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continued on the back inside cover

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ARTICLE

Bat assemblages at two contrasting agricultural sites in northern Algeria: a preliminary conservation assessment

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Abstract: Agricultural intensification is a key driver of biodiversity loss in Mediterranean agroecosystems, yet its effects on protected bat assemblages remain poorly documented in northern Africa. All six bat taxa recorded are legally protected in Algeria. Several of the recorded species are also covered by international conservation instruments for their European populations, while the probable North African endemic *Plecotus* cf. *gaisleri* is of particular biogeographic interest. We conducted a preliminary assessment of bat activity, diversity, and community composition at two representative agricultural sites—a low-input citrus orchard and an intensively managed vineyard—in northern Algeria. Acoustic monitoring was conducted from March to November 2023. A total of 349 acoustic contacts were recorded at the citrus orchard site and 74 at the vineyard site, corresponding to a 4.6-fold difference in observed activity. Negative binomial modelling indicated a substantially lower fitted contact rate at the vineyard than at the orchard (IRR = 0.215, 95% CI: 0.130–0.355). Monthly taxon richness and Shannon diversity were also higher at the orchard. The vineyard assemblage was strongly dominated by *Pipistrellus kuhlii*, whereas a more taxonomically diverse assemblage was detected at the orchard. NMDS suggested site-associated structuring of bat assemblages, and a paired PERMANOVA detected a significant difference between the two sampled sites ($R^2 = 0.281$, pseudo-$F = 6.26$, $p = 0.004$). No statistically significant difference in multivariate dispersion was detected (PERMDISP: $F = 0.808$, $p = 0.100$), although the small sample size limits the power of this diagnostic test. Although based on a single orchard–vineyard pair, these results suggest that the low-input orchard examined here may provide favourable conditions for a protected bat assemblage. Replicated multi-site studies are needed before generalizing this pattern to low-input perennial agroecosystems across North African farmland.

Keywords: Acoustic monitoring, agroecosystems, biodiversity conservation, community composition, low-input farming, Mediterranean landscapes, preliminary assessment.

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INTRODUCTION

Agricultural pests are a major constraint on crop productivity and represent a significant source of economic loss in global agroecosystems (Oerke 2006). In Algeria, pest-driven reductions in agricultural output intersect with broader economic vulnerabilities linked to hydrocarbon dependency and climate variability, increasing the need for resilient and sustainable agricultural systems (Bouchenak 2021). Climate change is expected to intensify pest pressure through shifts in phenology, distribution, and trophic interactions (Deutsch et al. 2018; Lehmann et al. 2020), further reinforcing the urgency of effective pest management strategies.

Integrated Pest Management (IPM) provides a coherent framework for reducing reliance on synthetic pesticides while maintaining crop yields and profitability (Pretty & Bharucha 2014). IPM combines biological control, habitat management, resistant cultivars, diversified cropping systems, and decision-support tools to prevent or limit pest outbreaks (Roubos et al. 2014; Gurr et al. 2017). Beyond direct pest suppression, IPM can enhance biodiversity and long-term agroecosystem resilience by promoting functional diversity and ecosystem services (Gupta et al. 2024; Marcelino et al. 2024). These approaches are particularly relevant in Mediterranean agricultural systems, where pest outbreaks and pesticide resistance generate substantial economic and environmental costs (Biondi et al. 2012).

Insectivorous bats constitute a potentially important, yet underutilized, component of biological control in agricultural landscapes. Numerous studies show that bats consume large proportions of agricultural pest taxa, often exceeding 40% of their diet in intensive crop systems (Zhu et al. 2024), and bats have been estimated to provide agricultural pest-control services worth at least USD 3.7 billion annually in North America, although such estimates remain context-dependent (Boyles et al. 2011; Maas et al. 2016). In Mediterranean contexts, bat assemblages exploit agricultural pest prey and can provide ecologically and economically relevant pest regulation services (Russo & Ancillotto 2015; Ancillotto et al. 2022). The efficiency of these ecosystem services depends on bat species composition, habitat structure, landscape complexity, and exposure to agrochemical inputs (Tuneu-Corral et al. 2023). Structurally complex agricultural habitats with permanent vegetation generally support greater insect abundance and foraging opportunities, whereas intensive management and frequent pesticide applications may reduce prey availability and limit bat activity, thereby decreasing the potential for natural pest suppression.

In northern Africa, chiropteran research has predominantly focused on natural, cavernicolous, urban, and rural habitats, documenting species distributions, roosting ecology, trophic patterns, and conservation status (Bendjeddou et al. 2014, 2017, 2020; Farfar et al. 2017; Loumassine et al. 2017a,b, 2019, 2020; Mokrani et al. 2018a,b). More recently, studies in Algeria have expanded to forest ecosystems, including Mediterranean montane habitats (Hamida et al. 2021; Ait-Abdesselam et al. 2025; Boukhari et al. 2025). Collectively, this literature highlights the taxonomic and functional diversity of Algerian bats across non-agricultural environments. However, agroecosystems remain largely unstudied, despite being characterized by high pest pressure, frequent pesticide use, and landscape simplification, and despite the well-established role of bats as biological control agents in agricultural systems elsewhere.

Bat taxa recorded in the present study are legally protected under Algerian national legislation. Several of the identified species are also covered by international conservation instruments for their European populations, although these listings should not automatically be interpreted as applying to the Algerian populations recorded here. Despite their national legal protection, bat diversity, activity, and habitat use in Maghreb agroecosystems remain poorly documented, even though agricultural landscapes occupy extensive areas of the Mediterranean lowlands. Assessing bat assemblages in agricultural landscapes can therefore provide useful baseline information for regional conservation planning and the development of biodiversity-friendly farming practices.

The present study addresses this knowledge gap by characterizing bat assemblages at two contrasting agricultural sites in the Sebaou Valley, near Draâ Ben Khedda, Tizi Ouzou Province, northern Algeria. Because only one citrus orchard and one vineyard were surveyed, the study should be interpreted as a preliminary conservation-oriented case study rather than as a spatially replicated comparison of crop types or management systems. Given the preliminary two-site design, we evaluated three site-specific predictions: (1) monthly taxon richness and Shannon diversity would be higher at the sampled citrus orchard than at the sampled vineyard; (2) the vineyard assemblage would show stronger numerical dominance by generalist taxa, particularly *Pipistrellus* spp.; and (3) assemblage composition would differ between the two sampled sites. Potential relationships with vegetation structure, management intensity, pesticide use, and prey availability were treated as hypotheses for future replicated studies rather than as mechanisms directly tested here. By integrating acoustic activity, α-diversity indices, and community composition analyses, this study provides a first preliminary assessment of bat communities in Algerian agroecosystems and highlights their potential conservation value within Mediterranean agricultural landscapes.

MATERIALS AND METHODS

Study area and sampling sites

The study was conducted in the Sebaou Valley, near Draâ Ben Khedda, Tizi Ouzou Province, northern Algeria (36.733° N, 3.950° E), at an elevation of approximately 56 m. The area lies within the sub-humid Mediterranean bioclimatic zone and is characterized by mild winters. Mean annual temperature is approximately 19.2°C, and annual precipitation exceeds 600 mm. Soils at both study sites were classified as sandy clay loam. The surrounding area is predominantly agricultural and includes several crop types (Image 1).

The first selected citrus orchard (Site A) is embedded within an extensive agricultural landscape dominated by long-established citrus orchards, interspersed with vegetable cropping systems. This orchard is managed under an extensive conventional production system, characterized by a low planting density (800–850 trees ha^{-1}), infrequent application of agricultural inputs, and the absence of weed management practices. Over the monitoring period spanning March–November 2023, no pesticide treatments were applied by the farmer (Table 1).

By contrast, the second selected vineyard is located in an area characterized by high agricultural production intensity. This table grape vineyard operates under a high-input intensive production system, featuring a high planting density (1,111–1,200 vines ha^{-1}), raised-bed cultivation, and drip irrigation combined with frequent applications of agrochemical inputs, including fertilizers, herbicides, and pesticides, with the objective of maximizing yield. Weed management was continuously implemented through the use of chemical herbicides throughout the study period (Table 1).

