Erlenbusch is shown in **Figure 2** – especially the surfaces of old-

Figure 1.
Geographical location and satellite image of the Erlenbusch forest, west of Cologne.

grown forests have been reduced since decades especially because of mining activities (f.e. carbon, sand). The study area with deciduous forest up to 150 years and older has been successively reduced since decades. Further reduction took place during the period of data collection (late September 2014 to late July 2021) from approximately 92 ha (until November 2014) to 84 ha (since October 2016). Recently (October 2021) the forest was again reduced (ca. 1,5 ha) by mine exploitation. Next step on the way to total erasure is planned for October 2022.

The composition of the forest consists predominantly of *Fagus sylvatica* of different ages, with (patches of) *Quercus* sp., *Carpinus betulus*, *Betula* sp., *Fraxinus excelsior*, *Salix* sp., *Picea abies*, *Aesculus hippocastanum*, *Tilia* sp., *Alnus* sp., *Acer* sp., forest pond with *Juncus* sp.; *Pteridium aquilinum* (Carpinion betuli (CRPN-V), Galio odorati-Fagenion (GFN-V) (Landesamt für Natur, 2020).

Site selection

We established 18 (2017) respectively 27 (2020-2021) sampling sites distributed within the forest (**Figure 3** shows the sampling sites for 2017), to be characteristic of the study area, also to include as many distinctive habitat elements as possible (e.g., forest composition and age for each sampling site, canopy cover, grassy layer, presence of roads/paths that could be used as flight routes, presence of dead trees). Due to the known effects of nocturnal noise and light emissions on the success of the hunt and the use of space by bats (Schaub *et al.*, 2008; West, 2016; Lewanzik & Voigt, 2017), a minimum distance of 140 m to the motorway and the multi-lane road in the east was maintained. The collection period for data is shown in **Table 1**.

Figure 2.
The lack of forests prevailing today within a radius of 30 km around the Erlenbusch.

Figure 3.
Location of listening stations over complete nights (automatic recordings) July 9th to 24th 2017 in Erlenbusch Forest (Orthophoto: Google Earth from aerial survey on March 30th, 2021).

Sampling methods and bat call analysis

Recordings were made with in total 18 bat detectors (10 Batlogger A, 1 Batlogger A+, 3 Batlogger C and 4 Batlogger M with Strongbox; Elekon AG, Lucerne, Switzerland). For the evening transects 2014-2016, one Batlogger M was used. For automatic recording during complete nights, 18 (2017), respectively 27, (2020-2021) sample points were established (some Batloggers have been shifted during the recording period). Batloggers were equipped with microphone extensions, the omnidirectional microphones installed on tree branches up to a height of 2.5 m, oriented horizontally (at a 90° angle) and set at a minimum distance of 2 meters from neighbouring vegetation to reduce cluttered echoes (Schnitzer & Kalko, 2001). Bat call sequences contained calls from foraging bats, transiting bats and social calls. We used the overall bat activity as a measure for the intensity of habitat use.

The recordings from 2017 were analysed with BatExplorer (Elekon AG). As all automatic softwares need to be manually controlled at least for certain species for selection of bat sequences and species identification, we manually analysed too all the automatic results which were of particular interest. These sequences from 2017, and a selection of results from 2014, 2015, 2020 and 2021 were manually reassessed and analysed using generated spectrograms (FFT size 512 pts) on BatSound 4.4 (Petersson Electronic, Uppsala, Sweden) to validate or correct species identification, to note activity type, to count the number of individuals and the number of contacts. Specific call parameters (start and end frequency, peak frequency, duration and interpulse interval of calls) were measured, identified and interpreted according to the Acoustic ecology method (Barataud, 2020), sometimes compared and reconciled with values obtained from standard literature (e.g., Russ, 2021; Skiba, 2009). The sibling

Table 1.
Years and seasons of acoustic surveys in the Erlenbusch; type of survey and survey effort are indicated. The number of recorded and analysed sequences includes sequences without bat sounds (* five listening points were exactly the same in 2017 and 2020-2021).

