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Short communication

# Organic farming sustains bats in Mediterranean farmland

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ABSTRACT

Organic agriculture is often deemed effective in conserving and promoting biodiversity, yet most studies have so far only focused on farmland in temperate areas and a few taxonomic groups, mainly birds and arthropods. Mediterranean agroecosystems host considerable biodiversity, and their wildlife likely delivers quantitatively important ecosystem services to agriculture, yet information is still limited. Here, we test the importance of organic farming and habitat structure for bat activity and richness in the Mediterranean. We disentangled the effects of organic vs. conventional management and habitat structure by adopting acoustic surveys and a matched-pair sampling design. Foraging bats preferred organic over conventional farming, with a scale-independent effect of local farm management on activity (but not richness), consistently across bat species and functional guilds. While fine-scale habitat structure had contrasting effects on bat species and guilds, the positive influence of linear landscape elements on bat activity was consistent and independent of management options. We highlight the key role of organic farming in preserving and promoting bat activity in agricultural areas, which brings the mutual benefit of sustaining bat conservation and emphasising the precious ecosystem services bats provide. To increase bat richness, however, appropriate management of landscape structure must be secured at larger geographical scales.

## 1. Introduction

The European Union (EU) has long recognised the importance of agricultural areas for the economic and environmental wellbeing at all scales, yet the Common Agricultural Policy has meanwhile encouraged environmentally unsustainable practices such as the expansion and intensification of crops, mainly to support food security (Navarro and López-Bao, 2018). More recently, the key role of agroecosystems in sustaining biodiversity was also recognised, and biodiversity-friendly Agri-Environmental Schemes were developed and implemented (Ekroos et al., 2014). The EU2030 Biodiversity Strategy includes actions aiming at increasing the conversion of conventional into organic farming to reduce the use of chemicals and pesticides that hamper the biodiversity of such important ecosystems, and safeguard people's health (Hermoso et al., 2022).

Unlike conventional farming, organic farming is usually characterised by smaller crop surfaces, higher crop diversity, the interspersion of natural habitat patches within cultivated areas, and the avoidance of chemical fertilisers and pesticides – all factors that favour wildlife (Hole et al., 2005). While the desired effect of many pesticides tends to weaken over time as specific resistance evolves in the target insects (Hawkins et al., 2019), pesticides may paradoxically have adverse effects on the predators that would help control pests (e.g., Relyea and Edwards, 2010; Gibbons et al., 2015). Fertilisers too may have negative effects on insect populations by altering plant communities, in turn potentially affecting ecosystem functions such as pollination (Dupont et al., 2018). In recent years, insectivorous bats have been increasingly recognised as fundamental providers of ecosystem services in farmland after being long overlooked in the study of pest suppression (Russo et al., 2018). Few studies investigated the effects of farming on bat populations in the Mediterranean (Aizpurua et al., 2018; Baroja et al., 2021), and all focused only on specific crops, such as olive groves and vineyards. Here, we compared differences in bat richness and activity in organic vs. conventional farmland in Mediterranean study sites. We hypothesise that bats will prefer organic over conventional farming and predict that bat activity levels for all species will be higher at organic sites than at

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paired conventional ones. We also hypothesise that habitat structure will influence bat activity. We thus predict that specific ecological requirements will be reflected by each species' responses to habitat structure, i.e., bats will show species-specific responses according to their ecological traits. For example, we predict that interior foragers will depend upon woody vegetation more than open space–edge foragers and that the latter will be more associated with ecotonal margins.

## 2. Materials and methods

### 2.1. Study areas and site selection

We conducted our study in four areas in Peninsular Italy (hereafter labelled as a, b, c, and d; see Fig. S1 in Supplementary materials), all falling within the Mediterranean bioclimatic zone; all sites are at an altitude < 250 m a.s.l., and are < 30 km from seacoasts (a: 41°53′N 12°18′E; b: 45°32′N 12°42′E; c: 42°00′N 14°49′E; d: 40°29′N 15°29′E). To account for large-scale landscape effects (Froidevaux et al., 2017; Lentini et al., 2012), we applied a matched-pair sampling design by combining sampling plots at two levels, as follows. First, we matched farms from the same geographical area by selecting two adjacent (<3.0 km apart) farms, one organic and one conventional – classified after personal interviews with farms' managers and staff – and thus surrounded by a comparable habitat structure. Then, each sampling plot in a given farm was paired with a comparable plot in the matched farm (mean distance between plots: 1.10 km), to control for crop type and position (margin or centre of the sampled field). Within each farm, we located recording plots in numbers proportional to farm size (range: 5–9), totalling 54 plots. Each plot was sampled once, and paired plots were sampled simultaneously to control for temporal and spatial variation in bat activity.