Vineyards in the area are also susceptible to fungal diseases, notably powdery mildew (*Uncinula necator*) and downy mildew (*Plasmopara viticola*), for which farmers applied fungicides such as Mancozeb and Cyproconazole. To control insect pests, including the African leafhopper, mites, and grape moths, insecticides such as Deltamethrin and Chlorpyrifos-methyl were used. Glyphosate was applied for weed control as a chemical herbicide.

Because only one citrus orchard and one vineyard were included, these two sites were considered representative examples of contrasting agricultural management contexts rather than independent replicates of each habitat type. Therefore, observed differences in bat activity and assemblage structure should be interpreted as site-specific patterns that provide preliminary insights for future multi-site investigations.

Sampling design

Acoustic surveys were conducted monthly from March to November 2023 at both study sites. Each monthly survey consisted of a one-hour acoustic monitoring period conducted after sunset during the period of peak bat activity. The same fixed 500-m transect was traversed four consecutive times, once during each 15-minute segment (P1–P4), at an approximately constant walking speed of 2 km h^{-1}. The Batlogger M operated throughout the monitoring period and stored triggered acoustic files of 5 s at a sampling frequency of 312.5 kHz. The four 15-minute segments within each monthly survey were treated as non-independent subsamples and pooled at the site × month level before statistical analyses. Thus, all inferential analyses were based on 18 pooled site × month observations. These observations represent repeated monthly measurements from the same two sites and should not be interpreted as independent spatial replicates of orchard and vineyard habitats (Image 2).

Acoustic surveys and environmental variables

At each site, a fixed 500-m transect was traversed four consecutive times during the one-hour session, with each traversal lasting approximately 15 min at a walking speed of about 2 km h^{-1}. Successive traversals were conducted in alternating directions along the same route. Surveys began at sunset. The two sites were surveyed on consecutive nights, with each survey beginning at sunset. Survey order was alternated among months: when Site A was surveyed on the first night and Site B on the following night during one monthly survey, Site B was surveyed first during the next monthly survey. Bat calls were recorded using a Batlogger M (Elekon AG, Lucerne, Switzerland; firmware v2.6.2). The detector operated continuously in automatic trigger mode

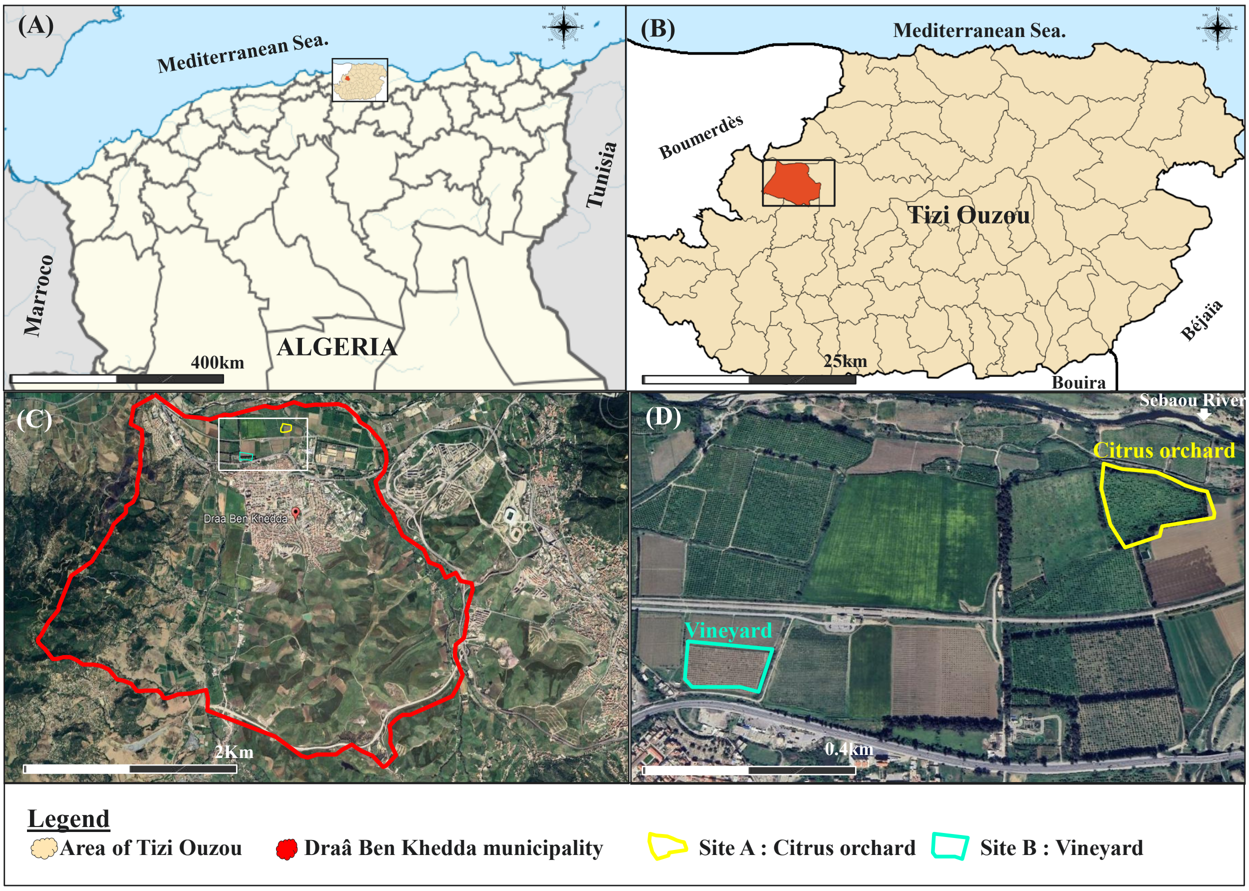

Image 1. Study area: A—Location of the study area in northern Algeria | B—Location of Tizi Ouzou Province within Algeria | C—Draâ Ben Khedda municipality showing the locations of the citrus orchard and vineyard study sites | D—Enlarged satellite image of the study sites in Draâ Ben Khedda municipality.

throughout each one-hour survey and stored triggered acoustic events as 5-s recordings. Acoustic signals were sampled at 312.5 kHz, corresponding to a Nyquist frequency of 156.25 kHz. During each one-hour survey, air temperature and relative humidity were measured every 15 minutes using an IHM6150SI pocket thermo-hygrometer (type K) (precision ±1°C; ±5% RH). Cloud cover and wind speed were also recorded to document weather conditions potentially influencing bat activity and detectability (Russo & Jones 2003). Weather variables were recorded to document survey conditions and to ensure that surveys were not conducted during rainfall or strong winds. They were not included as model covariates because of the small sample size, the limited number of observations relative to the number of potential predictors, and their seasonal collinearity with month. Consequently, seasonal climatic effects cannot be separated from other sources of month-related variation.

Call identification

Recorded calls were manually inspected using BatSound v3.10 (Pettersson Elektronik AB, Sweden). Spectrograms were examined using call structure, start and end frequencies, frequency of maximum energy, bandwidth, call duration, and pulse shape. Taxonomic assignments followed Barataud (2012) and regional reference data from northwestern Africa (Russo & Jones 2003; Disca et al. 2014; Dalhoumi et al. 2016; Ahmim et al. 2020).

A total of 1,978 call sequences were recorded during the sampling period. After manual validation, 423 high-quality sequences (21.39%) were retained for species identification and acoustic analyses. The remaining 1,555 recordings were excluded (78.61%) because of poor signal quality, ambiguous acoustic characteristics, or environmental and insect noise.

A bat contact was defined as one triggered 5-s recording containing a sequence of echolocation calls attributable to a single bat pass. Recordings containing simultaneous calls from clearly distinguishable taxa were counted separately for each taxon.

