

Connecting Constable and Gainsborough Country: baselining for landscape recovery using multi-taxa passive acoustic monitoring

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SUMMARY

Background Connecting Constable and Gainsborough Country is a DEFRA-funded Landscape Recovery project. This report describes the use of passive acoustic monitoring (PAM) to assess the status and distribution of birds, bats, terrestrial small mammals, and bush-crickets across the Stour, Brett, and Box valleys in south Suffolk. The project supports habitat restoration and woodland connectivity, with a focus on rare or declining species of conservation concern, including the Hazel Dormouse, informed by robust monitoring.

Coverage During 2024-2025, core surveys were conducted at 80 locations across arable (n = 21), grassland (n = 19), and woodland (n = 40) habitats. Static acoustic recorders were deployed during three spring and summer survey periods, with each site sampled for approximately one week per period. Recording effort comprised 1,075 days of low-frequency (audible) recording across 72 survey days, targeting birds, and 1,362 nights of high-frequency (ultrasonic) recording across 89 survey nights, primarily targeting bats, with incidental detections of terrestrial small mammals and bush-crickets. Additional targeted acoustic surveys of Hazel dormouse were carried out at four sites in September 2025.

Results Following manual validation, 293,999 bird recordings and 751,128 ultrasonic recordings were confirmed. The surveys detected 107 bird species, including 26 Red-listed and 28 Amber-listed species, alongside at least 11 bat species, five small mammal species, and seven bush-cricket species. Notable records included Nightingale, Turtle Dove, and three Vulnerable or Near Threatened bat species (Barbastelle, Serotine, and Leisler's Bat). Hazel Dormouse was detected at two of the core survey sites and one of the additional targeted sites.

Species accumulation curves indicated that sampling effort was generally sufficient to characterise community composition across habitats. Woodland sites supported a more distinct bird assemblage, while arable and grassland habitats clustered together and shared many species. Statistical analysis identified 20 bird species as significant habitat indicators, including key farmland specialists (e.g. Skylark, Yellowhammer, Linnet) and woodland specialists (e.g. Great Spotted Woodpecker, Nuthatch, Treecreeper). These species are particularly valuable for long-term monitoring due to their strong habitat associations and reliable acoustic detectability.

Quantification of acoustic activity provided further insights into habitat use and its seasonal variation for both birds and bats. For bats, the ability to distinguish between echolocation calls, feeding buzzes, and social calls for several species was especially informative, revealing not only patterns of presence but also areas of concentrated activity. This approach offers a promising means of identifying important foraging and social sites and of improving understanding of bat behaviour across the landscape.

1. BACKGROUND

Connecting Constable and Gainsborough Country (CCGC) is a Landscape Recovery project, funded by DEFRA (Department for Environment, Food & Rural Affairs), that aims to restore woodlands and reconnect habitats throughout south Suffolk. Working with the Stour Valley Farmer Cluster and Wool Towns Farm Cluster, Suffolk Wildlife Trust's vision for the project is to develop the pilot scheme in which they enhance and connect wildlife habitats across farmlands in the project area - which extends through the Stour, Brett, and Box valleys.

The goal is to create a wilder environment in which wildlife can move across the landscape including an expansive network of farmland enhanced for nature. This will include habitat corridors encompassing woodland, scrub, grassland, and ponds; wildlife-friendly farmland landscapes; well managed ancient and secondary woodlands; and natural heritage features. A principal focus of the Landscape Recovery Project is to recover, restore, and reconnect woodland sites across the valleys - habitats vital for flagship species such as Nightingale (*Luscinia megarhynchos*), Turtle Dove (*Streptopelia Turtur*), Great Crested Newt (*Triturus cristatus*), and specialist flora. Most notably, the project hopes to reconnect rare populations of Hazel Dormouse (*Muscardinus avellanarius*) which are currently restricted to a small number of sites in south Suffolk & north Essex (<https://species.nbnatlas.org/species/NHMSYS0000080214>).

Long-term monitoring in Britain highlights that Hazel Dormouse numbers have declined substantially over recent decades, with national surveys reporting population losses of around 50–70% since 2000 (Goodwin, Hodgson, et al. 2017) and continued downward trends at a majority of sites (People's Trust for Endangered Species 2023). These declines are attributed to habitat loss and fragmentation, changes in woodland management, and climate-related impacts on hibernation and breeding (Goodwin, Suggitt, et al. 2018). Such national syntheses underline the importance of habitat restoration and woodland connectivity to support dormouse persistence at the local scale.

2. AIMS & OBJECTIVES

This project aims to use passive acoustic monitoring as an effective tool for assessing the status of broad range of species groups, with the opportunity for monitoring changes in populations over time. This includes using acoustics as a novel approach to assess Hazel Dormouse presence, where owing to the long deployment time that the technology allows, it potentially offers a better chance of detecting the species than from short duration visits by human surveyors. In addition, by using recording equipment that can record at low frequency (audible) and the high frequency (ultrasonic) range, the project aims to improve understanding of the status, distribution and timing of occurrence of bird, bat, small mammal and bush-cricket species in the study region, while also identifying habitat-specific associations and key indicator taxa. This report presents some initial results to support these varied aims.

The first year of sampling, carried out in 2024, focused on woodland habitat throughout the survey area. The results of this first year of monitoring are reported in an earlier research report (Ashton-Butt et al. 2025). The second year of survey (2025) extended sampling across arable and grassland habitats, allowing assessment of landscape-scale patterns in species composition and acoustic activity. This report presents the results of both years

of sampling, encompassing woodland, arable, and grassland habitats. Both audible (low frequency, targeting birds) and ultrasonic (high frequency, targeting bats and small mammals) monitoring were conducted across all sites.

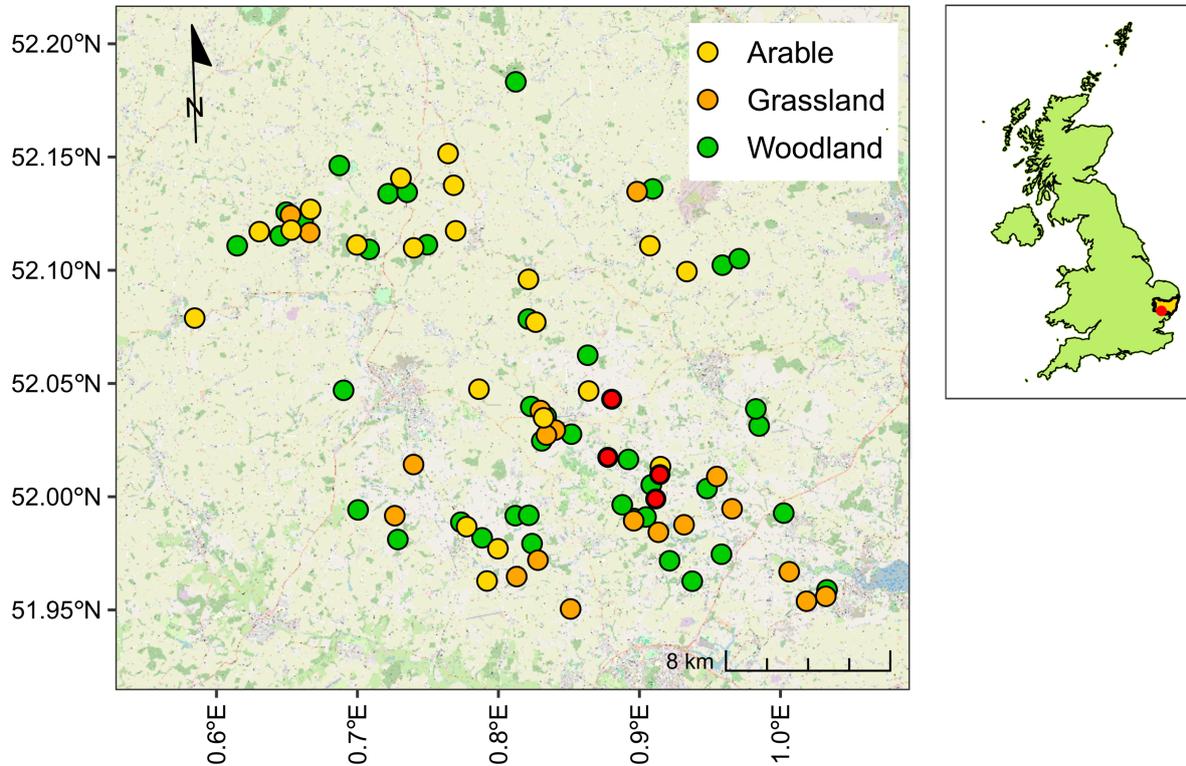


Figure 1: . Map of the Connecting Constable and Gainsborough Country survey area (left) and its spatial position with the UK (right). Each point represents a sampling location, coloured according to the habitat type. The red points on the main map indicate the four sites where additional targeted acoustic surveys for Hazel dormouse were conducted in September 2025 (n = 5 locations per site). In the UK map, Suffolk is highlighted alongside the location of the survey area.

3. METHODS

Planning, liaison with landowners, deployment of recording equipment, collation of audio recordings and processing through the BTO Acoustic Pipeline were undertaken by the Suffolk Wildlife Trust (LT). Acoustic identification verification, data analysis and reporting were undertaken by BTO (SN, AW and AAB, AJ). Classifier development was undertaken by BTO (SEN). Report writing was led by JT; analyses and visualisations were performed using R version 4.5.1 (R Core Team, 2025) and made extensive use of the following packages as well as those stated in the methods: `ggplot2` (Wickham 2016), `tidyverse` (Wickham et al. 2019), `maptiles` (Giraud 2025).

3.1 Static recorder protocol

Passive acoustic recorders (Song Meter Mini Bat, Wildlife Acoustics) were deployed throughout the survey area landscape (Figure 1) and programmed to alternate between daytime birdsong

recording using the acoustic (low frequency) microphone and night-time recording of bats, small mammals, and bush-crickets using an ultrasonic (high frequency) microphone.

For low frequency recording, a sample rate of 22,050 Hz was used, with recording blocks of one minute in every fifteen minutes (either continuously or between sunrise and sunset). For high frequency, a sample rate of 256,000 Hz and a high pass filter of 13,000 Hz defined the lower threshold for the triggering mechanism. Recording was set to continue until no trigger was detected during a 2 second period, up to a maximum of 5 seconds, and to activate between sunset and sunrise the following day. Recorders were mounted on 2 m poles and positioned at least 1.5 m from vegetation, water, or other obstructions to reduce ground noise and avoid recordings of reflected calls.

3.2 Survey effort and timing

Recording devices were deployed during the spring and summer months, with survey periods defined as early-, mid-, or late-season (Table 1). In each period, twenty devices were deployed at unique locations for one week before being moved to a second set of twenty locations for a second week, resulting in approximately 40 unique locations per period.