Year	Month (beginn)	Month (end)	Evening transect (manuel)	Whole night (automatic)	Number of listening points	Pressure of listening (evening or night)	Number of sound files recorded	Number of sound files manually analysed
2014	late September	mid November	X		(transect)	18	14 044	276
2015	March	beginn of October	X		(transect)	32	7 195	276
2016	beginn of March	end of July	X		(transect)	6	2 649	0
2017	July 9th	July 24th		X	18	126	121 471	121 471
2020-2021	late September	late July		X	27	3 284	1 355 521	90 526
TOTAL					**40***	**3 466**	**1 500 880**	**212 549**

species *Myotis myotis* and *M. blythii* can be acoustically separated only in few behavioural contexts (Barataud, 2020). In some cases, pooled classifications (= species complex) were used, like 'Long-eared Bats' (*Plecotus* spp.), '*Myotis* Bats' (*Myotis* spp.), FM signals from *Nyctalus/Eptesicus* species; they were included in the quantitative results as taxonomic units at the same level as species. The levels of identification reliability are as follows: certain: species represented by one or more sequences, with specific criteria absolutely reliable; probable: species represented by one or more sequences, with criteria typical of a species, but which may occasionally be used by another species.

Data analysis

One bat pass (one contact) corresponds to the occurrence of bat signals of a given individual of one species per five-second period (Barataud, 2020). We used the number of all recorded bat call sequences per hour to measure the overall bat activity which was calculated by dividing the total number of bat call sequences collected over a sampling night by the recording time in hours.

Each species uses a sonar adapted to its preferred habitat and flight behaviour. The range of the signals depends largely on their duration and frequency band. Species that fly high above the ground at great speeds use long signals that sweep through a narrow spectrum of frequencies (quasi-constant frequency signals) – signals with a long range that retrieve information from a long way ahead. The intensity of the sound also depends on the bats behaviour in flight (no need to emit intense pulses when the obstacles are quite near): it therefore tends to be a fairly constant species-specific trait reflecting the ecological specialization of the species. The outcome of this is that some species can be detected with a bat detector one hundred metres away while others can only be picked up from less than five metres. It would be meaningless

to compare the activity indices of species with such dissimilar intensities of sonar emission because the probability of detecting them is so different. In order to be able to correctly compare activity indices (in number of contacts per hour) between species or between listening stations (Chiroptera spp.), we applied the specific coefficients (**Table 2**). Each raw contact (occurrence of bat signals of a given individual of one species per five-second) is multiplied by the coefficient of the species concerned, for weighting the differences in emission intensity between species (Barataud, 2020). Weighted activity values are expressed as number of adjusted contacts per hour.

Results

The preliminary results presented here are based on 212549 sound files manually analysed across all investigated sampling sites and seasons, but mainly throughout the main study period (9-24th of July 2017 and September 2020 to March 2021). Of all sequences determined at species or group of species level, 89.1% (2017) and 94.6% (2020-2021) were assigned to the "certain" level, and 0.7% (2017) and 4.4% (2020-2021) to the "probable" level.

A total of 18 bat species were identified, 16 with certainty and 2 at probable level (**Table 3**).

Table 2.
European bat species listed in order of increasing intensity of emission, along with detection range and resulting detectability coefficient. Values applied in forest understorey (after Barataud, 2020).

Intensity of emission	Species	Detection range (m)	Detectability coefficient
Very weak to weak	*Rhinolophus hipposideros*	5	5,00
	Plecotus spp (duration < 4 ms)	5	5,00
	Myotis emarginatus	8	3,13
	Myotis nattereri	8	3,13
	Rhinolophus ferr/eur/meh.	10	2,50
	Myotis alcathoe	10	2,50
	Myotis mystacinus	10	2,50
	Myotis brandtii	10	2,50
	Myotis daubentonii	10	2,50
	Myotis bechsteinii	10	2,50
	Barbastella barbastellus	15	1,67
	Myotis oxygnathus	15	1,67
	Myotis myotis	15	1,67
Medium	*Pipistrellus pygmaeus*	25	1,00
	Miniopterus schreibersii	25	1,00
	Pipistrellus pipistrellus	25	1,00
	Pipistrellus kuhlii	25	1,00
	Pipistrellus nathusii	25	1,00
	Plecotus spp (duration 4 to 6 ms)	20	1,25
Strong	*Hypsugo savii*	30	0,83
	Eptesicus serotinus	30	0,83
Very strong	*Eptesicus nilssonii*	50	0,50
	Eptesicus isabellinus	50	0,50
	Vespertilio murinus	50	0,50
	Nyctalus leisleri	80	0,31
	Nyctalus noctula	100	0,25
	Tadarida teniotis	150	0,17
	Nyctalus lasiopterus	150	0,17

In the 2017 recordings in the Erlenbusch, the most active species was *Pipistrellus pipistrellus* (83% of all recorded bat passes). This species was recorded at every station in 2017 with more than 64% of the overall recorded passes (at 13 of the 18 sampling stations, the species dominated with over 90% of the total number of passes).