High-duty-cycle calls of *Rhinolophus hipposideros* were identified from their characteristic FM/CF/FM structure and a peak-frequency range of 115.9–121.0 kHz reported for northern Algeria (Ahmim et al. 2020). Because rhinolophid calls are highly directional and may be detected less readily during walked transects, only recordings with a clear constant-frequency component and diagnostic harmonic structure were retained.

Low-duty-cycle calls assigned to *Eptesicus isabellinus*, *Hypsugo savii*, *Pipistrellus kuhlii*, and *Pipistrellus pipistrellus* were identified from a combination of FM/QCF structure, frequency of maximum energy, pulse shape, and regional reference data. Calls falling within known frequency-overlap ranges and lacking additional diagnostic characteristics were retained only at acoustic-group level and excluded from species-level analyses.

Calls assigned to *Plecotus* showed an FM structure and a starting-frequency range consistent with regional descriptions of *P. gaisleri* (Dalhoumi et al. 2016). However, because species within *Plecotus* cannot be reliably distinguished using acoustic data alone, these records are reported provisionally as *Plecotus* cf. *gaisleri*. This designation indicates probable, but not definitive, species identity.

The six bat taxa retained for analysis were *Rhinolophus hipposideros* (Borkhausen, 1797) (Rhinolophidae), *Eptesicus isabellinus* (Temminck, 1840) (Vespertilionidae), *Hypsugo savii* (Bonaparte, 1837) (Vespertilionidae), *Pipistrellus kuhlii* (Kuhl, 1817) (Vespertilionidae), *Pipistrellus pipistrellus* (Schreber, 1774) (Vespertilionidae), and *Plecotus cf. gaisleri* (Benda et al., 2004) (Vespertilionidae).

Acoustic parameters measured in the present study are summarized in Table 2, and representative spectrograms are shown in Image 3. The global conservation status, international convention listings, and Algerian legal protection status of all recorded bat taxa are summarized in Supplementary Table S1.

Data structure and response variables

For each sampling session, the dataset contained species-specific contact counts. Overall bat activity per session was quantified as the total number of acoustic contacts across all detected species: Total contacts = $\sum_{n=1}^{6} n_i$, where n_i is the number of contacts for species *i* in that session. A sampling session was considered positive when Total contacts > 0. Monthly totals (per site) were obtained by aggregating the four periods (P1–P4) within each month.

Taxon richness, composition, and diversity indices

Taxon richness was computed per site × month as the number of detected taxa (contacts > 0). Assemblage composition was expressed as the proportion of total contacts contributed by each taxon at each site.

Community diversity was quantified monthly using standard indices. Shannon diversity was computed as $H' = -\sum_{i=1}^{S} p_i \ln(p_i)$ following Shannon (1948), with $p_i = \frac{n_i}{N}$ and $N = \sum_{i=1}^{S} n_i$. Diversity metrics were computed in R ver -sion 4.5.2 (R Core Team 2025) following standard community ecology workflows, including the *vegan* package (version 2.7-1) when applicable (Oksanen et al. 2022).

Statistical analysis

Different statistical approaches were used to address complementary ecological questions. Monthly taxon richness and Shannon diversity were compared using Wilcoxon signed-rank tests, bat activity was analysed using a negative binomial regression model, whereas differences in community composition were evaluated using NMDS and PERMANOVA. This analytical framework avoided the use of multiple statistical tests to address the same biological question.

Wilcoxon signed-rank test

To compare monthly taxon richness and Shannon diversity between the citrus orchard and the vineyard, we used the Wilcoxon signed-rank test for paired comparisons. This non-parametric test was selected because the paired data did not meet the assumptions of normality. The Wilcoxon signed-rank test was therefore applied only to taxon richness and Shannon diversity. Statistical significance was assessed at $p < 0.05$ using the function wilcox.test in R.

Non-metric multidimensional scaling (NMDS)

Community composition was analyzed using a taxon-by-sample abundance matrix based on the number of acoustic contacts recorded for each bat species at the site × month level (n = 18), with detections pooled across the four 15 min segments within each monthly session. Bray–Curtis dissimilarities were calculated from quantitative acoustic activity data to quantify differences in assemblage composition among sampling units. Non-metric multidimensional scaling (NMDS) was performed using the *vegan* package in R (Oksanen et al. 2022). The stress value was used to evaluate ordination quality, with values < 0.1 considered indicative of a good representation of the data.

Permutational analysis of variance (PERMANOVA)

Site-associated differences in bat assemblage structure were evaluated using PERMANOVA based on Bray–Curtis dissimilarities, implemented with the *adonis2* function in the *vegan* package (Oksanen et al. 2022). The analysis was conducted on the taxon-by-sample matrix containing the 18 pooled site × month observations. To preserve the paired temporal structure, permutations of the Site labels were restricted within Month. With nine monthly pairs, 511 permutations were generated in addition to the observed configuration. Because only one site represented each agricultural context, the analysis evaluates a repeated contrast between the sampled orchard and vineyard and does not provide spatial replication of crop type or management intensity. Homogeneity of multivariate dispersion was evaluated using *betadisper* (Anderson 2001) and *permutest*, with permutations following the same paired monthly structure.

Negative binomial model of bat activity

Monthly bat activity was analysed using a negative binomial generalized linear model with a log link, implemented in the glmmTMB package (family = nbinom2; Brooks et al. 2017). The response variable was the total number of acoustic contacts recorded during each pooled one-hour site × month session (n = 18). Site and Month were included as fixed effects, and the fitted model was: Total contacts ~ Site + Month. Because each agricultural context was represented by only one site, the Site coefficient is interpreted strictly as a contrast between the sampled orchard and vineyard rather than as a general effect of crop type or management intensity. Effect sizes are presented as incidence rate ratios with 95% confidence intervals obtained by exponentiating the model coefficients.

Model diagnostics

Model adequacy was assessed using simulation-based residual diagnostics implemented in DHARMa (Hartig 2016), including checks for residual uniformity, dispersion, and outliers.

Data visualization and software

All analyses were performed in R (RStudio environment). Figures were produced using ggplot2 (Wickham 2016) and exported at publication-quality resolution.

RESULTS

Bat activity

A total of 423 bat acoustic contacts were recorded across both agricultural habitats during the sampling period. Bat activity was substantially higher in the orchard (Site A), with 349 contacts, compared to the vineyard (Site B), where only 74 contacts were detected, corresponding to a 4.6-fold difference in total activity.

Bat contacts were detected in 33 of the 36 15-min segments at the orchard site (91.7%) and in 21 of the 36 segments at the vineyard site (58.3%). Segment-level detection frequencies are reported descriptively only; all inferential analyses were conducted at the pooled site × month level. Monthly activity patterns differed markedly between sites (Image 4). In the orchard, bat activity peaked in March (92 contacts) and remained relatively high in August (53 contacts) and October (47 contacts), followed by a pronounced decline in June (4 contacts) and November (18 contacts). In contrast, vineyard activity remained consistently low throughout the season, with moderate increases in October (20 contacts) and in July and September (12 contacts each), and minimal activity in June (1 contact) and November (3 contacts).

The negative binomial model indicated a significantly lower fitted contact rate at the sampled vineyard than at the sampled orchard (IRR = 0.215, 95% CI = 0.130–0.355, $p < 0.001$). The fitted contact rate at the vineyard was approximately 79% lower than that at the orchard. This estimate represents a contrast between the two sampled sites and should not be interpreted as a general effect of habitat type or management intensity. Relative to March, activity was significantly lower in June and November, whereas the remaining month-specific coefficients did not differ significantly from the March reference level (Table 3).

Taxon richness and diversity

Taxon richness was consistently higher in the orchard than in the vineyard throughout the sampling period (Image 5). A total of six bat taxa were detected in the orchard, including *R. hipposideros*, *E. isabellinus*, *H. savii*, *P. kuhlii*, *P. pipistrellus*, and *Plecotus* cf. *gaisleri*. In contrast, only three taxa were recorded in the vineyard: *E. isabellinus*, *P. kuhlii*, and *P. pipistrellus*.