In the first year of sampling (2024), recorders were deployed at woodland locations. However, low-frequency recordings were not successfully collected during the mid-season due to equipment issues. In 2025, the focus shifted to arable and grassland habitats, with recordings obtained across all three periods.

Although each device was placed in a designated habitat, the surrounding landscape comprised a mosaic of habitat types, including linear features such as hedgerows and waterways, as well as many small habitat patches. As a result, observed differences in species composition or acoustic activity among habitats may reflect the presence of both habitat specialists and species using the wider landscape surrounding each recording location.

Across both years, the devices recorded a total of 1075 sampling days of low frequency data and 1362 sampling nights of high frequency data (Table 1).

Table 1: Survey effort across the two years of monitoring. ‘Total sites’ gives the number of unique sites sampled, ‘Average days/nights per site’ indicates mean sampling duration (± 1 standard deviation), and ‘Total recording days/nights’ is the cumulative sampling effort. Habitat types: W = woodland, A = arable, G = grassland.

Detection frequency	Year	Period	Period span	Total sites	Average days/nights per site (± 1 sd)	Total recording days/nights	Habitat types
Low	2024	Late	19th Aug - 6th Sep	38	7.0 \pm 2.0	265	W
	2025	Early	15th Apr - 2nd May	39	6.7 \pm 1.5	260	A + G
		Mid	2nd Jun - 20th Jun	40	7.0 \pm 0.0	270	A + G
		Late	11th Aug - 28th Aug	39	6.9 \pm 0.5	280	A + G
High	2024	Mid	19th May - 10th Jun	40	6.9 \pm 1.1	276	W
		Late	18th Jul - 4th Sep	39	7.1 \pm 1.5	275	W
	2025	Early	14th Apr - 30th Apr	39	6.7 \pm 1.1	262	A + G
		Mid	1st Jun - 18th Jun	40	6.9 \pm 0.3	276	A + G
		Late	10th Aug - 26th Aug	39	7.0 \pm 0.0	273	A + G

An additional block of targeted acoustic surveys for hazel dormouse was undertaken in early September 2025 to supplement the core survey effort. Recorders were deployed at five locations within each of four sites for approximately two weeks. Three of these sites comprised habitat considered suitable for Hazel Dormouse (one being known to support a population), and one site was assessed as suboptimal habitat. All hazel dormouse detections returned by the classifier were manually verified, alongside those of brown rat, a common confusion species. Data from these additional surveys are used to summarise occupancy at the supplementary sites. All other analyses involving Hazel Dormouse in this report only use the core survey data.

3.3 Processing recordings and species identification

3.3.1 Audible recordings of birds

All audible recordings were processed by the BTO. As the BTO Acoustic Pipeline ‘all species’ classifier is still in development (<http://bto.org/pipeline>), we processed all recordings through BirdNet, a machine-learning based acoustic classifier developed by Cornell University (Kahl et al. 2021). BirdNET was configured to return all detections with a confidence score of at least 0.5 and with no spatial or temporal species filters applied. Positive identifications of each species for each site were then manually verified by two individuals. This was done by selecting 100 detections (or as many as possible if fewer detections) of each species for each site and each year with the highest confidence scores. These were checked until at least one true positive detection was found, thus producing a verified species list for each site and each year.

Vocal activity (number of calls per unit time) and derivations of it were included in our analyses for birds, but it should be interpreted cautiously because the accuracy of BirdNET varies among species (see Pérez-Granados 2023 and Tseng, Hodder & Otter 2025, for further discussion). Specifically, ‘precision’ (the proportion of detections that are of the correct species) and ‘recall’ (the proportion of actual vocalisations that are detected) may vary widely among species and across sites, and we did not have the resources to quantify these metrics directly for this project. We calculated activity for all bird species that were confirmed as occurring at each site using recordings with a BirdNET confidence score ≥ 0.5 . For analyses and data summaries related to birds, we either present species presence for the verified data, or activity metrics using this threshold.

In addition to classification uncertainty, there are also ecological (some birds vocalise more than others or occupy strata closer to the height at which recorders were deployed) and physical factors (some sounds travel further than others) that contribute to variation among species in their detected vocal activity. Vocal activity therefore reflects not only local abundance or presence, but also species-specific calling behaviour, seasonal patterns (e.g. breeding versus non-breeding periods), and environmental context. For example, bird species with loud, frequent, or stereotyped calls are more likely to be detected than quieter or less vocal species, even when present at similar densities. Similarly, habitat structure, weather conditions, and background noise can influence sound transmission and detectability, potentially biasing comparisons among sites or years.

These factors mean that acoustic activity metrics should not be interpreted as direct measures of population size or density. Instead, they provide a relative index of vocal activity that integrates behaviour, detectability, and presence. While this limits the strength of inferences that can be

drawn about absolute abundance, such metrics can still be informative for comparing broad patterns across sites, seasons, or years when interpreted in conjunction with verified species presence data.

3.3.2 Ultrasonic recordings of bats and small mammals

At the end of a recording session, uncompressed wav files produced by the bat detectors, together with associated information on the survey location, were uploaded volunteers to the BTO's Acoustic Pipeline for processing.

The BTO Acoustic Pipeline uses machine-learning algorithms to detect and classify sound events within uploaded recordings. For each recording, the classifier may assign up to four candidate species identities, each associated with an estimated probability of correct classification. This probability represents the classifier's confidence that the assigned species identification is correct (e.g. a probability of 0.9 indicates a 90% likelihood that the identification is correct, and a 10% likelihood that it is incorrect).

Following recommendations in Barré et al. (2019), species identifications with a probability of correct classification below 0.5 (50%) were discarded. To assess the impact of this threshold, a subset of recordings with probabilities below 0.5 was manually audited, confirming that few valid detections were lost. At the same time, all recordings with probabilities ≥ 0.5 were manually checked. Exceptions were made for the two most frequently detected species, Common Pipistrelle (*Pipistrellus pipistrellus*) and Soprano Pipistrelle (*Pipistrellus pygmaeus*), for which a random sample of 1,000 recordings were manually verified to check the classification error rate which was negligible (less than 0.02% of recordings were assigned to the wrong species). Note that the classifier also distinguishes between echolocation calls, feeding buzzes and social calls for several species, which can be used to provide more information on what bats are doing in different habitats or at different times of year.

For bush-crickets and audible moths where there can be many recordings, often of the same individual, we instead focused on producing an inventory of species presence. For these taxa, the three recordings with the highest classification probability for each site and night were selected for manual auditing.

Verification of species identification was carried out through the manual checking of spectrograms using software SonoBat (<http://sonobat.com/>) which was used as an independent check of the original species identities assigned by the Pipeline. All subsequent analyses use final identities upon completion of the above inspection and (where necessary) correction steps.

It is important to note that the criteria for distinguishing Whiskered Bat (*Myotis mystacinus*) and Brandt's Bat (*Myotis brandtii*) are very subtle and poorly defined. For this reason, until further ground-truthing of the identification can be carried out, we treat these two species as a species pair.

3.4 Data presentation and analysis

3.4.1 Species attributes and conservation status

Species were assigned a range of predefined attributes to support interpretation of species occurrence, richness, and activity patterns across habitats. For birds, species were classified

as farmland or woodland indicators based on their inclusion in the respective official Wild Bird Indicators produced by the BTO and partner organisations (British Trust for Ornithology 2026). In both cases species are classified as specialists or generalists (e.g., woodland generalist). For context, there are currently 19 species in the Farmland Bird Indicator, of which 12 are specialists, and 37 species in the woodland bird indicator, 9 of which are specialists.

These indicator classifications were used to summarise richness and activity patterns of characteristic farmland and woodland bird assemblages but are distinct from the statistically derived indicator species identified through multivariate analyses (Section 3.4.4).

Local conservation status for birds followed the Birds of Conservation Concern 5 (BoCC) assessment, which assigns species to Red and Amber lists based on population trends, range changes, and other criteria (Stanbury et al. 2021). For bats and small mammals, local conservation status was taken from the UK Mammal Red List (Mathews & Harrower 2020). Conservation status information was used to assess the relative conservation value of habitats and species assemblages, rather than as input variables in statistical analyses.

3.4.2 Species occurrence and species richness

For all taxonomic groups, species richness was calculated as the total number of species detected at each sampling location within each survey period. Only sites with at least five consecutive days (for birds) or nights (for bats, small mammals, and bush-crickets) of recording were included in richness analyses to ensure comparable sampling effort. Species richness was summarised by habitat type (arable, grassland, woodland) and sampling period (early, mid, late) to assess spatial and temporal variation in biodiversity.

For birds, additional richness metrics were calculated for subsets of species classified as farmland or woodland indicators, and for Birds of Conservation Concern (see Section 3.4.1), to assess the conservation value of different habitats. Bat species were also classified by conservation status. Site presence, defined as the proportion of sites at which each species was detected, was calculated separately for each habitat type and summarised across all sites to distinguish widespread species from those restricted to particular habitats.

Finally, to assess how species richness increased with sampling effort, species accumulation curves were generated. Daily bird detections and nightly bat detections were converted to presence-absence, and only sites with at least five days/nights of recordings per survey period were included. For each habitat x period combination, accumulation curves were calculated across days using the 'specaccum' function in the `vegan` R package (Oksanen et al. 2025) with the 'random' method - adding days in random order - and 1,000 permutations. This resampling approach provides estimates of mean cumulative species richness and associated standard deviations.

3.4.3 Acoustic activity metrics and seasonal activity

Acoustic activity, defined as the number of detections per day (birds) or per night (bats, small mammals), was used as a proxy for relative abundance and habitat use intensity. For each species, we calculated mean daily or nightly activity per site-period for locations with at least five days or nights of continuous recording in each period.

Activity metrics were averaged by habitat type, with bootstrapped 95% confidence intervals (1,000 iterations) calculated by resampling site-period mean values; thus, accounting for

variation in detection rates across sites and periods. For birds, only detections with BirdNET confidence scores ≥ 0.5 were included. For bats and small mammals, all manually verified detections were included as described in Section 3.2. These activity metrics were further used to qualitatively assess the timing of peak acoustic activity for each taxon. For each group, we report the number of species whose peak activity occurred within each period; for bats, this analysis was also conducted by call type.

For bats, seasonal variation in feeding activity and social activity was additionally assessed using 'buzz ratios' and 'social call ratios' for species with sufficient data (Common Noctule, Common Pipistrelle, and Soprano Pipistrelle - where the classifier detected enough feeding buzzes and social calls). For each of these species, the feeding buzz ratio was calculated as the number of feeding buzzes divided by the number of echolocation detections per night and was used to examine seasonal variation in relative feeding activity. A buzz ratio of one indicates that every bat pass contains a feeding buzz (e.g., Vaughan, Jones & Harris 1997; Hermans et al. 2024). The 'social call ratio' was calculated similarly use the ratio of social calls to echolocation calls.