The *Eptesicus*/*Nyctalus* complex (probably *N. leisleri* in most cases) shows sometimes a high activity in undergrowth, with many FM signals (22,3% of overall contacts during 10/07/2017 night for example) indicating flight in cluttered conditions and social calls.

Nyctalus leisleri seemed to be more abundant than *N. noctula*, and *N. lasiopterus* was found in only two sequences. *N. noctula* was recorded in the same locations as *N. leisleri*, but the highest activity was recorded in station n° 1 in 2017, near the forest edge, this being the main feeding location.

Table 3.

List of bat species occurring in the Erlenbusch; first results. Roosting and foraging preferences after Dietz & Kiefer (2014). **Legend**: Symbols indicate the frequency of forest use by bats according to our results: - not known; + occasionally; ++ frequently. Conservation status ATL DE (Temple & Terry, 2007). Conservation status of the species in the Atlantic biogeographical region of Germany: FV, favourable; U1, unfavourable-inadequate; U2, unfavourable-bad; XX, unknown; n.s., not specified. IUCN Red List Europe (Hutson *et al.*, 2001): EN, Endangered; VU, Vulnerable; NT, Near Threatened; LC, Least Concern; DD, Data Deficient. Red List Germany (Meinig *et al.*, 2020) and NRW (North Rhine-Westphalia) (Meinig *et al.*, 2011): 1, Critically Endangered; 2, Endangered; 3, Vulnerable; R, very rare; G, Endangerment of unknown extent; V, Least Concern, *, Least Concern; D, Data Deficient; n.s., not specified; nl, not listed in Germany according to Bundesamt für Naturschutz (2019).

Species	Identification level	Hunting	Social	Roost prob. in vicinity	Forestry specialist	Status IUCN List Europe	EHZATL Germany	Red List NRW (2011)	Red List Germany (2020)	Habitats Directive 92/43/EEC
Myotis alcathoe	certain	++	-	-	++	DD	XX	nl	1	IV
Myotis bechsteinii	certain	+	-	-	++	VU	U1	2	2	II, IV
Myotis blythii	certain	+	-	-	+	NT	nl	nl	nl	II, IV
Myotis daubentonii	certain	++	++	yes	+	LC	FV	G	*	IV
Myotis emarginatus	certain	++	+	yes	++	LC	H2	2	2	II, IV
Myotis myotis	certain	++	-	-	++	LC	U1	2	*	II, IV
Myotis mystacinus	certain	++	+	yes	++	LC	XX	3	*	IV
Myotis nattereri	certain	++	-	-	++	LC	FV	*	*	IV
Nyctalus lasiopterus	certain	+	-	-	+	DD	nl	nl	nl	IV
Nyctalus leisleri	certain	++	++	yes	+	LC	U1	V	D	IV
Nyctalus noctula	certain	++	+	yes	+	LC	FV	R	V	IV
Pipistrellus nathusii	certain	++	-	-	+	LC	FV	R	*	IV
Pipistrellus pipistrellus	certain	++	++	yes	+	LC	FV	*	*	IV
Pipistrellus pygmaeus	certain	++	++	-	+	LC	XX	D	*	IV
Plecotus auritus	certain	++	++	yes	++	LC	FV	G	3	IV
Plecotus austriacus	certain	++	++	yes	+	LC	U1	1	1	IV
Eptesicus serotinus	probable	+	+	-	+	LC	U1	2	3	IV
Myotis brandtii	probable	+	+	-	++	LC	U1	2	*	IV
Total	16 (18)	13++; 3(5)+	6++; 3(5)+	8	7(8)++; 9(10)+					

M. daubentonii is the most active among genus *Myotis*, with as much as 49,7 adjusted contacts per hour during the night of 18/07/2017, with the frequent simultaneous presence of several individuals together emitting social calls.
M. emarginatus and *M. alcathoe* give very high hunting activities (10.4 and 7.5 adjusted contacts per hour respectively) during the night of 01/10/2020; the overall species activity during this night is 77.1 c/h, which is among the highest values calculated for the Erlenbusch in July 2017.
M. blythii was identified, according to exclusive and reliable acoustic criteria (shape, duration, end frequency, peak frequency, bandwidth of sonar signal), in 46 sequences (30 at «certain» level) at five listening points, in Summer 2015 and Autumn 2020 (see selection on **Table 4**); all contacts occur from 22nd of May to 31st of October, and between 10°C and 18°C.
P. auritus and *P. austriacus* are both present, with frequent social calls on several stations.