Monthly taxon richness in the orchard ranged 2–6 taxa, with a maximum observed in April, whereas vineyard assemblages were frequently dominated by a single taxon and reached a maximum of three taxa only in August. Wilcoxon signed-rank tests indicated

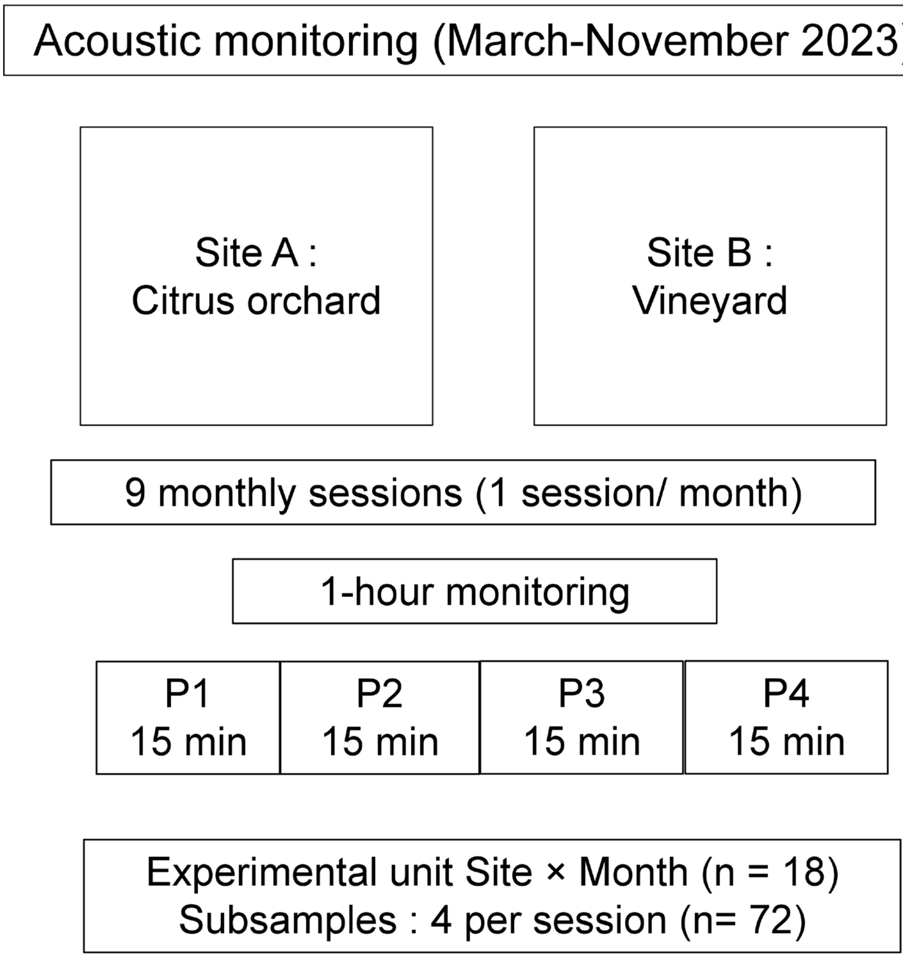

Image 2. Nested sampling design of monthly acoustic monitoring: Monthly acoustic monitoring was conducted at two sites from March to November 2023. Each site × month session (n = 18) consisted of one hour of continuous acoustic monitoring in automatic trigger mode, during which detected acoustic events were stored as 5-s recordings subdivided into four consecutive 15-minute segments (P1–P4; 72 subsampling segments in total).

Table 1. Characteristics of the selected citrus orchard and vineyard in the Sebaou Valley, near Draâ Ben Khedda, Tizi Ouzou Province, northern Algeria.

Characteristics	Site A: citrus orchard	Site B: vineyard
Geographical coordinates	36.740° N, 3.958° E	36.741° N, 3.960° E
Variety	Orange (Washington Navel)	Table grape (Red Globe)
Rootstock	*Citrus volkameriana*	41B
Management intensity	Low-input management	High-input management
Weeding method	No weeding	Chemical weeding
Phytosanitary pressure	No pesticide application during the monitoring period; historically low input use.	Regular treatments
Type of irrigation	Drip irrigation	Drip irrigation
Soil texture	Sandy clay loam	Sandy clay loam
Age (years)	5	5
Area (ha)	1.0	1.5
Plant spacing (m)	3 × 4	3 × 3

significantly higher monthly taxon richness in the orchard (V = 28, $p = 0.0213$), with median values of three taxa per month compared to one taxon per month in the vineyard, corresponding to a median difference of two taxon (Table 4).

Shannon diversity followed a similar pattern (Image 6). Median Shannon diversity was 0.971 in the orchard and 0 in the vineyard, and this difference was statistically significant (V = 44, $p = 0.0129$). Overall, these findings indicate that the citrus orchard supported significantly richer and more diverse bat assemblages than the vineyard.

Taxon composition

Taxon composition differed markedly between the two agricultural habitats (Image 7). In the orchard, bat activity was co-dominated by *P. kuhlii* (43.6% of total contacts) and *E. isabellinus* (43.3%), with additional

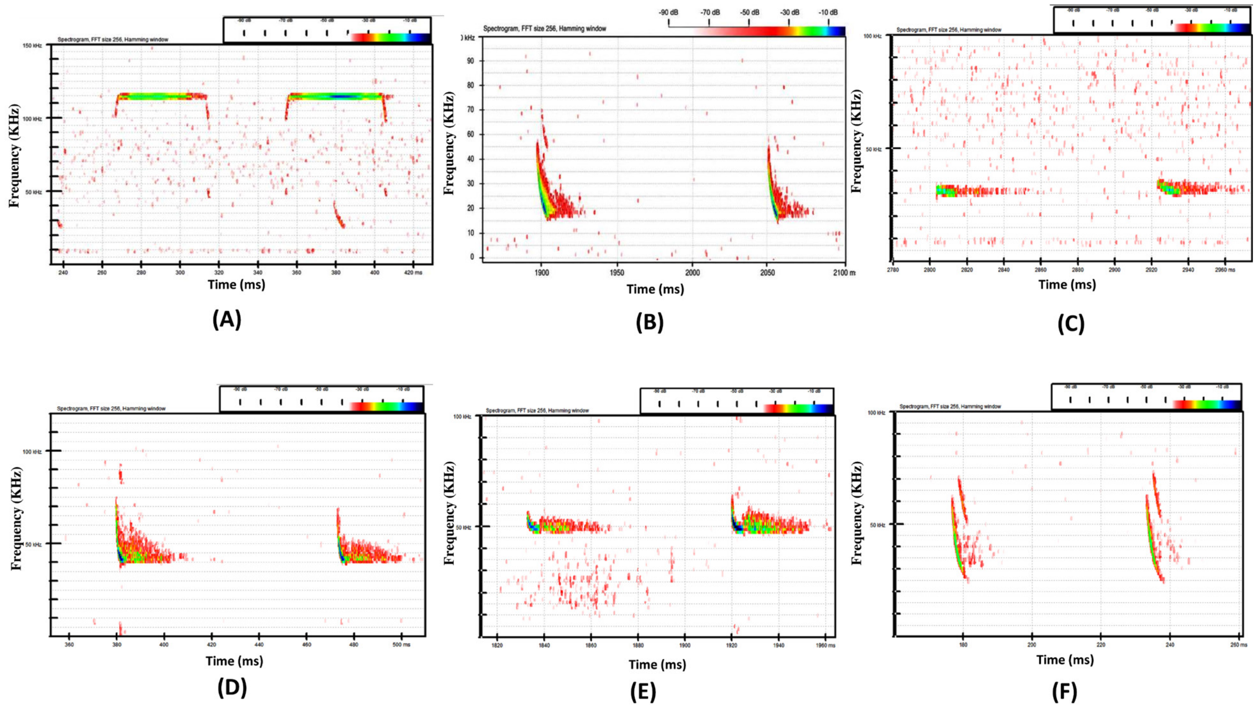

Image 3. Representative spectrograms of echolocation calls assigned to the six bat taxa recorded at the two agricultural study sites in northern Algeria: A—*Rhinolophus hipposideros* | B—*Eptesicus isabellinus* | C—*Hypsugo savii* | D—*Pipistrellus kuhlii* | E—*Pipistrellus pipistrellus* | F—*Plecotus* cf. *gaisleri*. Spectrograms were generated in BatSound v3.10. Frequency is shown in kHz and time in ms. Display ranges were adjusted to facilitate visualization of the diagnostic call structure of each taxon.