### 2.2. Bat recording

Bat echolocation calls were recorded by deploying autonomous ultrasound recorders (Pettersson d500x by Pettersson, and Audiomoth 1.2 by OpenAcoustics) between June and September 2021, during dry and warm nights (min T > 12 °C). The same model of recording devices was used for both plots of each pair, to control for potential differences in microphone sensitivity and directionality. Recorders were set to record 5 s wav files, continuously from sunset to dawn, with a medium gain and a 384 kHz sampling rate. Recorders were secured opportunistically to poles or fences, clear of vegetation, and pointed upward with a 45° angle towards the field centre. All files recorded were manually processed in BatSound 4.0, and echolocation calls were assigned to species/species groups following Russo and Jones (2002). We quantified bat activity as the numbers of bat passes per night (Wickramasinghe et al., 2003). Calls whose classification was uncertain were grouped at the genus level, or into phonic groups. This was done for *Myotis* (all species pooled as *Myotis* sp.), *Plecotus* (classified as *Plecotus* sp.), and for *Nyctalus* sp. and *Eptesicus serotinus* (pooled as *Nyctalus / Eptesicus*).

### 2.3. Habitat structure metrics

Habitat structure around each sampling plot was manually assessed by photointerpretation of satellite images, following the CORINE Land Cover coding, classifying land use within three concentric circular buffers centred around each sampling plot. Buffers encompassed circular areas at 50, 200 and 500 m radii around each sampling plot. We selected such distances to explore any scale-dependent effect on bat activity, as these spatial scales correspond to the size of bat foraging sites (Bellamy et al., 2013). Land use composition was assessed as the per cent of each land use class comprised within each considered buffer, classified as either farmland (any type of farmed crop/orchard), woodland (areas with indigenous trees, with linear dimension ≥ 50 m), water bodies, or urban areas (covered by buildings and impervious surfaces, e.g., paved roads). We also measured the distance to the closest water source and the extent of linear landscape elements (hereafter LLE), both potentially influencing bats. LLE were any conspicuous vegetation patches (either trees or shrubs, and riparian vegetation) with at least one dimension < 50 m (Lucas et al., 2019). As indicators of the extent of LLE, we calculated i) the total perimeter of each LLE falling within the considered buffer(s), and ii) the per cent surface occupied by LLE within the buffer(s).

### 2.4. Statistical analyses

To evaluate the effects of farmland management (organic vs conventional) and habitat structure on bat activity, we employed generalised linear mixed models (GLMMs). In such models, habitat structure metrics were entered as fixed factors (predictors), assuming a negative-binomial error distribution and a log-link function; farmland area id (n = 4) and plot pair (1−27) were used as random factors. To exclude any bias in habitat structure metrics between management practices, we also preliminary ran GLMMs using each metric as the response variable, management as a predictor, and farmland area as a random effect. These models showed no significant difference between matched organic and conventional farms in terms of habitat structure and LLE. Such a preliminary assessment allowed us to disentangle the independent effects of habitat structure and farmland management regimes upon bat activity. As response variables, we used total bat activity, single species/species-group activity, species richness, and guild activity. The latter was calculated by pooling passes of species belonging to two well-known bat functional groups, i.e., interior foragers (genera: *Rhinolophus*, *Myotis*, and *Plecotus*), and open-edge foragers (genera: *Pipistrellus*, *Hypsugo*, *Nyctalus / Eptesicus*, and *Tadarida*). The two groups may respond differently to farm management and landscape modifications due to specific ecological needs and vulnerability to habitat changes (Safi and Kerth, 2004). Before running models, we checked for collinearity among predictors by running a cross-correlation analysis; we retained only one out of each pair of predictors with Pearson's r values $> |0.7|$ and $p < 0.05$, selecting the variable with higher ecological relevance to bats. As such, we only retained the amount of wooded and urban areas, distance from the closest water source, and LLE perimeter. Models were run separately for each spatial scale, using the *glmer.nb* function in the lme4 package (Bates et al., 2007). Each dependent variable was first rescaled between 0 and 100 to allow for a direct comparison of effect sizes. Models were evaluated according to their pseudo $R^2$ values, and variable effects were considered significant when $p < 0.05$, and when confidence intervals of the standardised estimate of effect sizes did not include 0.