The activity in Autumn and Winter shows a high level of activity in September and October, followed by a drastic decline from November until March. However, activity is not zero even in the depths of winter, although the number of nights without any contact is highest in January; *P. pipistrellus* is dominant in the whole of activities, and almost exclusive in January (**Figure 4**). Depending on the station, some species are especially active in early Autumn 2020: *M. daubentonii* (4 c/h), *M. mystacinus* (2.1 c/h) and *M. myotis-blythii* (8 c/h; more than *P. Pipistrellus* = 6.6 c/h). Apart from *P. pipistrellus* and *P. nathusii*, which could be active each month, we contacted in late Autumn or in Winter f.e. *M. bechsteinii* (f.e. 8th of November, 12°C), *M. emarginatus* (f.e. 6th of November, 8°C), *M. mystacinus* (f.e. 26th November, 8°C), *M. nattereri* (up to 6th of December, 3°C), *N. leisleri* (f.e. 22nd of December, 7°C and 15th of January, 1°C) and *N. noctula* (f.e. 15th of January, 1°C), *Plecotus* sp. (f.e. 11th of January, 5°C, social calls) and *M. daubentonii* (f.e. 12th of November, 8°C and 22nd February, 9-10°C).

Table 4.
Selection (only «certain» level and once per date) of sound sequences of *M. blythii*, currently found among the acoustic data collected in the Erlenbusch. Coodinates in UTM WGS 84; contacts are adjusted.

Species	Level	Year	Month	Day	Hour	Min	N. contacts	T° C	File name	Habitat	Longitude	Latitude
M. blythii	certain	2015	08	29	22	12	1.70	16	1713-0192	meadow	6.7678	50.9216
M. blythii	certain	2020	09	24	20	15	5.10	18	1122-0027	forest clearing	6.7654	50.9232
M. blythii	certain	2020	09	25	03	41	6.80	11	1122-1329	forest clearing	6.7654	50.9232
M. blythii	certain	2020	09	28	20	07	5.10	12	1122-0007	forest clearing	6.7654	50.9232
M. blythii	certain	2020	09	29	22	10	3.40	12	1122-0033	forest clearing	6.7654	50.9232
M. blythii	certain	2020	09	30	21	11	3.40	15	1122-0106	forest clearing	6.7654	50.9232
M. blythii	certain	2020	10	01	02	47	5.10	13	1122-0280	forest clearing	6.7654	50.9232
M. blythii	certain	2020	10	02	22	53	3.40	15	1122-0139	forest clearing	6.7654	50.9232
M. blythii	certain	2020	10	03	03	30	6.80	15	1122-0268	forest clearing	6.7654	50.9232
M. blythii	certain	2020	10	04	21	33	1.70	11	1119-0031	forest	6.7784	50.9253
M. blythii	certain	2020	10	23	03	26	3.40	14	1119-0078	forest	6.7784	50.9253
M. blythii	certain	2020	10	31	01	14	1.70	14	1119-0111	forest	6.7784	50.9253