3.4.4 Bird indicator species analysis

For birds, community composition across habitats was explored using indicator species analysis based on acoustic activity data. Mean daily detections for each species were calculated for each site and sampling period where at least five days of recording occurred ($n = 146$ periods). To focus the analysis on more commonly detected species and reduce noise from rare detections, the 50 species with the highest overall activity were retained. Species activity data (detections per species per period per location) were Hellinger transformed to reduce the influence of very abundant species and make the data suitable for ordination.

Non-metric multidimensional scaling (NMDS), using Bray-Curtis dissimilarity, was subsequently applied to the transformed data to visually compare the bird communities across habitats. Indicator species analysis was then conducted to identify species strongly associated with arable, grassland, or woodland habitats, using the 'multipatt' function from the `indicspecies` R package (De Cáceres & Legendre 2009; De Cáceres, Legendre & Moretti 2010). The function combines two components: how exclusively a species occurs in one habitat compared to others, and how consistently it is found at sites within that habitat. The indicator value ranges from 0 to 1, where higher values indicate stronger habitat associations. Statistical significance of each indicator value was assessed using a permutation test (999 permutations), and only species with $p \leq 0.05$ were considered significant indicators.

Only species with statistically significant associations ($p \leq 0.05$) for a single habitat were considered key indicators. Multi-habitat indicators were also included if significant but were not emphasised in the NMDS plots, as they provide less habitat-specific information.

Note that some species included in the Farmland Bird and Woodland Bird Indicators were detected but at low acoustic activity (i.e., detected at few sites) and were therefore did not appear as significant indicators in the formal indicator analysis, as the method requires consistent present across sites. However, these species are still discussed qualitatively as habitat indicators where relevant, especially in terms of the conservation value. Indicator species analysis was not conducted for bats or small mammals as the lower number of species, combined with the low detections of many species, prevents meaningful analysis.

4. RESULTS

4.1 General results

Collectively across all sites, 1075 days of low-frequency recording effort was conducted, spanning 72 different days across the two years of survey. Following manual verification to establish a confirmed species list, BirdNET detections for these species were filtered by confidence threshold (≥ 0.5), reducing the dataset from 3,081,758 to 293,999 recordings for subsequent analyses. For ultrasonic recordings targeting bats, terrestrial small mammals, and bush-crickets, 1362 nights of recording effort was achieved, spanning 89 different nights and resulting in 1,235,407 ultrasonic recordings, of which 751,128 remained after full manual verification (Section 3.2.2).

Manual verification confirmed 107 unique bird species across the two years of monitoring, including 28 Amber-listed and 26 Red-listed species. Notable records included Nightingale and Turtle Dove, which were detected at 4% and 2% of sampled sites, respectively.

Analysis and verification of ultrasonic recordings confirmed 127,010 bat detections and 5,131 small terrestrial mammal detections. Species of conservation importance included Barbastelle (*Barbastella barbastellus*), Serotine (*Eptesicus serotinus*), and Leisler’s Bat (*Nyctalus leisleri*), each of which were detected in large numbers of recordings across multiple sites (Table 5), and Hazel Dormouse, which was detected at only three sites. In addition, six bush-cricket species and two audible moth species were recorded. The breakdown of species richness across taxonomic groups and survey periods is presented in Table 2.

Table 2: Species richness for each taxonomic group by period across the study area. *Bird species totals by period were calculated using a BirdNET confidence threshold of 0.5, applied to species that were manually confirmed as present in that year. This threshold affects only period-specific bird counts. Annual (“All”) bird totals reported elsewhere, as well as counts for all other taxonomic groups (by period or by year), are restricted to manually verified records

Year	Period	Bird species*	Bat species	Small mammal species	Bush cricket species	Audible moth species
2024	Mid	-	10	3	-	1
	Late	56	11	4	4	1
	All	56	11	4	4	2
2025	Early	90	11	4	-	-
	Mid	86	11	3	1	2
	Late	83	11	3	6	1
	All	105	11	4	6	2

4.2 Birds

4.2.1 Habitat-specific richness and site occurrence of birds

Bird species richness varied significantly across habitats and recording periods. Woodland sites supported the lowest mean species richness (20.8 ± 3.5 species per site-period (mean \pm 1sd)), compared to grassland (32.2 ± 4.3) and arable (30.0 ± 5.0) habitats. Similarly, woodland habitats also harboured fewer farmland and woodland indicator species, as well as fewer species of conservation concern (Figure 2).

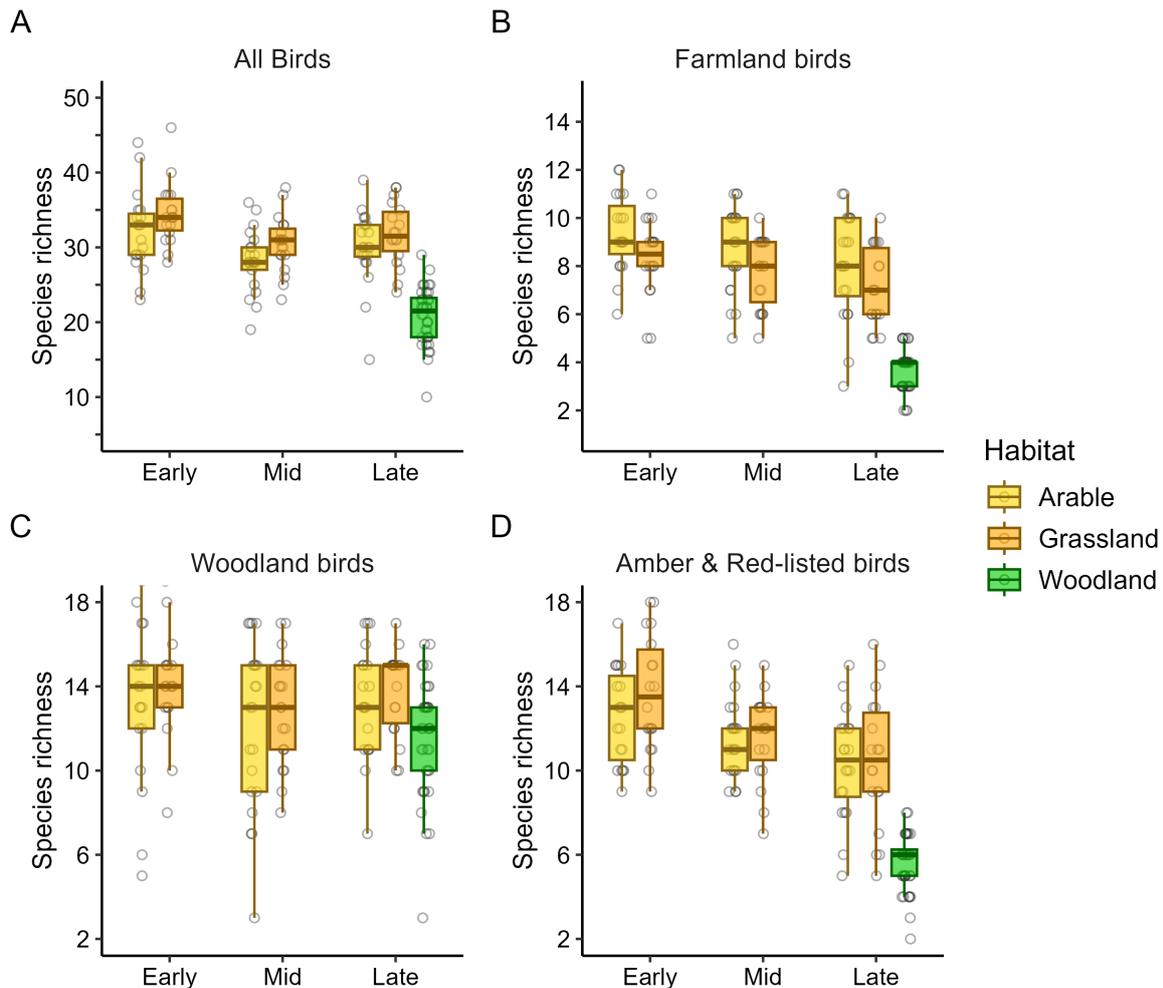


Figure 2: Bird species richness by habitat and recording season. A – all bird species; B – farmland indicator species; C – woodland indicator species; D – Birds that are red- or amber- listed on the Birds of Conservation Concern 5. Each point represents a unique sampling location with at least 5 days of continuous recording. Boxplots summarise the spread of distribution of data, showing the lower quartile, median, and upper quartile, with whiskers extending to 1.5 times the interquartile range. Site-periods with fewer than 5 days of data were excluded to avoid downward bias in richness estimates.

The greater sampling effort at woodland sites also resulted in the species accumulation curve in this habitat approaching an asymptote (Figure 3), indicating that survey effort was sufficient to detect most of the woodland bird community accessible to recorders and identifiable by the BirdNET algorithm. By contrast, species accumulation curves for both grassland and arable sites were further from reaching their asymptotic values, suggesting that additional sampling effort in these two habitats would likely detect further species, albeit probably uncommon ones. The early recording period (April) produced the highest species richness for arable and grassland habitats.

The presence of bird species across all sites and habitats is presented in Table 3.

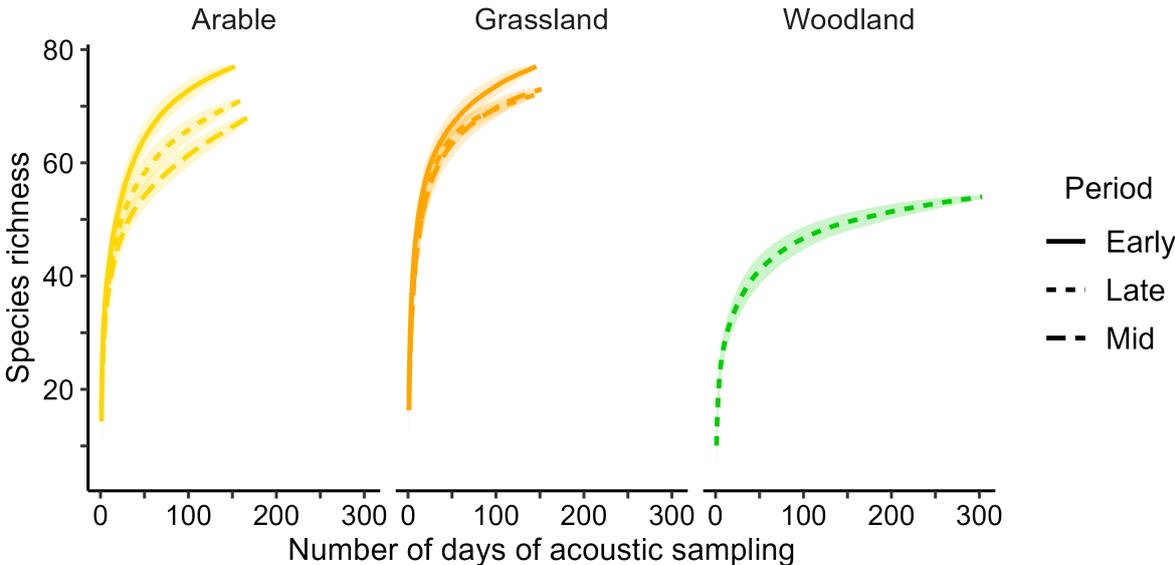


Figure 3: Species accumulation curves for birds in each habitat type and period of the year. The resampling procedure used to generate the curves was agnostic to the site but was restricted to all sites that provided continuous data for at least 5 days, so that most sites contributed similar amounts of effort to the curves. Reproducing the analyses at the level of site (site inventories resampled rather than day inventories) resulted in qualitatively similar patterns

Table 3: Bird species detected across all sites and their detection frequency by habitat type. Indicator categories: FG = farmland generalist, FS = farmland specialist, WG = woodland generalist, WS = woodland specialist. BoCC Status: R = Red-listed, A = Amber-listed.