## 3. Results

We recorded and identified 1321 bat passes (mean ± sd: 24.5 ± 23.9 passes/night per sampling plot; range 0–116 passes; Fig. 1), 988 of which (74.8%) in organic plots. We recorded calls by 11 bat species/species groups, > 50% of which were from *P. kuhlii* (31.0%) and *Hypsugo savii* (21.1%). Total, guild, and species activity levels were all significantly affected by farm management at all spatial scales, with a strong negative effect of conventional farming over organic (all $p < 0.05$; see Fig. 2 for confidence intervals), yet the effect was especially strong for interior foragers, with standardised mean effects being ca. twice as that for open-edge foragers (Fig. 2). Species richness was not affected by any variable at any spatial scale (all $p > 0.05$).

The second most frequently significant variable in our models was LLE perimeter, showing a positive effect on the activity of open-edge (at both 50 and 200 m scales) and interior foragers (50 m scale only), as well as on all single taxa in at least one of the considered spatial scales. LLE perimeter positively influenced *P. kuhlii*, *Rhinolophus* spp. (50 and 200 m scales), *Myotis* spp. and *Nyctalus/Eptesicus* (50 m scale only).

Habitat structure metrics also played a role in influencing bat activity, with distance to water exerting diverging effects on *P. kuhlii*