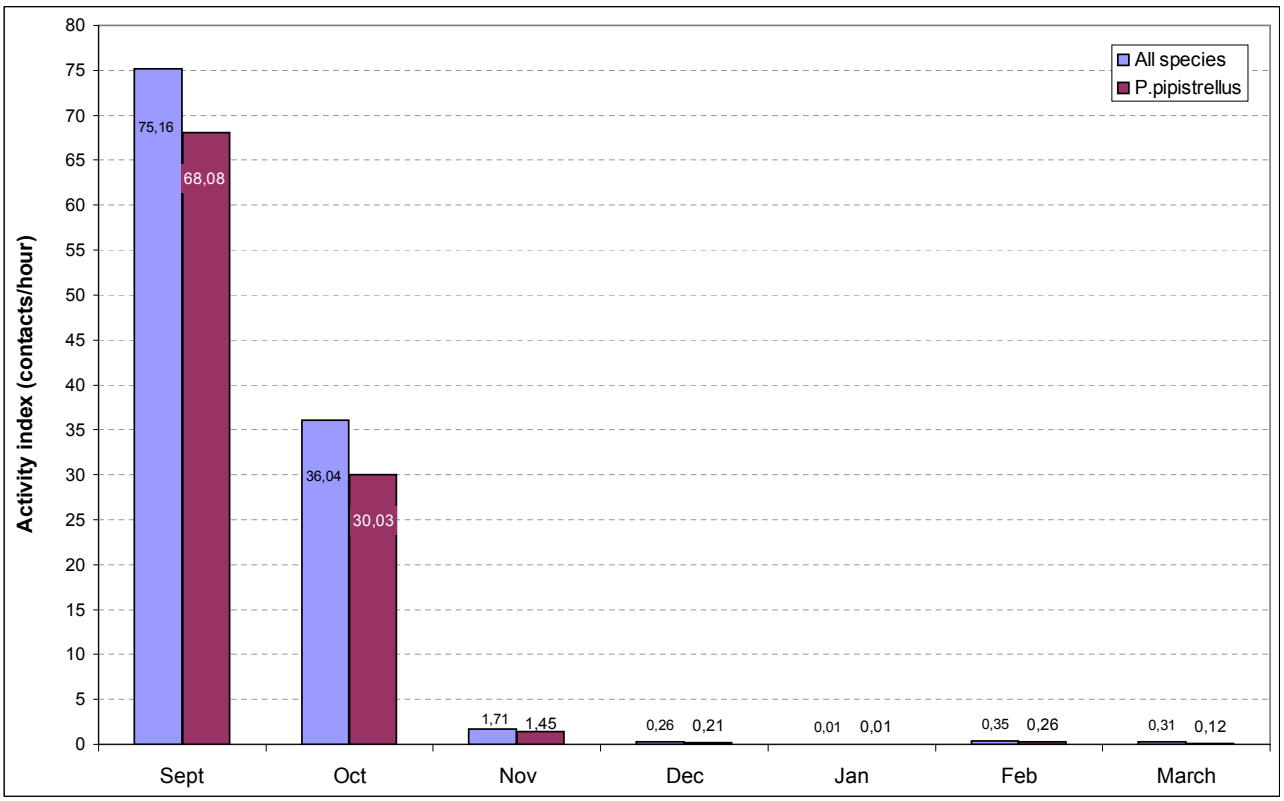

Figure 4.
Monthly activity (adjusted contacts) for all bat species and for *P. pipistrellus* only, between September and March, at two listening stations in the Erlenbusch.

Discussion

The study revealed the high diversity of tree-dwelling bats in old-growth Erlenbusch, representing at least 72% (overall species) or 64% (certain species) of Germany's bat fauna. According to the Red List for Mammals in North Rhine-Westfalia, 71,4% of the bat species occurring in the Erlenbusch and assessed in the Red List are endangered or rare in North Rhine-Westfalia (1-3 according to CR, EN, VU as well as R; Meinig *et al.*, 2011), of which 14.3% are in the highest endangerment level (CR, 1) and 21.4% are severely endangered (EN, 2, including the probable species the figure is 35.7%). The fact that 3 *Nyctalus* species, 8 *Myotis* species and 2 *Plecotus* species are present in this forest, is a strong indicator of its value as a high quality forest refuge.

In the other research forests (see for comparison **Annex**; Metz, 2021) from Ville (Special Area of Conservation, Natural Forest Reserves), in the period 2014 to 2020 a total of 13 bat species were identified on an area of 4,706 ha (Fehr, 2021; Striepen *et al.*, 2021). Dietz (2007) mentions 16 species in nine natural forest reserves in Hesse (463 ha), obtained by the acoustic and netting method from 2002-2007, while we identified 18 (certain and probable) species on an area of 84 ha. In the 143 ha of the «Grouf» natural forest reserve, nine bat species and a pair of species were identified (Dietz & Pir, 2013). In the 456 ha of the 11 natural forest reserves in Rhineland-Palatinate, 13 bat species were identified in the period from 2000 to 2016, by the netting and bat detector surveys (Balcar, 2013; Bundesanstalt für Landwirtschaft und Ernährung, 2018-2020; Forschungsanstalt für Waldökologie und

Forstwirtschaft Rheinland-Pfalz, 2005; Schorr, 2001, 2002, 2007). At least five different bat species have been mentioned in the 69 ha of Gitschger Nature Reserve in Bavaria, 40 km east of Bayreuth (Hübner *et al.*, 2018); the area was studied in 2017, through bat detector surveys and controls of bat boxes. For the forest areas in the Donau-Ries district (3,587 ha in 20 forest areas, including six forest areas with a total of 1,627 ha in 4 different SACs), Liegl (2005) mentioned up to seven bat species that he observed between 19th of June to 1st of October 2004. A total of 14 bat species were found in the Hienheimer Forst, a forest area between the rivers Altmühl and Danube, west of Kehlheim, Bavaria. Of the 3100 ha of forest, 2400 are declared SAC. Information about bats was collected over a period of 13 years (2005-2017) by checking bird nesting and bat boxes (Hirschfelder, 2019).