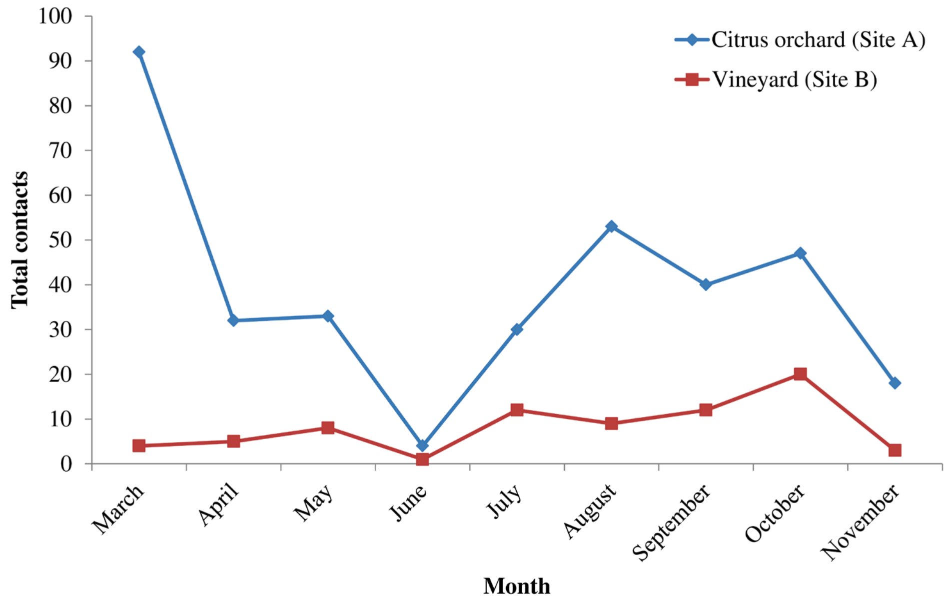

Image 4. Monthly bat activity (total contacts) in the citrus orchard (Site A) and vineyard (Site B) from March to November.

contributions from *H. savii* (5.7%), *P. pipistrellus* (4.6%), *Plecotus cf. gaisleri* (2.3%), and *R. hipposideros* (0.6%).

In contrast, the vineyard assemblage was overwhelmingly dominated by *P. kuhlii*, which accounted for 93.4% of all contacts, while *E. isabellinus* (3.9%) and *P. pipistrellus* (2.6%) were only sporadically detected. This overwhelming dominance by a single species was consistent with the lower taxon richness and Shannon

Table 2. Acoustic parameters of bat taxa recorded at the two agricultural study sites in northern Algeria. Values are presented as mean ± SD.

Taxon	N	Pulse structure	SF (kHz)	EF (kHz)	FME (kHz)	D (ms)	Identification source
Rhinolophus hipposideros	2	FM/CF/FM	100.06 ± 1.55	97.73 ± 0.89	115.8 ± 0.62	45.3 ± 2.70	Ahmim et al. (2020)
Eptesicus isabellinus	153	FM/QCF	39.58 ± 9.27	23.15 ± 1.57	27.24 ± 1.28	9.54 ± 2.01	Ahmim et al. (2020)
Hypsugo savii	20	FM/QCF	38.48 ± 4.02	31.63 ± 2.20	33.66 ± 1.17	9.01 ± 2.84	Disca et al. (2014)
Pipistrellus kuhlii	222	FM/QCF	63.94 ± 8.16	38.76 ± 1.23	41.24 ± 1.14	5.19 ± 1.50	Dalhoumi et al. (2016)
Pipistrellus pipistrellus	18	FM/QCF	62.9 ± 8.04	46.45 ± 3.1	50.02 ± 2.37	6.58 ± 2.22	Russo & Jones (2003)
Plecotus cf. *gaisleri*	8	FM	50.24 ± 5.20	26.86 ± 1.07	33.28 ± 0.94	3.11 ± 0.57	Dalhoumi et al. (2016);

N—number of sequences measured in this study | FM—frequency-modulated | CF—constant-frequency | QCF—quasi-constant-frequency | SF—start frequency | EF—end frequency | FME—frequency of maximum energy | D—duration | ms—milliseconds.

Table 3. Results of the negative binomial regression model (glmmTMB) for bat activity (total acoustic contacts per pooled one-hour site × month session). Regression coefficients (β), standard errors (SE), incidence rate ratios (IRR), 95% confidence intervals (95% CI), and p-values are presented.

Predictor	β	SE	z	p	IRR (95% CI)
Site: Vineyard vs Orchard	-1.538	0.256	-5.994	<0.001	0.215 (0.130–0.355)
Month: April vs March	-0.742	0.489	-1.517	0.129	0.476 (0.182–1.242)
Month: May vs March	-0.550	0.489	-1.125	0.261	0.577 (0.221–1.504)
Month: June vs March	-2.671	0.656	-4.071	<0.001	0.069 (0.019–0.250)
Month: July vs March	-0.392	0.492	-0.796	0.426	0.676 (0.257–1.774)
Month: August vs March	-0.219	0.475	-0.461	0.645	0.803 (0.317–2.039)
Month: September vs March	-0.254	0.484	-0.524	0.600	0.776 (0.301–2.003)
Month: October vs March	0.174	0.482	0.360	0.719	1.19 (0.462–3.061)
Month: November vs March	-1.287	0.515	-2.500	0.012	0.276 (0.101–0.757)

diversity observed in the vineyard.

Community structure: NMDS, PERMANOVA, and multivariate dispersion

The NMDS ordination suggested site-associated structuring of monthly bat assemblages (Image 8). The two-dimensional solution provided a good representation of the Bray–Curtis dissimilarity matrix (stress = 0.062). Orchard observations appeared more widely distributed in ordination space than vineyard observations.

PERMANOVA based on permutations restricted within Month detected a significant difference in assemblage structure between the two sampled sites (pseudo-F = 6.26, R^2 = 0.281, paired permutation p = 0.004). The repeated contrast between the orchard and vineyard therefore accounted for 28.1% of the variation in the monthly assemblage data. The test of multivariate dispersion did not detect a statistically significant difference between sites (PERMDISP: F = 0.808, paired permutation p = 0.100). Thus, there was no statistical evidence that the PERMANOVA result was explained solely by unequal multivariate dispersion, although the small sample size limits the power of the dispersion test. Because only one site represented each agricultural context, these findings describe a repeated difference between the two sampled sites rather than a general effect of orchard versus vineyard habitat.

Table 4. Comparison of monthly taxon richness and Shannon diversity between the citrus orchard and vineyard. Values represent median monthly observations. Differences between habitats were assessed using the paired Wilcoxon signed-rank test.