Species	Total detections	% of all sites	% of arable sites	% of grass-land sites	% of wood-land sites	Indicator	BoCC status
Barn Owl	3	2	5	5	0		
Bittern	1	1	0	0	2		A
Black-headed Gull	3	1	0	5	0		A
Blackbird	8659	65	100	100	30	WG	
Blackcap	6222	60	90	100	25	WG	
Blue Tit	9690	90	100	100	80	WG	
Bullfinch	79	20	29	32	10	WG	A
Buzzard	4349	90	95	100	82		
Canada Goose	97	15	19	37	2		
Carrion Crow	3689	94	100	100	88		
Cettis Warbler	399	9	0	37	0		
Chaffinch	486	32	48	74	5	WG	
Chiffchaff	39369	79	100	100	58	WG	
Coal Tit	514	44	52	53	35	WG	
Collared Dove	71	4	5	11	0		
Common Sandpiper	24	1	5	0	0		A
Coot	160	12	10	37	2		
Cormorant	11	1	0	5	0		
Corn Bunting	43	2	10	0	0	FS	R
Cuckoo	691	28	38	74	0		R
Curlew	6	2	5	5	0		R
Dunnock	3309	72	100	100	45	WG	A
Egyptian Goose	108	11	10	37	0		
Firecrest	31	11	10	5	15		
Gadwall	51	5	5	16	0		A
Garden Warbler	499	14	33	21	0	WG	
Goldcrest	1316	74	81	68	72	WG	
Golden Plover	1	1	5	0	0		
Goldfinch	3426	52	95	100	8	FS	
Grasshopper Warbler	88	1	0	5	0		R
GS Woodpecker	2097	84	90	100	72	WG	
Great Tit	1690	84	100	100	68	WG	
Green Sandpiper	6	4	5	11	0		A
Green Woodpecker	1684	89	100	100	78	WG	
Greenfinch	578	40	81	58	10	FG	R
Greenshank	2	2	0	11	0		A
Grey Heron	63	20	29	47	2		
Grey Partridge	13	5	14	5	0	FS	R
Grey Wagtail	35	6	14	11	0		A
Greylag Goose	1011	32	48	74	5		A
Hawfinch	35	2	0	5	2		R
Herring Gull	46	14	19	26	5		R
Hobby	78	11	5	16	12		
House Martin	457	40	62	68	15		R

Table 3: Bird species detected across all sites and their detection frequency by habitat type. Indicator categories: FG = farmland generalist, FS = farmland specialist, WG = woodland generalist, WS = woodland specialist. BoCC Status: R = Red-listed, A = Amber-listed. (continued)

Species	Total detections	% of all sites	% of arable sites	% of grass-land sites	% of wood-land sites	Indicator	BoCC status
House Sparrow	1	1	0	5	0		R
Jackdaw	28743	89	86	100	85	FG	
Jay	1162	79	81	89	72	WG	
Kestrel	136	29	38	53	12	FG	A
Kingfisher	88	15	10	47	2		
Lapwing	4	4	5	11	0	FS	R
LS Woodpecker	6	1	5	0	0	WG	R
Lesser Whitethroat	724	40	90	68	0	WG	
Linnet	6575	44	95	74	2	FS	R
Little Grebe	120	5	5	16	0		
Little Owl	97	8	5	26	0		
Long-tailed Tit	7845	95	100	100	90		
Magpie	4014	76	100	95	55		
Mallard	129	20	29	47	2		A
Mandarin Duck	5	1	5	0	0		
Marsh Tit	223	29	24	21	35	WG	R
Mistle Thrush	423	25	38	63	0		R
Moorhen	135	15	5	47	5		A
Mute Swan	1	1	0	5	0		
Nightingale	8	4	5	11	0	WG	R
Nuthatch	850	48	38	32	60	WG	
Oystercatcher	31	8	0	32	0		A
Peregrine	1	1	5	0	0		
Pheasant	4988	80	95	100	62		
Pied Wagtail	134	20	33	47	0		
Raven	117	26	38	21	22		
Red Kite	528	25	24	58	10		
Red-legged Partridge	1223	36	76	53	8		
Redstart	11	1	0	0	2	WG	A
Reed Bunting	1044	21	48	37	0	FG	A
Reed Warbler	30	4	5	11	0		
Ringed Plover	2	1	0	5	0		R
Robin	11387	90	95	100	82	WG	
Rook	10028	79	95	100	60	FG	A
Sand Martin	2	1	5	0	0		
Sedge Warbler	8	1	0	5	0		A
Shelduck	5	4	5	11	0		A
Siskin	2	1	0	0	2	WG	
Skylark	10263	36	90	53	0	FS	R
Song Thrush	3386	50	76	95	15	WG	A
Sparrowhawk	189	5	10	11	0	WG	A
Spotted Flycatcher	104	9	5	0	15	WG	R
Starling	2	2	5	5	0	FS	R
Stock Dove	2483	75	81	95	62	FS	A

Table 3: Bird species detected across all sites and their detection frequency by habitat type. Indicator categories: FG = farmland generalist, FS = farmland specialist, WG = woodland generalist, WS = woodland specialist. BoCC Status: R = Red-listed, A = Amber-listed. (continued)

Species	Total detections	% of all sites	% of arable sites	% of grass-land sites	% of wood-land sites	Indicator	BoCC status
Stone-curlew	1	1	5	0	0		A
Stonechat	8	2	10	0	0		
Swallow	420	40	71	79	5		
Swift	23	12	29	21	0		R
Tawny Owl	27	12	10	16	12	WG	A
Tree Pipit	15	2	10	0	0	WG	R
Treecreeper	788	71	52	79	78	WG	
Turtle Dove	61	2	0	11	0	FS	R
Water Rail	24	2	0	11	0		
Whimbrel	3	1	5	0	0		R
Whitethroat	10869	48	95	95	0	FS	A
Willow Warbler	34	10	14	21	2	WG	A
Woodpigeon	69143	95	100	100	90	FG	A
Wren	16494	95	100	100	90	WG	A
Yellow Wagtail	114	18	33	37	0	FG	R
Yellowhammer	7020	32	90	37	0	FS	R

4.2.2 Habitat-specific acoustic activity of birds

As expected, acoustic activity varied considerably among species and habitats, reflecting differences in species composition, abundance, and vocal behaviour. Figures 4 and 5 present the mean acoustic activity of all species, ordered according to their overall mean detection rate across all habitats, such that Wood Pigeon was the most detected species, followed by Chiffchaff (*Phylloscopus collybita*), and so on. Figure 4 shows the most acoustically active species (ranks 1-35), while Figure 5 displays those with intermediate activity (ranks 36-70). Species with lower activity are not plotted, as their infrequent detection across sites results in very low mean estimates and thus are of little interpretive value.

Habitat-specific patterns were evident for several species, including important indicators and species of conservation concern. Skylark (*Alauda arvensis*) and Linnet (*Linnaria cannabina*), both red-listed farmland specialists, showed substantially higher activity in arable and grassland habitats compared to woodland, consistent with their preference for open habitats. Similarly, Yellowhammer (*Emberiza citrinella*), another red-listed farmland specialist, was predominantly detected in arable and grassland sites.

Conversely, woodland-associated species such as Great Spotted Woodpecker (*Dendrocopos major*), Nuthatch (*Sitta europaea*), and various tit species (Paridae) showed higher activity in woodland sites, though many were also detected in arable and grassland habitats, likely utilising hedgerows and scattered trees within the agricultural landscape mosaic.