In the Erlenbusch, the bat activity levels (hunting and social) are often high during the breeding period. Up to mid-July, the only bats foraging are adults, but they are then joined by juveniles, which increase the bat numbers by some 40-60% (Barataud, 2020). In July 2017 in favourable weather, some nights analysed manually show an overall index of 426,9 c/h, which is among the highest values collected in low atlantic and continental caducifolious forests (Barataud, 2020; Barataud *et al.*, 2016, 2019; Barataud & Giosa, 2021).
P. pipistrellus had the greatest activity, with 83% of all the bat species recorded, followed by *Myotis* sp. with 6.42%. High activity of bats of the species *P. pipistrellus* was also observed by Adorf (2018) in other natural forest reserves such as Gottlob (*P. pipistrellus* 95.2%, followed by *Myotis* sp. with 4.23%), Ruppelstein (*P. pipistrellus* 90.57%, *Myotis* sp. with 9.2%) and Springenkopf (*P. pipistrellus* 86.82%, followed by *Myotis* sp. with 12.53%). Froidevaux *et al.* (2021) also mentioned the species *P. pipistrellus* and *Nyctalus* spp. being the most often detected in their study. In the case of the *P. nathusii*/*P. kuhlii* complex, the latitude of the Erlenbusch which is far from the north limit of *P. kuhlii*, the lack of the typical call ending of *P. kuhlii* and the presence of QCF signals while hunting lead us to believe we are always dealing with *P. nathusii*. Budenz *et al.* (2009) also observed *P. nathusii* sporadically between April and August; this observation was also confirmed by Ijäs *et al.* (2017), who noted that the presence of the species was significantly more concentrated in early autumn when they migrate from birthplaces to Central or Southern Europe to hibernate.
Schorr (2003) observed a surprising activity of *N. leisleri* in the Elmstein valley in the Palatinate Forest. The highest activity of *N. leisleri* in Buschbell woodland areas can be explained by the open space in the nearby or by the clearings in the forest. Because its foraging habitats include open areas, rivers, lakes or pastures, also deciduous and coniferous woodlands and streetlights surroundings (Shiel *et al.*, 1999), the potential existence of a nursing colony in the Erlenbusch is not excluded, since during the lactation period the females prefer to feed intensely in multiple core areas close to the roost (Shiel *et al.*, 1999), the feeding activity in station 4 in the Erlenbusch (2017) being confirmed by recorded feeding-buzzes. Ruczyński & Bogdanowicz (2005) found that *N. leisleri* used crevices and cavities caused by broken off branches more often (90%) than woodpecker cavities (10%), whereas *N. noctula* showed the opposite tendency and mainly occupied woodpecker-made cavities. *N. lasiopterus* appears to be rare in Germany, and its status remains undefined, with only a few

Erlenbusch forest is often partly flooded in the rainy season

isolated individuals observed so far (Dietz *et al.*, 2009). However, this high-flying species, which was probably rare but went unnoticed for decades before the advent of acoustic criteria, can be found all over Europe; a sequence of this species, recorded in September 2015 in southern Finland (H. Lehto, pers. com.), was for example validated as certain by one of us.

In Europe, *M. bechsteinii* is considered to have a strong affinity for mature natural deciduous forest, preferably oak, beech, and birch and is maybe common in optimal habitats only (Greenaway & Hill, 2004; Kaňuch *et al.*, 2008; Kerth *et al.*, 2003; Meschede & Heller, 2003). The preference for old forests may explain why it is so rare in Europe, showing insular distribution over its entire range (Napal *et al.*, 2009).

Myotis daubentonii occasionally takes refuge within trees whilst foraging, possibly for rest, for consumption of prey, protection from crepuscular predators, night roosting or going into torpor when temperatures are unfavourable (Todd & Waters, 2017). The numerous social calls recorded during July 2017 could indicate the close presence of one or more roosts. The activity levels of *M. daubentonii* in September and October 2020 are unusual in the forest, compared to our surveys in oak-beech forests in the Massif Central of France (Barataud, unpublished). A possible hypothesis would be that the proximity of the Rhine and the numerous riparian water bodies generate a large local population of this species, which invests in autumn (period of least activity of insects with an aquatic cycle) the rare old forests available. A further reduction in the area of the latter would have dramatic consequences, increasing the pressure of the most dynamic species on the relict areas, and accelerating the disappearance of the rarest and most sensitive species.