Metric	Citrus orchard (median)	Vineyard (median)	Median of paired monthly differences	Statistics (V; *p*)
Shannon diversity	0.971	0	0.656	44; 0.0129
Monthly richness	3	1	2	28; 0.0213

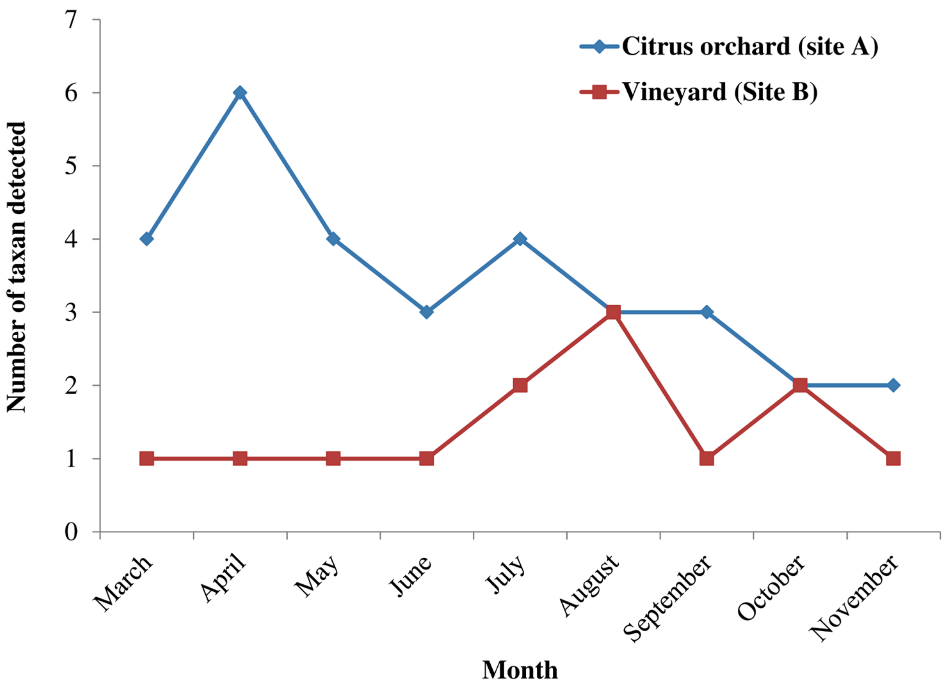

Image 5. Monthly taxon richness (number of taxa detected) in the orchard (Site A) and vineyard (Site B).

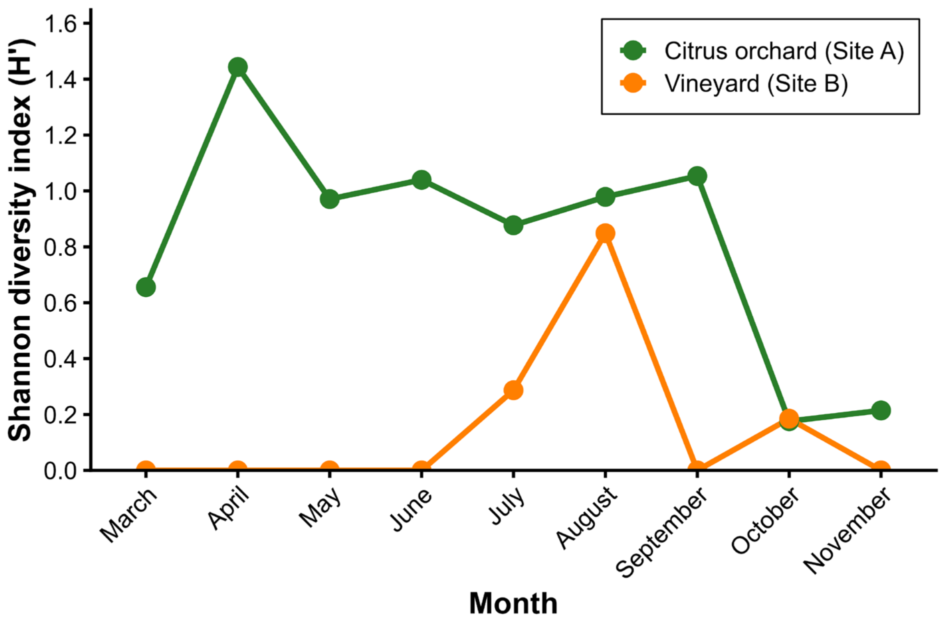

Image 6. Monthly Shannon diversity in the citrus orchard (Site A) and vineyard (Site B).

DISCUSSION

Before discussing the ecological implications of our findings, an important limitation of the present study should be acknowledged. Because the study was conducted in only one citrus orchard and one vineyard, habitat type is confounded with site identity, and the observed differences cannot be attributed solely to differences in agricultural management intensity. Consequently, our results should be interpreted as preliminary evidence highlighting contrasting bat assemblages between two representative agricultural

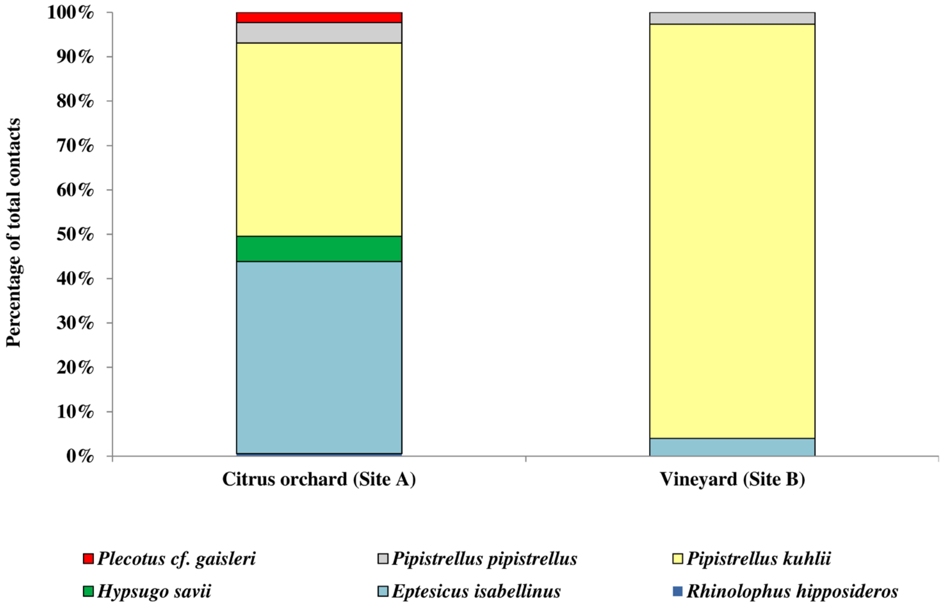

Image 7. Taxon composition (% of total contacts) in the citrus orchard (Site A) and vineyard (Site B).