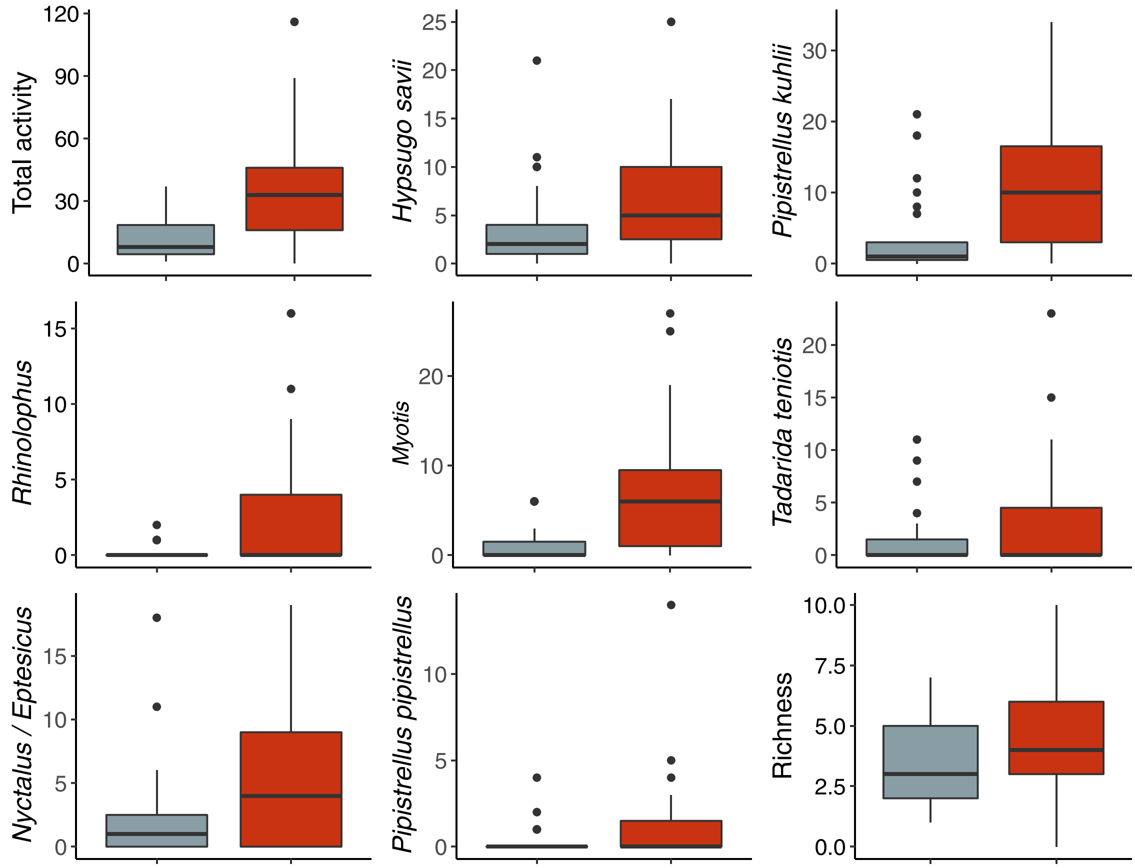


**Fig. 1.** Differences in activity levels (expressed as numbers of passes per night per sampling plot) of bat species/species groups between organic (in red) and conventional (in grey) farms (n farms=8; n sampling plots=54). Bold lines indicate median values; box limits indicate upper and lower quartiles; whiskers indicate 95% confidence intervals; black dots are outliers.

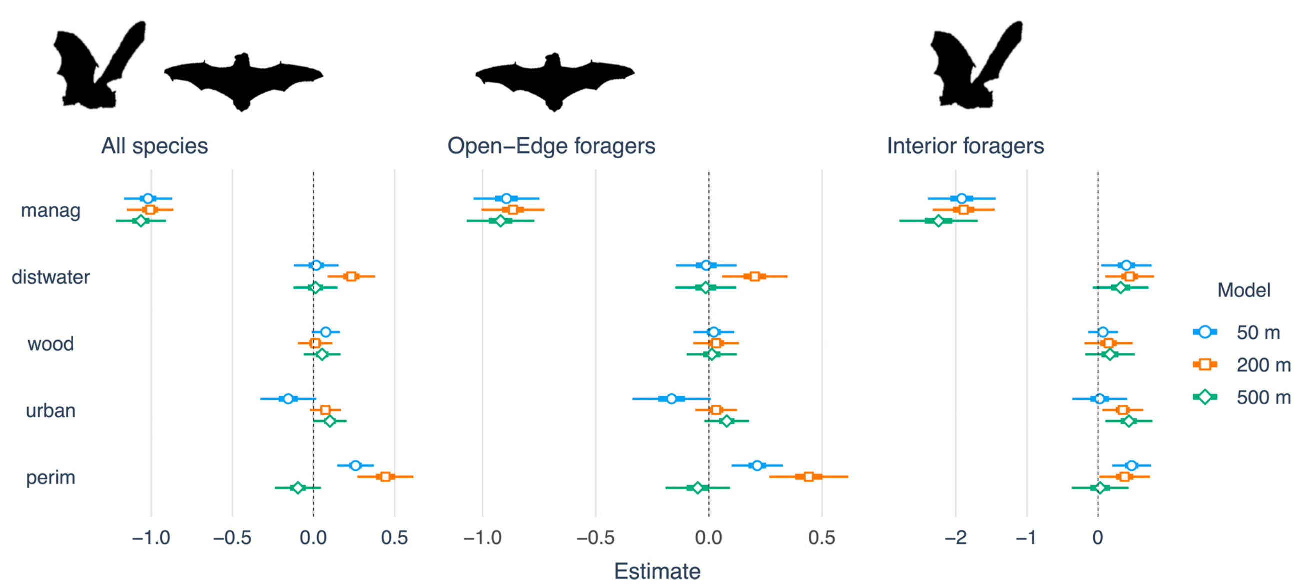


**Fig. 2.** Means (empty symbols) and confidence intervals (whiskers: 95%, filled boxes: 50%) for standardised estimates of effect sizes of farmland management and habitat structure metrics on all bat species pooled together (left), and functional guilds (mid panel: open-edge foragers; right panel: interior foragers). Models were GLMMs fitted with negative binomial distributions, run separately for three spatial scales around sampling sites (blue circle: 50 m; orange square: 200 m; green diamond: 500 m). Abbreviations: *manag*=farm management (conventional vs organic); *distwater*=linear distance to the closest water source; *wood*=percent wooded area; *urban*=percent built-up area; *perim*=total perimeter of linear landscape elements.