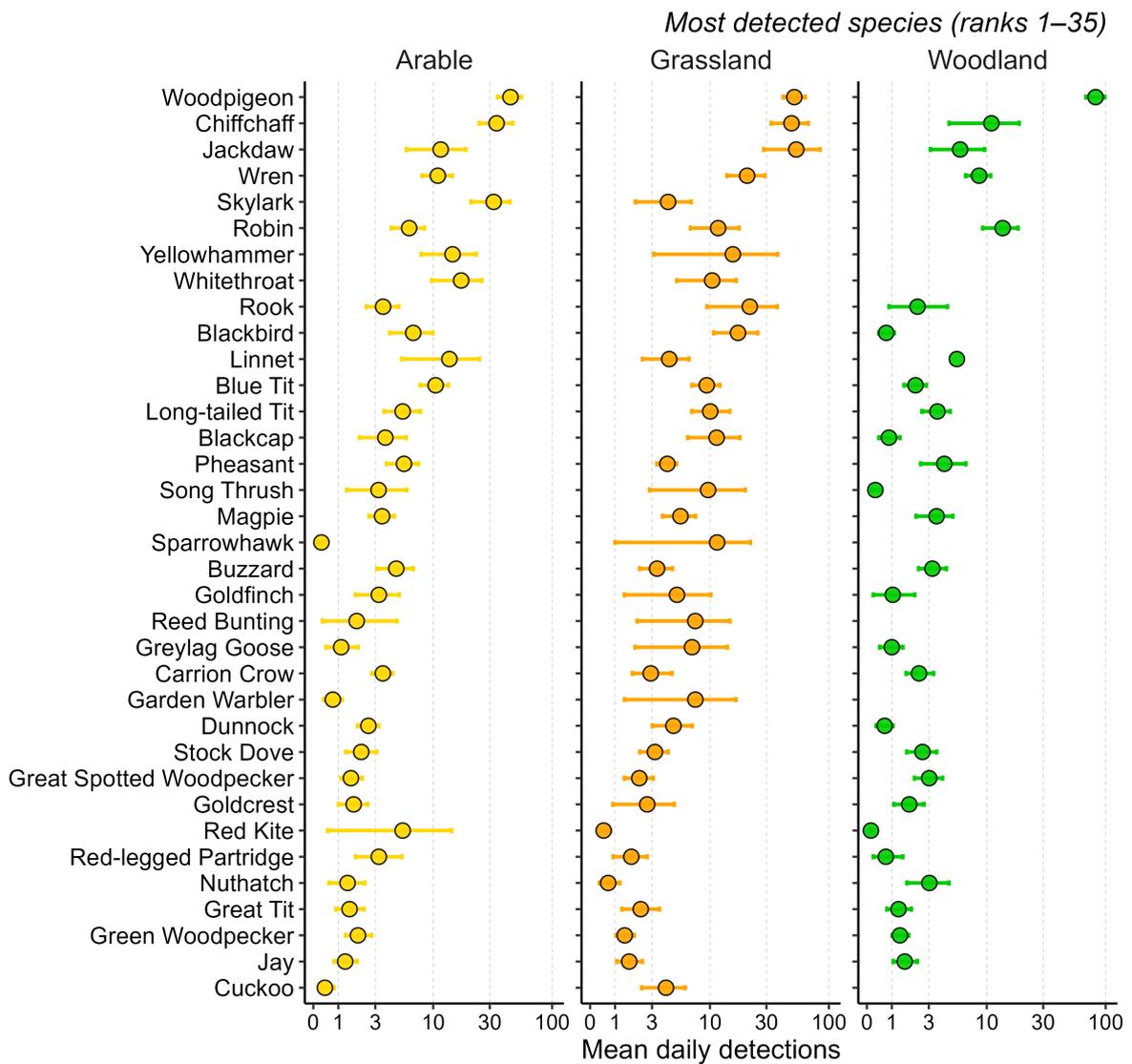


Figure 4: Mean daily bird activity per species across habitat types for species with highest acoustic activity (ranks 1-35). Points show the mean activity per species per habitat, averaged across sites. Horizontal bars represent bootstrapped 95% confidence intervals obtained by resampling site-period means. Species are ordered according to their overall mean daily detections across all habitats. The x-axis is \log_{10} -scaled to accommodate highly skewed detection counts and include zero values.

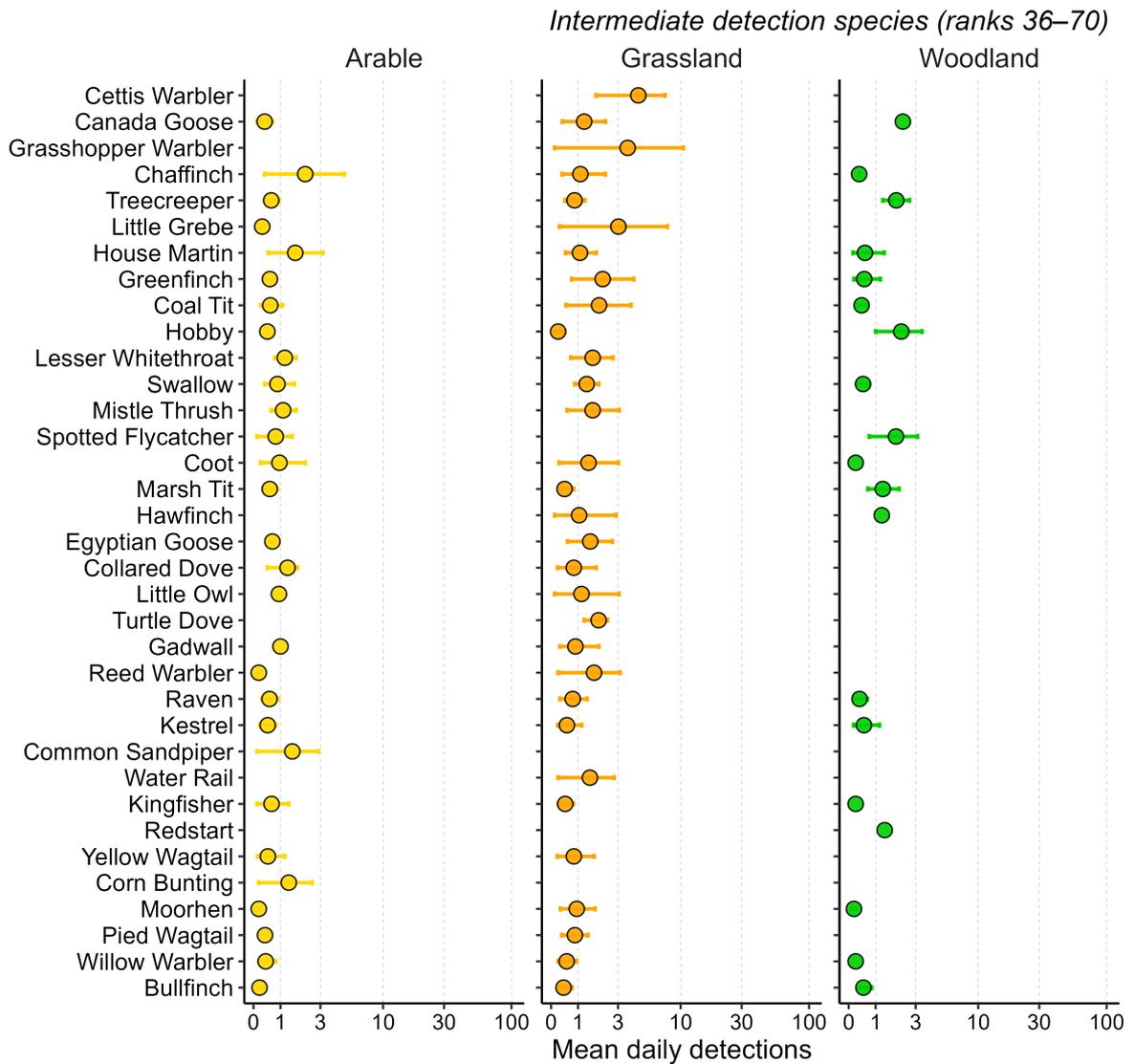


Figure 5: Mean daily bird activity per species across habitat types for species with intermediate acoustic activity (ranks 36-70). Points show the mean activity per species per habitat, averaged across sites. Horizontal bars represent bootstrapped 95% confidence intervals obtained by resampling site-period means. Species are ordered according to their overall mean daily detections across all habitats. The x-axis is \log_{10} -scaled to accommodate highly skewed detection counts and include zero values.

4.2.3 Bird community composition and indicator species

NMDS ordination revealed that arable and grassland sites clustered together in ordination space, indicating relatively similar bird communities, while woodland sites formed a distinct cluster, suggesting a compositionally different assemblage (Figure 6A). This pattern likely reflects differences in habitat structure, with woodland sites characterised by closed canopy and vertical stratification, whereas arable and grassland sites share more open-habitat characteristics despite differences in vegetation structure and management.

Indicator species analysis identified 20 species significantly associated with specific habitats (Table 4, Figure 6B). Woodland indicator species included Great Spotted Woodpecker, Nuthatch, Treecreeper (*Certhia familiaris*), and several woodland warblers. Arable habitats were characterised by Skylark, Yellowhammer, Linnet and Red-legged Partridge (*Alectoris Rufa*), species strongly associated with cultivated farmland and field margins. Grassland sites showed associations with eight species, though of these, only greylag goose (*Anser anser*) could perhaps be considered heavily dependent on permanent pasture or meadow habitats that define grassland. Some species showed significant associations with multiple habitats (shown in grey in Figure 6B), suggesting their use of habitat mosaics within the landscape.

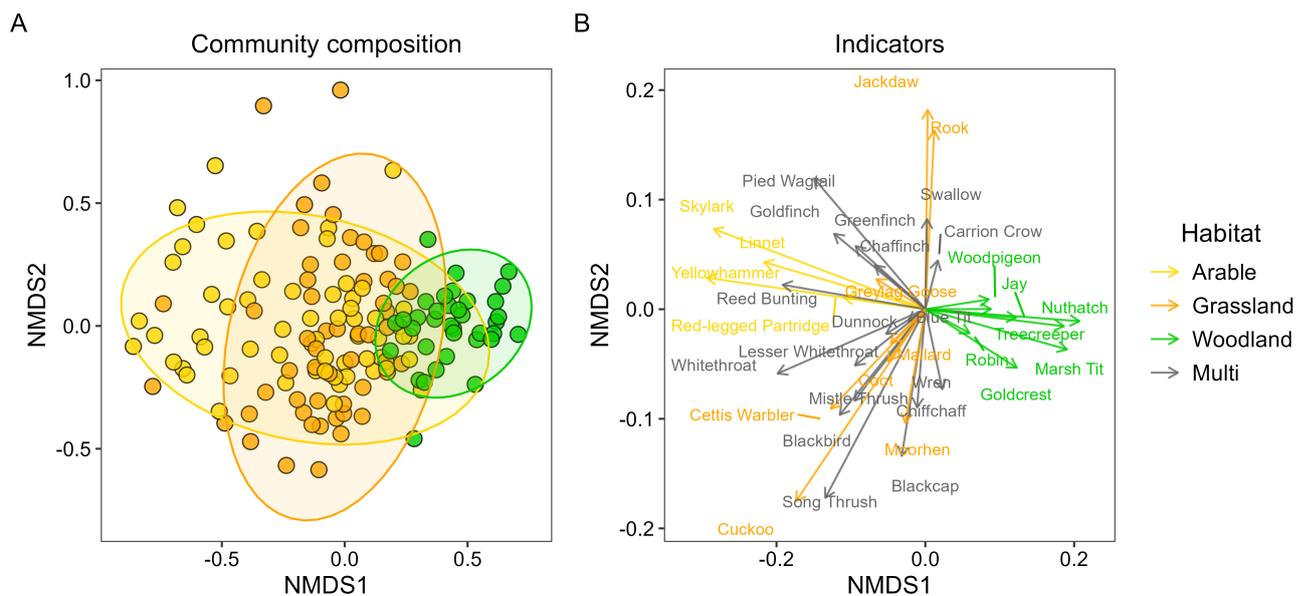


Figure 6: Bird community composition and indicator species across habitats. (A) Non-metric multidimensional scaling (NMDS) ordination of bird communities at each site for a given period (week) of sampling, with points representing sites and shaded ellipses indicating habitat groupings. (B) NMDS species biplot showing statistically significant indicator species. Arrows represent species positions in ordination space; arrow direction indicates the association of each species with the main compositional gradients, and arrow length reflects the strength of this association. Colours denote single-habitat indicator species, while multi-habitat indicators are shown in grey (Table 4).

It is important to note that the indicator species identified through this analysis (Table 4) are statistically derived from the acoustic data and reflect observed patterns of habitat association within this particular dataset. They are not directly comparable to the species included in the official Farmland Bird Indicator or Woodland Bird Indicator, which are defined based on broader national-scale habitat associations, population trends, and expert synthesis. The two approaches complement one another.