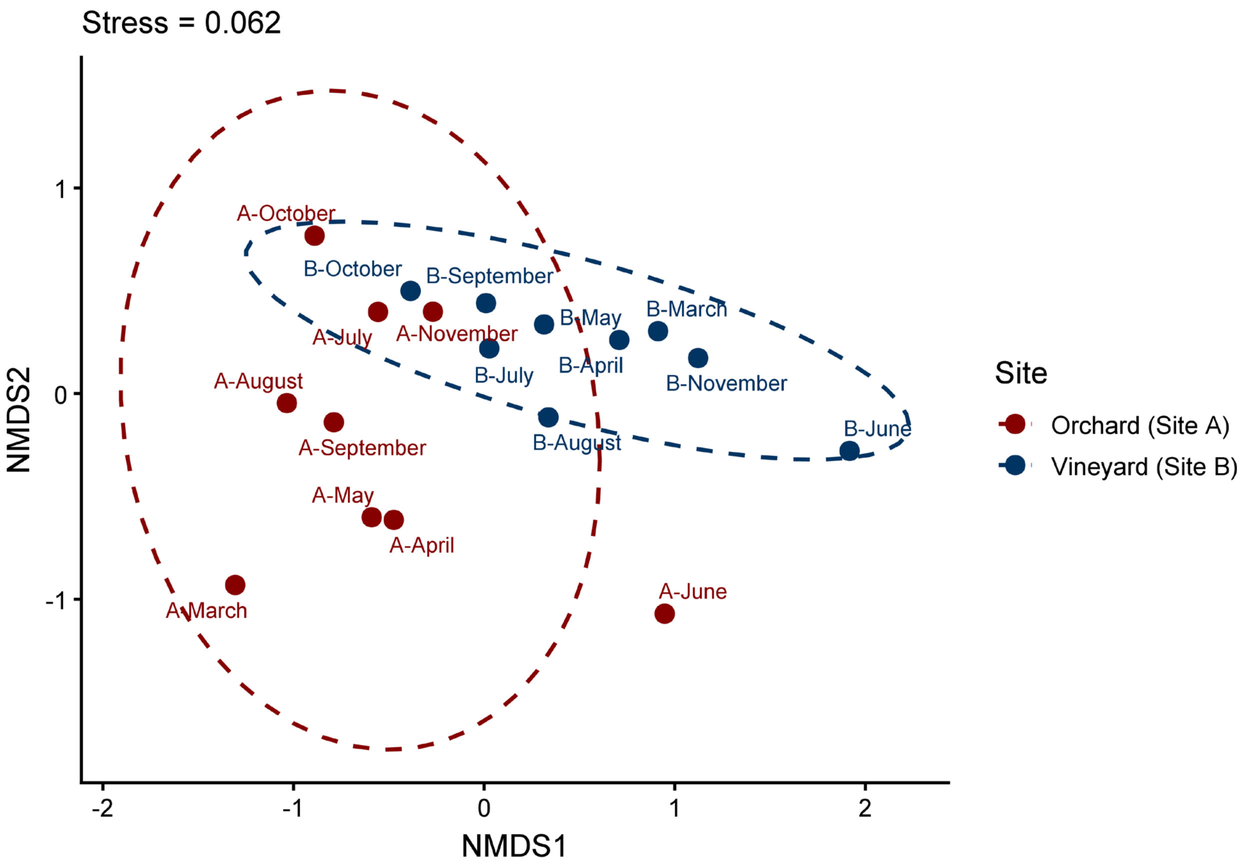

Image 8. NMDS ordination based on Bray–Curtis dissimilarities of monthly bat assemblages at the citrus orchard (Site A) and vineyard (Site B): Points represent pooled site × month observations, and distances reflect differences in assemblage structure. The two-dimensional solution had a stress value of 0.062. A paired PERMANOVA, with permutations of site labels restricted within month, detected a significant contrast between the two sampled sites (pseudo-*F* = 6.26, R^2 = 0.281, *p* = 0.004). Multivariate dispersion did not differ significantly between sites (PERMDISP: *F* = 0.808, *p* = 0.100). Ellipses are included for descriptive visualization only.

sites rather than definitive comparisons between cropping systems. These findings provide a baseline for future replicated, multi-site studies that incorporate direct measurements of insect prey availability, pesticide exposure, and other environmental variables to better disentangle the effects of agricultural management from site-specific characteristics.

Within the limits of this two-site case study, the sampled citrus orchard consistently showed higher bat activity, richness, and Shannon diversity than the sampled vineyard. These differences describe contrasting patterns between the two sites but cannot be attributed specifically to crop type, management intensity, pesticide use, or vegetation structure because these factors were not independently replicated.

Several non-exclusive mechanisms could plausibly explain the higher activity observed at the orchard site. Its perennial canopy, unmanaged ground vegetation, and lower reported input use may provide greater structural complexity and potentially more stable prey resources than the vineyard. However, insect abundance, pesticide residues, surrounding landscape composition, roost proximity, and microclimatic conditions were not quantified. These explanations should therefore be treated as hypotheses for future replicated studies (Russo & Jones 2003; Fahrig et al. 2011; Park 2015; Azam et al. 2016). Evergreen orchards, in particular, may sustain insect populations across seasons, thereby offering more reliable foraging opportunities for bats. Previous studies have shown that vegetation structure, hedgerows, and landscape heterogeneity can influence bat activity and prey availability in agricultural landscapes (Boughey et al. 2011; Maas et al. 2016; Froidevaux et al. 2019). Recent Algerian studies have also documented variation in bat activity and richness along environmental gradients and among structurally different habitats (Ait-Abdesselam et al. 2025; Boukhari et al. 2025).

In contrast, the vineyard exhibited low bat activity and strong dominance of *P. kuhlii*, a generalist species widely recognized for its tolerance to habitat simplification and anthropogenic disturbance (Barataud 2012; Jung & Threlfall 2016). Such dominance reflects a community simplification process frequently observed in intensively managed agricultural systems, where habitat homogenization and chemical inputs act as strong ecological filters (Geiger et al. 2010; Tscharntke et al. 2012). Vineyards are often associated with frequent pesticide applications, which can reduce arthropod abundance and diversity and thereby limit food resources for insectivorous bats (Wickramasinghe et al. 2004; Sánchez-Bayo & Wyckhuys 2019). Although pesticide applications were reported at the vineyard site, neither pesticide exposure nor insect abundance was quantified. The observed differences therefore cannot be attributed directly to chemical management and may also reflect vegetation structure, landscape context, roost proximity, or other site-specific factors.

Although most taxa recorded in this study are currently classified as Least Concern (LC) globally, and *Plecotus* cf. *gaisleri* is not evaluated, global assessments may not fully reflect regional population trends or local pressures associated with agricultural intensification. The legal protection of these taxa in Algeria, together with the limited information available on their use of northern African agroecosystems, highlights the need for regional baseline data. Moreover, agri-environment schemes do not necessarily benefit all bat taxa or biodiversity components in conventional agricultural landscapes, and some management prescriptions may have limited or even negative effects (Fuentes-Montemayor et al. 2011; MacDonald et al. 2012; Park 2015). These considerations underscore the importance of evaluating the effectiveness of farming practices and conservation measures under local conditions.

Monthly activity varied over the survey period, with particularly low values in June and November relative to March. Such variation may reflect seasonal changes in weather, prey availability, reproduction, migration, or torpor. Because these mechanisms were not measured directly and only one annual cycle was sampled, the observed monthly pattern should not be interpreted as evidence that the orchard buffered seasonal environmental stress (Russo & Jones 2003; Adams 2010).

Multivariate analyses indicated site-associated differences in assemblage structure. NMDS suggested partial structuring between orchard and vineyard observations, and the paired PERMANOVA detected a significant Site contrast after restricting permutations within Month (pseudo-F = 6.26, R^2 = 0.281, p = 0.004). The test of multivariate dispersion did not detect a statistically significant difference between sites (PERMDISP: F = 0.808, p = 0.100). Thus, there was no statistical evidence that the PERMANOVA result was explained solely by unequal dispersion, although the limited number of monthly observations reduces the power of this diagnostic test (Anderson 2001; Legendre & Legendre 2012; Oksanen et al. 2022). These findings describe contrasting assemblage structures at the two sampled sites but should not be interpreted as demonstrating a general effect of orchard versus vineyard habitat because each agricultural context was represented by only one site.

From a conservation perspective, the higher bat activity and diversity observed at the sampled orchard suggest that some low-input perennial agricultural sites may provide favourable conditions for bats. Bats can provide important ecosystem services in agricultural landscapes, particularly insect-pest suppression (Boyles et al. 2011; Kunz et al. 2011; Russo et al. 2018). However, replicated studies are required before this pattern can be generalized to low-input agricultural systems across the region. Maintaining vegetation cover and reducing unnecessary chemical inputs are plausible conservation measures, but their effects should be tested directly in replicated studies.

In addition to the absence of spatial replication, acoustic monitoring may underestimate taxa with low-intensity calls and may not permit definitive species-level identification of acoustically similar taxa. The walked-transect design may also generate taxon-specific differences in detectability. Future studies should include multiple orchard–vineyard pairs and integrate direct measurements of insect abundance, pesticide exposure, vegetation structure, landscape composition, and roost availability.

This preliminary case study revealed consistently higher bat activity, monthly richness, and Shannon diversity at the sampled low-input citrus orchard than at the sampled intensively managed vineyard. The orchard also supported a more compositionally diverse assemblage, whereas activity at the vineyard was dominated by *Pipistrellus kuhlii*. These findings indicate that the two agricultural sites differed substantially in their use by bats during the monitoring period.

Because only one site represented each agricultural context, these differences cannot be attributed specifically to crop type or management intensity. They may also reflect site-specific variation in surrounding landscape, roost proximity, prey availability, microclimate, or detection conditions. The results should therefore be considered baseline evidence and a source of hypotheses rather than a general comparison of orchards and vineyards.