activity (negative effect at all spatial scales) and total activity, *Nyctalus/Eptesicus* and *Rhinolophus* activity (positive effects at 50 and 200 m scales). The per cent wooded area positively influenced only *Rhinolophus* and *Nyctalus/Eptesicus* activity at the 200 and 500 m scales. The amount of urban land use affected total bat activity (500 m scale), as well as interior foragers (200 and 500 m scales), yet at the species level, this result was confirmed only for *P. kuhlii* (all scales; see Table S1 in Supplementary materials).

## 4. Discussion

We show that bats strongly prefer organic over conventional farming. All the recorded bat species or species groups were significantly more active at organic than at conventional sites, in agreement with our first hypothesis. Farm management retained its significance at all spatial scales and for all bats, supporting a strong scale- and guild-independent effect. This confirms and broadens the outcome of a recent study (Puig-Montserrat et al., 2021) where gleaning bats showed higher activity rates in organic over conventional olive groves. Species richness instead did not differ according to management, which suggests that farmland practices are unlikely to influence the number of species that exploit foraging sites. Agricultural landscapes are a much-simplified version of natural areas (Benton et al., 2003), and like other anthropogenic habitats, they act as environmental filters, i.e., they “sieve” species according to specific traits (Marcolin et al., 2021; Santini et al., 2019). In farmland, highly mobile species, which may easily cross open or unsuitable areas, are advantaged over those species whose flight is adapted to cluttered spaces (Cole et al., 2002), which explains the abundance of open/edge foragers in our sample. Interior foragers are mostly detected in specific crop types such as olive groves, which resemble the natural woody habitats where they typically forage (Russo and Jones, 2003).

Our study also confirms the importance of habitat features such as hedgerows and natural vegetation along field edges for most species in the two guilds we considered, regardless of organic vs. conventional management. Such features are widely recognised as highly important for bats (Heim et al., 2018) at various spatial scales (Froidevaux et al., 2019). Unlike we predicted in association with our second hypothesis, bats from both the considered guilds responded quite consistently to several habitat structure metrics, yet differences emerged at the species level. Many bat species use water sites for both foraging and drinking (Russo and Jones, 2003), so the distance to water sources was predicted to influence bat activity. In this study, we found contrasting evidence of this prominent role of water sites, which was clear for *P. kuhlii* but had the opposite effect over noctule/serotine and horseshoe bats. While all these species may forage in riparian habitats (Russo et al., 2003; Waters et al., 1999), the artificial ponds used for irrigation that accounted for most water sites may fail to provide profitable hunting space due to the absence of riparian vegetation. The positive influence of water presence on *P. kuhlii* is well-known, particularly during the reproductive season (Ancillotto et al., 2019, 2015), as the species’ limited mobility (Salinas-Ramos et al., 2021; Serangeli et al., 2012) may constrain it within the surroundings of sources of drinking water. Wooded areas close to the sampling sites also favoured species that either roost (Waters et al., 1999) or forage in forests or richly structured habitats (Ancillotto et al., 2021, 2017; Puig-Montserrat et al., 2021). Proximity to urban sites favoured activity by several species or species groups, probably because in the study areas they mostly consisted of barns, stables, and traditional buildings, all frequently used by bats for roosting (Russo and Ancillotto, 2015).

## 5. Conclusions

Bats play a key role in European agroecosystems, as they provide essential pest suppression by consuming arthropods that may seriously damage crops (Boyles et al., 2011; Russo et al., 2018), and as such, understanding the effects of farmland management on bat occurrence and activity is vital to inform landscape management and biodiversity conservation. Although we found that organic farming promotes bat foraging, whether this translates into positive demographic effects for the species in question has yet to be ascertained. Establishing that organic agriculture elicits greater bat foraging activity as done in our study anticipates that the economic benefit bats provide to farming will be especially important for this management type, likely replacing or compensating for the non-use of pesticides.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data Availability

Data will be made available on request.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agee.2022.108230.

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