Table 4: Observed indicator analysis of bird communities. Significant species ($p \leq 0.05$) are listed with the habitat(s) they indicate. The test statistic measures the strength of association, with higher values indicating stronger habitat specificity. These indicators are derived from the empirical data and are independent of the Wild Bird Indicators for arable and woodland habitats.

Species	Test statistic	p-value	Indicator group
Skylark	0.51	0.001	Arable
Yellowhammer	0.41	0.001	Arable
Red-legged Partridge	0.41	0.001	Arable
Linnet	0.39	0.001	Arable
Cuckoo	0.39	0.001	Grassland
Mallard	0.34	0.001	Grassland
Jackdaw	0.32	0.001	Grassland
Moorhen	0.32	0.001	Grassland
Cettis Warbler	0.31	0.001	Grassland
Rook	0.21	0.034	Grassland
Greylag Goose	0.21	0.034	Grassland
Coot	0.19	0.042	Grassland
Woodpigeon	0.68	0.001	Woodland
Treecreeper	0.62	0.001	Woodland
Nuthatch	0.51	0.001	Woodland
Marsh Tit	0.36	0.001	Woodland
Robin	0.34	0.002	Woodland
Goldcrest	0.34	0.001	Woodland
Great Spotted Woodpecker	0.31	0.004	Woodland
Jay	0.3	0.001	Woodland
Dunnock	0.5	0.001	Arable + Grassland
Whitethroat	0.45	0.001	Arable + Grassland
Goldfinch	0.44	0.001	Arable + Grassland
Lesser Whitethroat	0.44	0.001	Arable + Grassland
Blackbird	0.43	0.001	Arable + Grassland
Chiffchaff	0.41	0.001	Arable + Grassland
Blue Tit	0.4	0.001	Arable + Grassland
Blackcap	0.4	0.001	Arable + Grassland
Greenfinch	0.29	0.001	Arable + Grassland
Swallow	0.29	0.002	Arable + Grassland
Song Thrush	0.27	0.004	Arable + Grassland
Mistle Thrush	0.27	0.001	Arable + Grassland
Pied Wagtail	0.26	0.004	Arable + Grassland
Chaffinch	0.21	0.026	Arable + Grassland
Reed Bunting	0.19	0.037	Arable + Grassland
Carrion Crow	0.27	0.006	Arable + Woodland
Wren	0.2	0.039	Grassland + Woodland

4.2.4 Seasonal activity of birds

Of the 55 bird species with at least 100 detections, 21 showed peak acoustic activity in the early sampling period, 19 in the mid-period, and 15 in the late period (Figure 7). The reliability of these peak activity estimates probably increases with the total number of detections for each species; thus, species positioned higher on the y-axis provide more robust assessments of seasonal activity patterns. Considering all species together, acoustic activity was highest in the mid-season period (306.6 ± 186.8 detections per day per site (mean \pm 1sd)), followed by the early-season period (261.5 ± 127.7), and lastly the late-season period (194.3 ± 122.2).

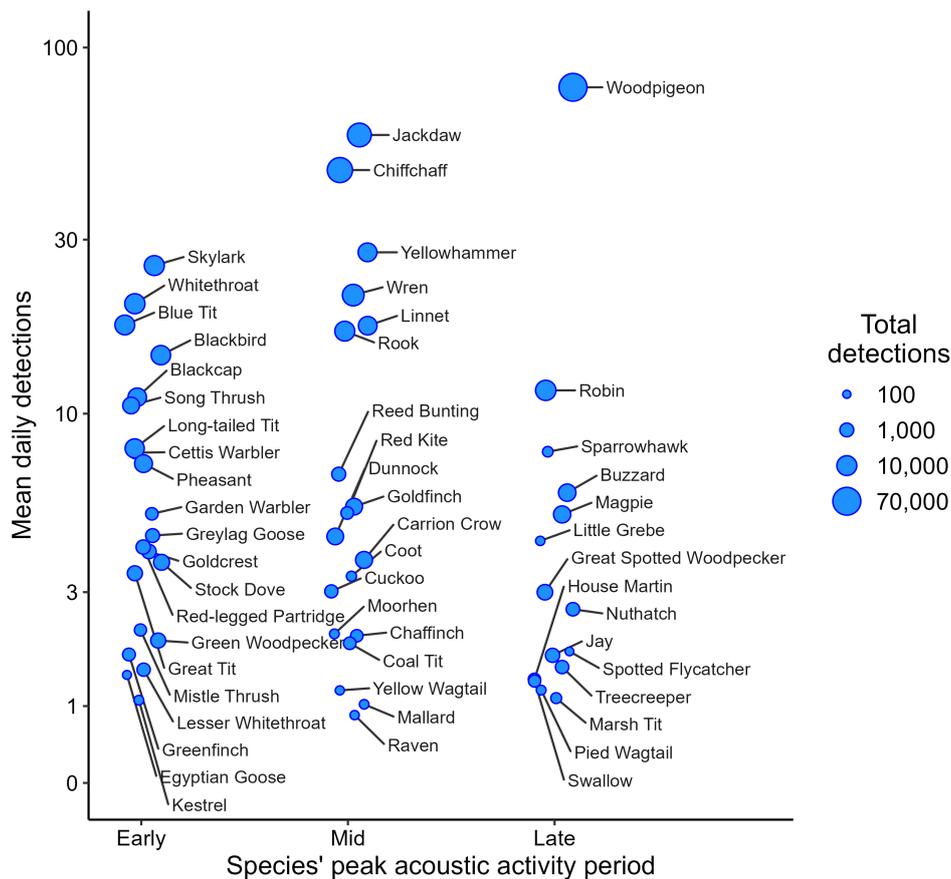


Figure 7: Timing and magnitude of peak vocal activity for bird species detected in acoustic recordings. Each point represents a species positioned by the period in which its mean daily vocal activity was highest (Early, Mid, or Late). The vertical position indicates the log₁₀-transformed mean daily number of detections during the peak period, while point size reflects the total number of detections for that species across the study.

4.3 Bats

4.3.1 Habitat-specific richness and site occurrence of bats

Bat species richness varied across habitats and survey periods (Figure 8). Mean richness per site-period was lowest in woodland (7.3 ± 1.8 species; mean ± 1 SD), intermediate in arable (8.2 ± 1.8), and highest in grassland (9.3 ± 1.2) habitats. Grassland sites consistently supported the highest bat richness, on average, across all survey periods, while woodland sites showed a tendency toward lower richness values in the two periods that were monitored.

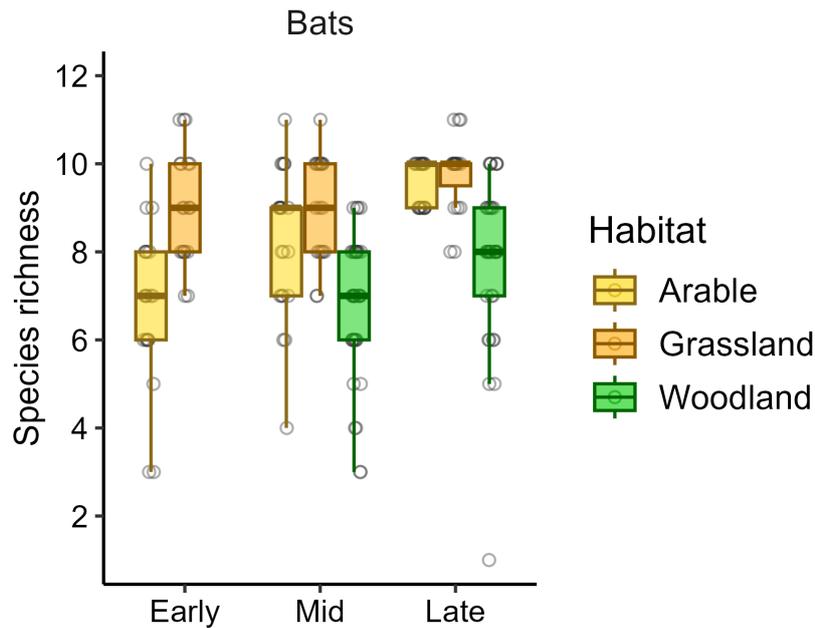


Figure 8: Bat species richness by habitat and recording season. Each point represents a unique sampling location with at least 5 days of continuous recording. Boxplots summarise the spread of data, showing the lower quartile, median, and upper quartile, with whiskers extending to 1.5 times the interquartile range.

Though woodland sites showed lower richness on a per site-period basis, the species accumulation curves (Figure 9) indicated that survey effort was more than sufficient to detect the species present in all habitat types. Indeed, all curves approached or reached their asymptotes after a relatively small number of nights of sampling across sites.

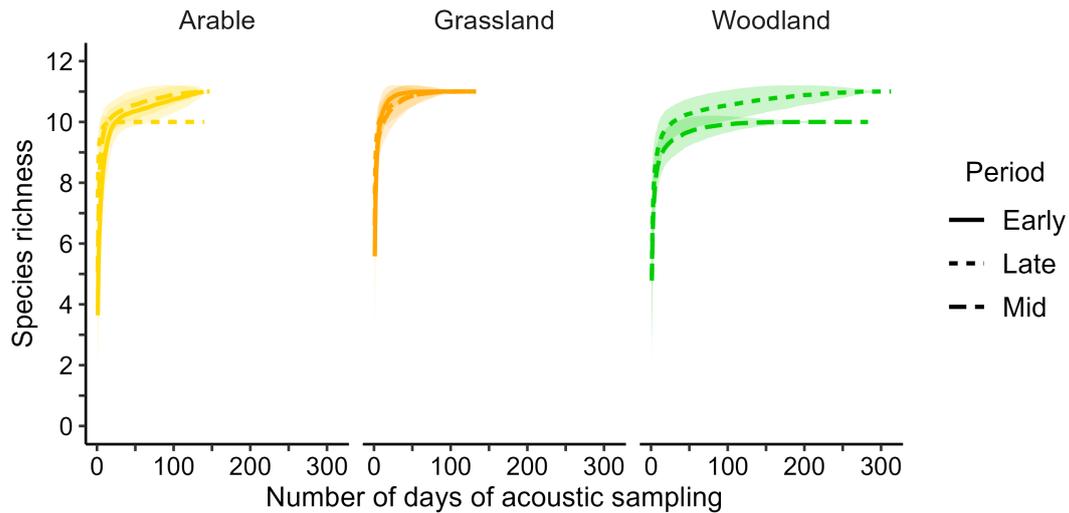


Figure 9: Species accumulation curves for bats in each habitat type and period of the year. The resampling procedure used to generate the curves was agnostic to the site but was restricted to all sites that provided continuous data for at least 5 days; so that most sites contributed similar amounts of effort to the curves.