The presence of *M. blythii* in the Erlenbusch is a puzzling surprise, as there seems to be no official record in Germany, even if Dietz & Dietz (2007) indicate a discovery of *M. blythii* near Tübingen (Baden-Württemberg). In 2010, a *M. blythii* was discovered in Richtenberg-Zandershagen (Mecklenburg-Western Pomerania) and, after examination, registered in the database of the Global Biodiversity Information Facility (GBIF, 2018). As this species is thermophilous, its known European distribution usually shows it further south in Switzerland or Austria near the German border (Caël, 2018; Walder & Vorauer, 2014, p. 51), or further east in Slovakia and southern Poland (Uhrin *et al.*, 2008; Piksa, 2006). In the Czech Republic, the presence of *M. blythii* is nevertheless known at 50° latitude (Güttinger *et al.*, 2006; Dietz *et al.* 2016). The risk of an acoustic misidentification can of course never be excluded. The 46 sequences discovered in the material analysed so far, belong with certainty to a large species of the genus *Myotis*, as it is attested by several reliable criteria (signal structure and curve, energy distribution along bandwidth) which rule out the closest species: *M. dasycneme*. These sequences correspond to two behaviours (transit in an open environment and passive search in undergrowth), which present characteristics sufficiently distant from those of the signals of *M. myotis* to be considered as exclusively related to *M. blythii*, according to the reference data (Barataud, 2020). Thus, the probability of an error seems very low (unless *M. myotis*, in the absence of *M. blythii*, extends its acoustic niche until it overlaps with the

Myotis blythii (individual in winter lethargy; Gouffre de La Fage, Corrèze, France), with its white spot between the ears, well visible in all seasons.

latter: this phenomenon, well observed in *Pipistrellus* spp. (Barataud, 1995), is still unknown in the genus *Myotis*). Would we be in the presence of a case of exceptional vagrancy, even if our data extend from 2015 to 2020? Could there be some isolated individuals of *M. blythii* in the vicinity of the Erlenbusch, which mix with breeding populations of *M. myotis*, as is the case in the northern Massif Central of France (M.B., personal observations)? Monitoring of nurseries and hibernation sites within a radius of 50 to 100 km could perhaps allow the observation of individuals with the characteristic white spot on the forehead, and then genetic analyses. It is in any case important to continue investigations in and around the forest, as the exceptional presence of such a species of community interest justifies a special research programme and protection (Appendix IV & II FFH Habitats Directive).

M. emarginatus is too a very rare species and belongs also to Appendix II FFH Habitats Directive; for species belonging to this Appendix, FFH-areas should be declared; but there is none for this species in the whole atlantical biogeographical region of Germany. For *M. alcathoe* it is the first (acoustic) proof in North Rhine-Westfalia – before only subfossil skeletal material had been found there (Vierhaus & Sassendorf, 2012); *M. alcathoe* is one of the rarest tree-dwelling bats in Europe, and seems to be linked to old forests (Coronado *et al.*, 2017; Lučan *et al.*, 2009).

The genus *Plecotus* (*P. auritus*/*P. austriacus*) was recorded in surprisingly large numbers in the Erlenbusch, but the word `surprising` does not characterize so much the number of recorded passes as the frequency of social calls used by the species here. In 2017, stations n° 5, 6 and 11 were most frequented, and they used social calls in 11 of the 13 stations where the species was found. The social calls showed similarity to the communication calls between mothers and their youngsters, similar to the calls used by *P. austriacus* in the birth colony (Crețu G., unpublished data). Unlike its sympatric cryptic sister species, *P. auritus* is primarily associated with deciduous woodlands and its shelters are mainly located in crevices or behind loose tree bark (Dietz *et al.*, 2018; Entwistle *et al.*, 1996; Fuhrmann & Seitz, 1992); *P. austriacus* only used woodlands extensively when ambient temperatures were low or during heavy rainfall (Razgour, 2012). When *P. auritus* and *P. austriacus* are in syntopy in the same forest, it corresponds to a strong vertical structure of the forest (presence of several woody strata); in this context, *P. auritus* hunts closer to the ground, and *P. austriacus* mainly in (or above) the canopy (Barataud & Giosa, 2021). In our study area, we recorded indeed a greater number of social calls from Plecotus sp. on the nights of July 22nd and 23rd, 2017, in worse weather condition as usual (13-17° C., rain).