Replicated studies across multiple farms should combine acoustic monitoring with measurements of insect abundance, pesticide exposure, vegetation structure, landscape composition, and roost availability. Such work is needed to determine whether low-input perennial crops consistently contribute to the conservation of protected bat assemblages in northern African agricultural landscapes.

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Table S1. Conservation status and legal protection of the bat taxa recorded at the two agricultural study sites in northern Algeria.

Taxon (authority) — Family	Common name	IUCN Red List category	Global population trend	CMS listing[1]	Bern Convention[2]	Legal status in Algeria[3]	Conservation relevance
Rhinolophus hipposideros (Borkhausen, 1797) — Rhinolophidae	Lesser Horseshoe Bat	Least Concern	Decreasing	European populations	Appendix II	Protected	Species with a decreasing global population trend; acoustically detected only at the orchard site
Eptesicus isabellinus (Temminck, 1840) — Vespertilionidae	Isabelline Serotine	Least Concern	Unknown	European populations	Appendix II	Protected	Western Mediterranean and North African taxon; one of the two dominant taxa at the orchard site
Hypsugo savii (Bonaparte, 1837) — Vespertilionidae	Savi's Pipistrelle	Least Concern	Stable	European populations	Appendix II	Protected	Widespread Mediterranean species; recorded only at the orchard site
Pipistrellus kuhlii (Kuhl, 1817) — Vespertilionidae	Kuhl's Pipistrelle	Least Concern	Increasing	European populations	Appendix II	Protected	Widespread generalist and the dominant taxon at the vineyard site
Pipistrellus pipistrellus (Schreber, 1774) — Vespertilionidae	Common Pipistrelle	Least Concern	Stable	European populations	Appendix III	Protected	Widespread species recorded at both study sites
Plecotus cf. *gaisleri* Benda et al., 2004 — Vespertilionidae[4]	Long-eared Bat provisionally assigned to Gaisler's Long-eared Bat	Not Evaluated for *P. gaisleri*	Unknown	Not confirmed for the North African taxon	Appendix II	Protected	Provisional identification of a probable northern African endemic taxon; acoustic data alone do not provide definitive species confirmation

[1] **CMS:** Listings follow Appendices I and II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS 2024). For the families concerned, Appendix II coverage is generally expressed in relation to European populations and should not automatically be interpreted as applying to the Algerian populations recorded in this study.
[2] **Bern Convention:** Listings follow Appendices II and III of the Convention on the Conservation of European Wildlife and Natural Habitats (Council of Europe 2024). Most microchiropteran bats are included in Appendix II, whereas *Pipistrellus pipistrellus* is included in Appendix III. These listings describe the status of the taxa under the Convention and should not be interpreted as the source of their legal protection in Algeria.
[3] **Algerian protection:** National legal status follows Executive Decree No. 12-235 of 24 May 2012 establishing the list of protected non-domestic animal species (*Décret exécutif n° 12-235 du 3 Rajab 1433 correspondant au 24 mai 2012 fixant la liste des espèces animales non domestiques protégées*; People's Democratic Republic of Algeria 2012).
[4] Calls assigned to *Plecotus* could not be unequivocally identified to species level. Because *P. gaisleri* is the expected regional taxon, the records are reported as *Plecotus cf. gaisleri*. This designation indicates probable, but not definitive, species identity.
CMS—Convention on the Conservation of Migratory Species of Wild Animals.

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Articles

Bat assemblages at two contrasting agricultural sites in northern Algeria: a preliminary conservation assessment
– Saida Meghezzi, Fatima Zohra Bissaad, Farid Bounaceur, Afaf Boukhari, Moncef Ait-Abdesselam & Leila Benfekih, Pp. 29375–29389

Linear power infrastructure and vulture electrocution risk: mitigation through carcass dump relocation in Sudhauwala, Dehradun, India
– Javed Anver, Yash Vardhan Singh Sengar, Bikash Ghimire, Vonchano Ngullie, Hemam Rama Nanda, Tashi P. Dorji, Ankit Sharma, Akshay Jain, Sas Biswas, Arun Kumar & M. Muzahed, Pp. 29390–29400

Avifaunal diversity of the central Western Ghats in Uttara Kannada, Karnataka, India
– Rounak Patra, Nonita Rana, S.J.D. Frank & Govindan Veeraswami Gopi, Pp. 29401–29417

A study on the avifaunal diversity and community dynamics of Karanji Lake, Mysuru, Karnataka, India
– S. Sushanth & K.S. Raghunandan, Pp. 29418–29429

A preliminary checklist and seasonal diversity of wetland-associated birds in Bajali District, Assam, India
– Bidyut Kumar Das, Pp. 29430–29446

Fish diversity and conservation status across habitat guilds in the river Rupnarayan, West Bengal, India
– Mridul Kanti Kar, Mohd Shahnawaz Khan, Anamitra Anurag Danda & Kripal Datt Joshi, Pp. 29447–29458

Community structure and environmental determinants of amphibians in the Western Ghats watersheds of eastern Goa, India
– Mayur M. Gawas, Sharan S. Sawal & Nitin S. Sawant, Pp. 29459–29469

Microhabitat associations and seasonal dynamics of amphibians in the lateritic rocky outcrops along the western coast of Goa, India
– Dipak Yashawant Bowalkar & Nitin Savlo Sawant, Pp. 29470–29482

Distribution, population status, associations, and biotic challenges of *Sanjappa cynometroides*, an endemic legume tree (Leguminosae: Caesalpinioideae) in the southern Western Ghats, Kerala, India
– Suresh Gopika & Moothedathu Venugopalan Nair Krishnaraj, Pp. 29483–29492

Lichen diversity of Churdhar Wildlife Sanctuary and adjacent areas of Himachal Pradesh, India
– Anupma Devi, Gaurav K. Mishra & Manjoosha Srivastava, Pp. 29493–29506

Communications

New record of the Malayan Porcupine (Rodentia: Hystricidae: *Hystrix brachyura* Linnaeus, 1758) in Tripura, India
– Omkar Patil, Ashutosh Joshi & Rutuja Digaskar, Pp. 29507–29514

Fishermen-led documentation of bycatch of sea snakes (Serpentes: Elapidae: Hydrophiinae) on the Malabar coast of southwestern India
– R. Sree Vishnu & S.R. Ganesh, Pp. 29515–29520

Checklist of the plants of Radhabai Kale Mahila Mahavidyalaya Campus, Ahilyanagar, Maharashtra, India
– Manjushree Gokul Bhagwat & Sharad Suresh Kambale, Pp. 29521–29531

Review

Exploring the agarwood trade in India and its promising horizon
–H.V. Girisha, Ajay Maletha, S.P. Goyal, Miatcha Tangjang, Avishek Bhattacharjee, Sayan Chakraborty , M.R. Ranjith Layola, Sudipta Sardar, Shabnam Bandyopadhyay, Bidisha Mallick, Oindrila Chakraborty, Sanchayita Sengupta, Tanay Shil, Sayak Chakraborty, Ranjan Shaw & Farheen Banu, Pp. 29532–29543

Short Communications

Nesting of Shikra *Accipiter badius* on *Gliricidia sepium* (Jacq.) Kunth (Leguminosae)
– Sunil M. Gaikwad & Manoj M. Lekhak, Pp. 29544–29547

New addition to the Odonata fauna of India: *Gynacantha basiguttata* Selys, 1882 (Odonata: Aeshnidae) from Arunachal Pradesh – a rectification
– R. Mahesh, Rajesh Gopinath, Dattaprasad Sawant, Gaurav Joshi & Roshan Upadhaya, Pp. 29548–29551

Notes

Breeding tern colonies in Valinokkam Lagoon, Tamil Nadu, India: additional records from the Gulf of Mannar region
– H. Maitreyi, H. Byju, N. Raveendran & S. Ravichandran, Pp. 29552–29554

Addition of *Athyrium rhachidosorum* (Hand.-Mazz.) Ching, 1934 (Polypodiales: Woodsiaceae) to the pteridophyte diversity of India
– Chhandam Chanda & Christopher Roy Fraser-Jenkins, Pp. 29555–29558

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