Despite the rapid accumulation of species at the community level, site occupancy varied considerably among individual bat species (Table 5). Common Pipistrelle and Soprano Pipistrelle were the most widespread species and were detected at all sites, reflecting their status as common and adaptable species throughout the UK. It is worth recalling that these two species also had a less rigorous verification procedure by virtue of the high number of classifier hits, which could slightly upwardly bias their numbers. Most other species were also widespread, with only Leisler’s bat, Nathusius’ Pipistrelle (*Pipistrellus nathusii*) and Whiskered or Brandt’s bat (*Myotis mystacinus* or *M. brandtii*) being detected at less than 75% of all sites. The frequent and widespread detection of the Barbastelle, listed as Vulnerable on the GB mammal red list, was particularly noteworthy, alongside good numbers of Serotine (Vulnerable) and Leisler’s Bat, highlights the importance of the survey area for populations of rare bats.

Table 5: The site presence of bats detected though PAM. The table summarises bat occurrence across sites by habitat type and by call type. Unlike for the birds, all records were manually verified so that detections represent all confirmed detections. N = 80 sites (21 arable, 19 grassland, 40 woodland).

Species	Total detections	% of all sites	% of arable sites	% of grass-land sites	% of wood-land sites	GB red list
Echolocation calls						
Barbastelle	25702	96	100	100	92	VU
Brown Long-eared Bat	10929	99	100	100	98	
Common Noctule	7252	89	100	100	78	
Common Pipistrelle	397695	100	100	100	100	
Daubenton’s Bat	2139	88	90	100	80	
Leisler’s Bat	1153	72	100	95	48	NT
Nathusius’ Pipistrelle	23	19	10	58	5	
Natterer’s Bat	11263	99	100	100	98	

Table 5: The site presence of bats detected through PAM. The table summarises bat occurrence across sites by habitat type and by call type. Unlike for the birds, all records were manually verified so that detections represent all confirmed detections. N = 80 sites (21 arable, 19 grassland, 40 woodland). (continued)

Species	Total detections	% of all sites	% of arable sites	% of grass-land sites	% of wood-land sites	GB red list
Serotine	6869	91	100	100	82	VU
Soprano Pipistrelle	156509	100	100	100	100	
Whiskered or Brandt's Bat	341	69	86	95	48	
Feeding buzzes						
Barbastelle	18	12	0	5	22	
Common Noctule	540	40	57	89	8	
Common Pipistrelle	13526	95	100	100	90	
Daubenton's Bat	24	16	10	11	22	
Natterer's Bat	58	21	0	0	42	
Serotine	28	19	33	26	8	VU
Soprano Pipistrelle	15836	96	100	100	92	
Social calls						
Barbastelle	28	18	5	0	32	VU
Brown Long-eared Bat	3	2	5	5	0	
Common Noctule	24	8	0	16	8	
Common Pipistrelle	37656	99	100	100	98	
Daubenton's Bat	18	10	5	11	12	
Leisler's Bat	2	1	0	0	2	NT
Natterer's Bat	5	2	0	0	5	
Serotine	1	1	0	0	2	VU
Soprano Pipistrelle	58875	92	90	100	90	

4.3.2 Habitat-specific acoustic activity of bats

Common Pipistrelle showed the highest acoustic activity across all habitat types (Figure 10), with mean nightly detection rates per site-period ranging from 100 to 300 detections per night across the three habitats. This was followed by Soprano Pipistrelle, which consistently showed mean activity levels exceeding 30 detections per night.

Habitat-specific differences in acoustic activity were generally subtle across species, and most species did not display a strong preference for any single habitat type. The exceptions to this general pattern include the higher acoustic activity of Common Pipistrelle, Soprano Pipistrelle and Serotine in woodland habitats, and the higher activity of Common Noctule in grassland.

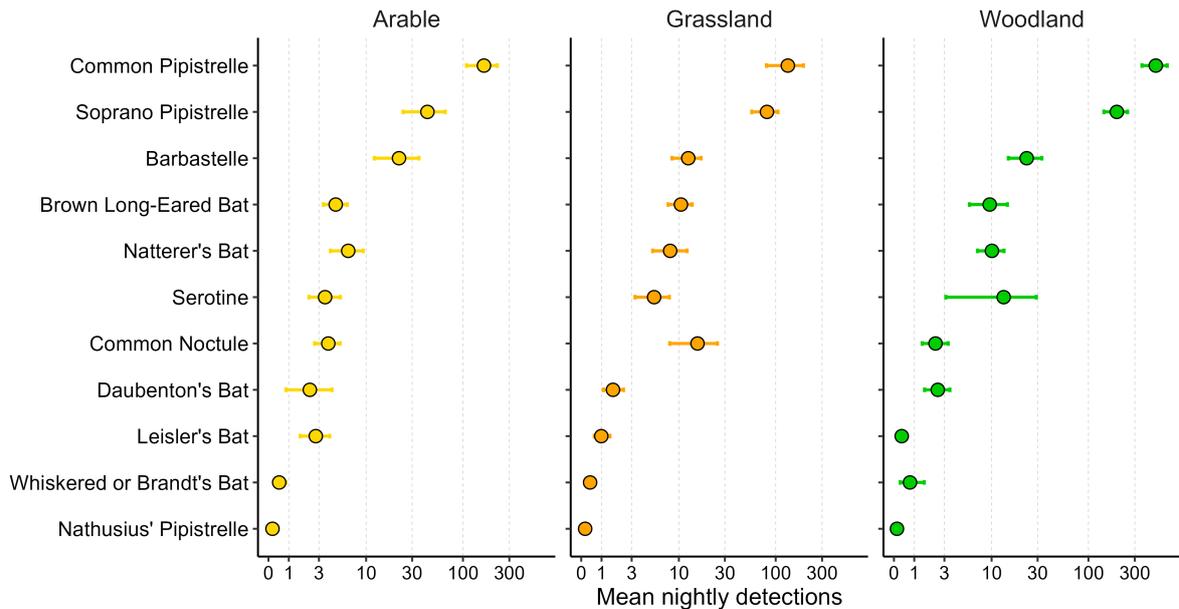


Figure 10: Mean daily bat activity per species across habitat types, based on echolocation call. Points show the mean activity per species per habitat, averaged across sites. Horizontal bars represent bootstrapped 95% confidence intervals obtained by resampling site-period means. Species are ordered according to the total number of detections across all habitat types. The x-axis is \log_{10} -scaled to accommodate highly skewed detection counts and include zero values.

4.3.3 Seasonal bat activity

Focussing on echolocation calls, bat acoustic activity peaked in the late-season period for 8 of the 10 species with at least 100 call detections across the whole dataset (Common Pipistrelle and Whiskered or Brandt's bat proving the exceptions that peaked mid-Season).

There was also seasonal variation in the timing of feeding buzzes and social calls for several species with sufficient detections. By plotting the ratio of feeding buzzes to echolocation calls and social calls to echolocation calls, we can examine changes in foraging behaviour and social activity across the season while accounting for overall detection rates (Figure 11).

For Common Pipistrelle, the feeding buzz ratio showed a clear peak during the mid-season period, suggesting intensified foraging activity during May-June. This ratio declined in the late season. Conversely, the social call ratio for Common Pipistrelle increased progressively throughout the season, with the highest ratios occurring in the late period.

Soprano Pipistrelle showed a different pattern. Feeding buzz ratios remained relatively stable across periods, suggesting consistent foraging behaviour throughout the breeding season. However, social call ratios increased in the late season, with many sites showing ratios exceeding 0.25 (i.e., more than one social call for every four echolocation calls). This sharp increase may reflect the onset of mating activity and increased social interactions as breeding colonies disperse in late summer. Common Noctule showed low feeding buzz ratios throughout the season, with a slight tendency toward increased ratios in the late period. Social calls were rarely detected for this species across all periods.

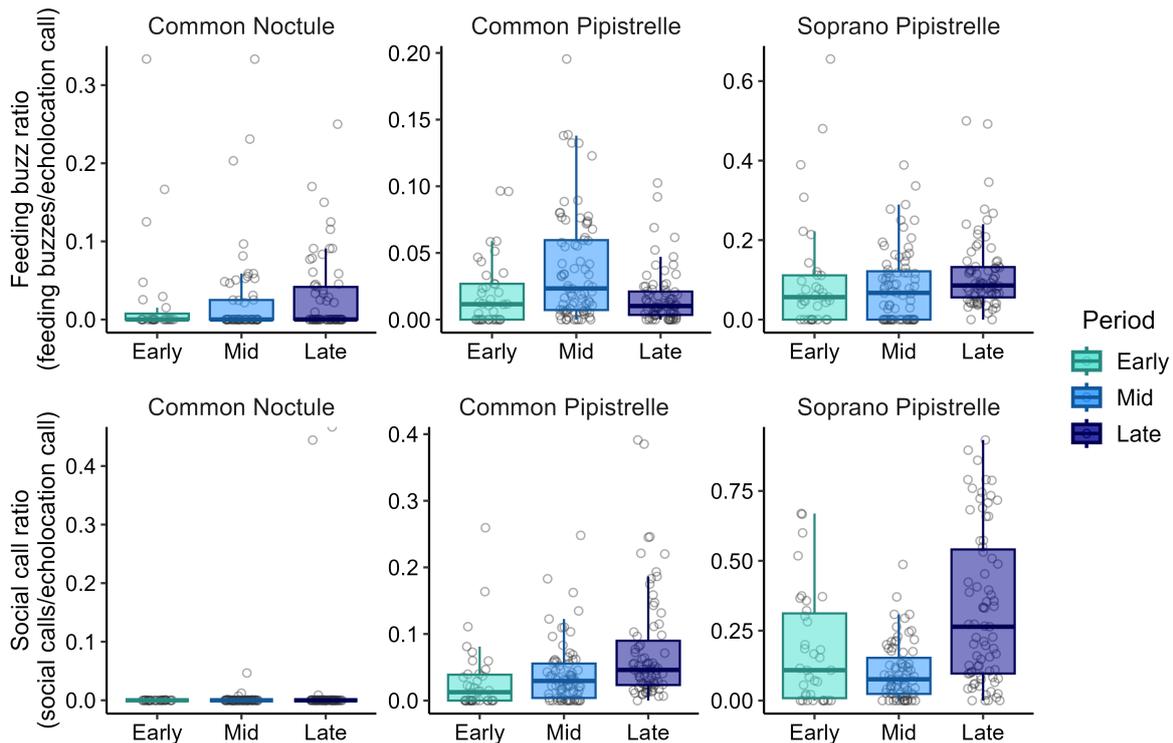


Figure 11: Seasonal variation in the feeding activity (upper) and social activity (lower) of commonly detected bat species. Data are presented as ratios of feeding buzzes or social calls relative to echolocation calls. Each point represents a sampling location with ≥ 5 days of continuous recording. Boxplots display the lower quartile, median, and upper quartile, with whiskers extending to 1.5 times the interquartile range.