The activity of hunting bats in Autumn and Winter remains little known (Reber, 2022). Some nights of October (like 01/10/2020 with 10 species for example, including *M. emarginatus* and *M. alcathoe*) provided a high species richness, and high levels of activity which are in the average of results obtained during Summer in richly structured French deciduous forests (Barataud *et al.*, 2016). Activity in the forest is high in September and October, which could indicate both hunting activity in preparation for winter hypothermia and increased movements of individuals due to the mating season. The decline is very sharp from November onwards, but the irregular continuation of hunting as soon as the weather conditions are sufficient, throughout the winter, shows

a behavioural plasticity for the species concerned. Furthermore, the bat activity in winter – which can be caused for example by hunting ambitions, changing of roosts for thermoregulation and/or because of hygienic reasons, or the bat was disturbed by someone/something – suggests winter roosts in the forest, because of the bats' need to restrict energy consumption which rises in flight.

Minimal anthropogenic interference leads to old trees, a high volume of trees and increasing dead wood. The roosting requirements of tree-dwelling bat species represent a major conservation issue, and an investigation of roost selection is needed to set up appropriate guidelines for forest management (Russo *et al.*, 2016). Deforestation is regarded as an especially serious threat to the conservation of these mammals causing loss of habitat; it is a major threat for these species, because damaging forest management techniques, for example the removal of old or dead trees, can destroy valuable habitat for tree-dwelling bats (Hutson *et al.*, 2001; Russo *et al.*, 2004).

Conclusion

One important aspect of bat biology is that their habitat preference may change during different stages of the reproductive cycle (Kunz & Fenton, 2003). Our data, gained from 2014 to 2021 in all four seasons of the year, including the breeding and hibernating period, suggest that the Erlenbusch, despite its small remaining size and isolation, fulfills the role of a feeding,

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Erlenbusch in Winter

roosting, shelter and reproduction area for at least 16 bat species.

Although some species (i.e., *M. alcathoe*, *M. emarginatus*, *Plecotus* spp.) are often underrecorded from the ground level when using ultrasound recorders, because of their activity mainly at canopy level (Barataud & Giosa, 2021), their relatively weak echolocation calls and, consequently, their short detection range (Table 2), the large number of species confirms the importance of old-grown Erlenbusch as a relic of old «Villewälder» (with a high supply of roosts, food and different ecological niches) and as a refugial-habitat for bats in a landscape widely disturbed by diffuse urbanisation and with highly degraded natural habitats due to deforestation and forestal mismanagement. This refuge value gives this ancient forest an ecological heritage value that must be preserved: In this area, the old-grown forests have been nearly exterminated and the remnants are disconnected, this being one of the regions in North Rhine-Westfalia with the lowest overall amount of woodland parts (only 11,5%, which is less than in the city of Cologne with 13,6%; the average in Germany is 32% (Bundesministerium für Ernährung und Landwirtschaft, 2018). Only a very small part of this woodland still consists of old grown forests being essential for the survival of bat species.

Comparing the bat richness of the Erlenbusch with that of the natural forest reserves (**Metz**, 2021), the number and composition of the bat species identified here ranks the Erlenbusch at the top of the most frequented bat habitats in Germany, respectively, the most valuable forests of Germany. As Dietz and his collaborators write, "a community of more than 12 bat species in a forest is remarkable and has a national importance" (Dietz *et al.*, 2018).

Annexes: free download files

Metz T. 2021. The bat fauna of the Erlenbusch. Comparison to other forest areas in Germany. 11 pp. (.pdf)**:** **http://www.plume-de-naturalistes.fr/wp-content/uploads/2022/04/METZ_2021_Bat-fauna-Erlenbusch_Comparison-other-forest-areas-Germany.pdf**

Bat species contacted at Erlenbusch forest, 28 time-expanded (x10) sound files (.wav) with comments (.pdf): **http://www.plume-de-naturalistes.fr/wp-content/uploads/2022/04/CRETU-et-al_2022_Bat-fauna-Erlenbusch-forest_sound-files.zip**

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Ethics

The research method is non-invasive and did not follow the guidelines for collections.

Competing interests

We have no competing interests.

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