4.4 Terrestrial small mammals

Ultrasonic vocalisations of five terrestrial small mammal species were recorded across the study area (Table 6). In the core surveys Hazel Dormouse was detected seven times, at two sites. It was also recorded at one site during the targeted 2025 surveys - where a population was already known - with 28 detections, all from a single location. The other four species, Brown Rat (*Rattus norvegicus*), Common Shrew (*Sorex araneus*), Eurasian Pygmy Shrew (*Sorex minutus*), and European Water Vole (*Arvicola amphibius*) were detected more frequently, with the detections spread relatively even among the different habitats.

Table 6: The site presence of small mammals detected through PAM. All records were manually verified so that detections represent all confirmed detections.

Species	Total detections	% of all sites	% of arable sites	% of grass-land sites	% of wood-land sites	GB red list
Brown Rat	726	24	19	21	28	
Common Shrew	575	54	52	63	50	
Eurasian Pygmy Shrew	1324	75	86	74	70	
European Water Vole	2	1	5	0	0	
Hazel Dormouse	7	2	0	0	5	VU

4.5 Bush-crickets

Six species of bush-cricket were confirmed as present in the survey area (Table 7), though three of these were at particularly low levels. The detection of Large Conehead (*Ruspolia nitidula*) represents one of the most northerly records of the species in the UK as it continues to expand its range northwards following its arrival in Britain in the early 2000s.

Table 7: The presence of bush-cricket species detected through PAM. All records were manually verified so that detections represent all confirmed nightly detections (the number of detector nights on which each species was detected).

Species	Total detection nights	% of all sites	% of arable sites	% of grass-land sites	% of wood-land sites
Dark Bush-cricket	405	86	76	84	92
Great Green Bush-cricket	8	2	5	5	0
Large Conehead	2	1	0	5	0
Long-winged Conehead	168	38	71	74	2
Roesel's Bush-cricket	136	30	71	42	2
Speckled Bush-cricket	493	95	90	95	98

5. DISCUSSION

This study demonstrates the value of passive acoustic monitoring (PAM) for assessing biodiversity across the Connecting Constable and Gainsborough Country landscape restoration area. Over two years, 80 locations spanning woodland, arable, and grassland habitats were surveyed, resulting in verified detections of 107 bird species, at least 11 bat species, five small mammal species, and six bush-cricket species. Analyses suggest that the sampling effort was sufficient to characterise bird and bat communities with a high level of coverage.

The detection of several species of high conservation concern - including Nightingale, Turtle Dove, Hazel Dormouse, Barbastelle, Serotine, and Leisler's Bat - underscores the conservation value of the survey area and highlights the importance of targeted habitat management to support these populations. Except for the noted bat species, most of these flagship taxa were detected at relatively low levels and at a small proportion of sites within each habitat; providing a clear window of opportunity to increase their numbers through targeted management in the coming years. Overall, the data deliver critical baseline information on species distributions, habitat associations, and activity patterns, enabling informed conservation management and the tracking of population changes as habitat restoration progresses. Below, we discuss specific results of interest and expand on the broader application of metrics derived from the acoustic survey.

5.1 Hazel dormouse detection and the potential of acoustic monitoring

One objective of the project was to assess the potential of passive acoustic monitoring for monitoring Hazel Dormouse, a species of conservation concern that has experienced severe population declines across Britain (Goodwin, Hodgson, et al. 2017; People's Trust

for Endangered Species 2023). Hazel Dormouse was detected at three sites, demonstrating that acoustic methods can successfully detect this elusive species. However, detections were limited, and ideally, it would have been preferable to record a greater number of vocalisations across a greater number of sites.

Traditional dormouse surveys rely on nest boxes or nut searches, which require repeated visits and may miss occupied sites if dormice are present at low densities or use areas away from survey points. Acoustic monitoring offers several potential advantages: recorders can be deployed for extended periods (weeks rather than single visits), they sample continuously through the night when dormice are active, and they require less intensive field effort once deployed. However, dormice vocalise infrequently compared to bats or many small mammals, which may result in low detection rates even when present (Newson & Pearce 2022).

The detection of dormice at only three sites could therefore reflect either genuine rarity within the survey area, which existing knowledge would suggest, or the low probability of detecting infrequent vocalisations. Given that acoustic surveys conducted using similar methods and the BTO Pipeline have detected higher levels of dormouse activity in woodland settings elsewhere in the UK (Thorley et al. 2026), it seems likely that dormouse populations are sparse in the study area. The site-specific nature of dormouse activity, the short attenuation distance of dormouse vocalisations (approximately 5 m), and their small home-range sizes (~0.2-0.5 hectares) will also introduce a degree of stochasticity in detections when populations are present at low densities.

Future work in this or other areas could compare acoustic detections with traditional survey methods at the same sites at the same time to better understand the sensitivity of acoustic approaches and optimise survey protocols. Nonetheless, the successful detection of this priority species demonstrates proof-of-concept and suggests that acoustic monitoring could work for broad-scale surveillance across multiple sites within a multi-taxa context.

5.2 Conservation value of the communities

For birds, the presence of Nightingale (detected at 4% of sites) and Turtle Dove (2% of sites) is significant given the severe declines both species have experienced nationally (Stanbury et al. 2021). Both are flagship species for the Landscape Recovery project, associated with scrubby woodland edges and dense hedgerows - habitat features that the project aims to enhance and expand. More generally, the high richness of Red-listed (26 species) and Amber-listed (28 species) birds further demonstrates that the survey area provides important habitat for declining farmland and woodland species. This assemblage of conservation-priority species supports the case for targeted landscape-scale restoration.

The detection of three Vulnerable or Near Threatened bat species (Barbastelle, Serotine, and Leisler's Bat) at high frequencies across the survey area is particularly noteworthy. Barbastelle was detected at 76% of all sites, with particularly high representation in woodland and grassland habitats. This suggests that the survey area supports important populations of this rare species, which is associated with well-connected woodland landscapes and diverse habitat mosaics. The widespread detection of Serotine (91% of sites) and good numbers of Leisler's Bat (72% of sites) further emphasises the bat conservation value of the landscape.

5.3 Habitat associations and indicators

Ordination analysis revealed distinct bird communities between woodland sites and open habitats (arable and grassland), which clustered together in species composition. However, the clustering of arable and grassland habitats should not be interpreted as these habitats being ecologically equivalent. The agricultural landscape in the survey area is a complex mosaic, with small habitat patches, linear features (hedgerows, ditches), and scattered trees interspersed throughout. Many bird species detected at arable and grassland sites may be using these linear features or adjacent woodland patches rather than the primary habitat. This emphasises the importance of maintaining and enhancing habitat connectivity and structural diversity within farmland landscapes.

The identification of 20 statistically significant bird habitat indicator species provides a robust foundation for monitoring ecological change as the Landscape Recovery project progresses. Farmland specialists such as Skylark, Yellowhammer, and Linnet are particularly valuable indicators due to their severe national declines and sensitivity to agricultural management (Stanbury et al. 2021). Increases in their site occupancy or acoustic activity would provide strong evidence of successful implementation of wildlife-friendly farming practices. Woodland specialists, including Great Spotted Woodpecker, Nuthatch, and Treecreeper, are equally important for tracking woodland quality and connectivity, as they depend on mature woodland features and are readily detected acoustically.

These habitat indicator species complement established national metrics such as the Farmland Bird Indicator and Woodland Bird Indicator. While national indicators summarise broad population trends, locally derived indicator species are sensitive to fine-scale habitat structure and management. Tracking changes in both site-level presence and relative acoustic activity of these species therefore offers a powerful, site-specific framework for evaluating restoration outcomes within the project area.

In contrast to birds, habitat-specific patterns in bat activity were generally subtle and an indicator analysis of this group (not presented) did not reveal any consistent, statistically informed indicators. Common Pipistrelle, Soprano Pipistrelle, and Serotine showed higher activity levels in woodland, while Common Noctule was more strongly associated with grassland. The relatively even distribution of most bat species across habitats likely reflects their high mobility and reliance on the landscape mosaic for foraging and commuting. With additional data or more detailed analyses of the geographic context of each sampling location, such as incorporating proximity to linear features and water bodies, habitat associations could be further clarified.

5.4 Activity patterns and behavioural insights

Quantifying acoustic activity across habitats and seasons provided insights beyond simple presence–absence data. For birds, seasonal patterns in acoustic activity broadly aligned with breeding phenology, with peak activity occurring in early and mid-season for most species. These patterns provide a useful proxy for breeding activity and can inform optimal timing for future monitoring surveys, especially if the situation arises where monitoring effort would need to be pared back.

For bats, the capability of the Pipeline’s ultrasonic classifier to distinguish between echolocation calls, feeding buzzes, and social calls yielded additional ecological insights for several species. Seasonal shifts in activity, such as increased feeding buzz ratios for Common Pipistrelle during

mid-season and higher proportions of social calls later in the season, likely reflect changes in foraging intensity, mating behaviour, and post-breeding dispersal. Sites with consistently high feeding buzz ratios may represent important foraging areas, while elevated levels of social calls in late season may indicate key mating or swarming locations which could be followed up on with more targeted monitoring. This approach demonstrates the potential of acoustic monitoring to move beyond species inventories towards an understanding of functional habitat use.

5.5 Future directions patterns and behavioural insights

Continued acoustic monitoring is essential for tracking how species and communities respond to habitat restoration across the CCGC survey area. Repeating surveys at the same, or directly comparable, sites using consistent protocols will allow robust assessment of community change and species-specific trends in acoustic activity, particularly changes in mean daily activity levels. To ensure comparability through time, an appropriate level of risk-based acoustic verification should be maintained, so that species identifications are comparable across years. While recording devices and automated classifiers may evolve over the course of the project, maintaining consistent verification standards will be critical to ensure data reliability. As restoration progresses, direct comparison of pre- and post-intervention data will provide a clear test of whether management actions are achieving their intended outcomes.

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Front cover: Nightingale, by Liz Cutting / BTO; back cover: Hazel Dormouse, by Ruud Foppen

Connecting Constable and Gainsborough Country: baselining for landscape recovery using multi-taxa passive acoustic monitoring

Connecting Constable and Gainsborough Country is a DEFRA-funded landscape recovery project. This report describes the use of passive acoustic monitoring (PAM) to assess the status and distribution of birds, bats, terrestrial small mammals, and bush-crickets across the Stour, Brett, and Box valleys in south Suffolk. The project supports habitat restoration and woodland connectivity, with a focus on rare or declining species of conservation concern, including the Hazel Dormouse, informed by robust monitoring.

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