



A systematic map of agricultural practices affecting insectivorous bats in temperate regions: cross-scale evidence patterns and implications for bat-friendly farming

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ABSTRACT

Agricultural landscapes cover large areas of temperate regions and harbour key components of biodiversity that contribute to ecosystem functioning. Insectivorous bats act as natural enemies of crop pests, yet the ways agricultural practices influence their populations and associated functions remain insufficiently synthesised. We conducted a systematic map of peer-reviewed literature to provide the first structured cross-scale classification and quantitative mapping of existing evidence on agricultural practices affecting insectivorous bats in temperate agroecosystems. We searched Web of Science, Scopus, and Google Scholar, screened 8416 records, and identified 164 eligible studies. Agricultural interventions were classified across three scales: local-scale practices, integrated farming systems, and landscape-scale management. Most studies focused on descriptive landscape-scale variables, highlighting the influence of landscape complexity, and agroecological infrastructures on bat activity and community composition. Conversely, evidence on local-scale practices, such as pesticide use, irrigation, tillage, and grazing intensity, was understudied. Bat responses were most frequently assessed through acoustic surveys, and relatively few studies directly quantify pest suppression, dietary composition, or physiological endpoints, meaning that ecosystem service benefits are often inferred rather than experimentally demonstrated. Proposed conservation measures focus on habitat and landscape management. By clarifying where evidence is robust and where inference remains indirect, this systematic map identifies priority areas for experimental research and multi-scale integration. Strengthening causal inference will be essential to support biodiversity-based agricultural transitions that credibly align bat conservation with ecosystem service provision in temperate regions.

1. Introduction

Modern agriculture has undergone profound transformations in recent decades, particularly across temperate regions of Europe and

North America, where intensification has reshaped landscapes and placed substantial pressure on biodiversity (Clough et al., 2020; Raven and Wagner, 2021; Tscharntke et al., 2012a). Practices such as monoculture expansion, the removal of semi-natural habitats (e.g.,

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hedgerows, wetlands), and widespread reliance on pesticides and fertilizers have reduced habitat quality for many farmland species and disrupted ecological balances (Batáry et al., 2015; Díaz et al., 2019). In Europe, over 75% of agricultural habitats and their associated species are now considered to be in poor conservation status (European Environment Agency, 2020). Similar patterns are evident in other regions, and specifically in North America, where agricultural intensification has contributed to declines in insectivores, pollinators, and other service-providing organisms (Forister et al., 2011; Janousek et al., 2023; Stanton et al., 2018). Biodiversity losses threaten key ecosystem services essential for food production, such as pest control, pollination, and nutrient cycling, thus increasing the risk farming systems become reliant on costly and environmentally harmful inputs (Dainese et al., 2019; Tscharnkte et al., 2012a). Conserving and restoring biodiversity within agroecosystem is therefore not only a conservation goal but also a cornerstone of resilient and sustainable food systems (Kremen and Merenlender, 2018; Rasmussen et al., 2024).

Among the species that contribute to the ecological processes underpinning agroecosystem functioning, insectivorous bats play a particularly important role as natural enemies of crop pests (Tuneu-Corral et al., 2023). Evidence for their role in pest control comes from dietary analyses confirming direct consumption of pest species (Charbonnier et al., 2021; Mata et al., 2021a), exclusion experiments demonstrating increased pest damage and reduced crop yields when bats are prevented from foraging (Beilke and O'Keefe, 2023; Maas et al., 2013; Maine and Boyles, 2015), and studies showing spatial and temporal overlap between bat activity and pest abundance (Tortosa et al., 2023). Boyles et al. (2011) estimated that bats provide pest control services worth billions of dollars annually to U.S. agriculture.

Despite their functional importance in agroecosystem, many bat species are of conservation concern, with populations declining at regional and global scales (Frick et al., 2020; Russo et al., 2018). In temperate regions, these declines are driven by multiple interacting pressures, including emerging diseases such as white-nose syndrome, which has caused dramatic population collapses in North American bats and generated cascading effects on ecosystem functioning and human well-being, notably through the loss of natural pest control (Frank, 2024). Beyond disease, agricultural intensification remains one of the most widespread drivers of bat declines worldwide, affecting prey availability, habitat structure, and roosting opportunities (Frick et al., 2020). Pesticide use significantly reduces insect abundance, contributing to lower bat activity in conventionally managed fields compared to organic systems (Douglas and Tooker, 2016; Put et al., 2018). Similarly, practices such as intensive tillage or high grazing pressure simplify habitat structure and reduce prey availability, thereby limiting foraging opportunities (Barré et al., 2018; Dietzer et al., 2024; Paniccia et al., 2025). At the landscape scale, homogenisation and the loss of semi-natural habitats, such as woodlands, hedgerows, and water bodies, also strongly influence bat activity and species richness (Frey-Ehrenbold et al., 2013; Valle et al., 2023). As highly mobile, central-place foragers, bats depend on these features, as well as on overall landscape composition and connectivity, similarly to other mobile taxa such as birds and many pollinator groups (Frey-Ehrenbold et al., 2013; Priyadarshana et al., 2024; Vallé et al., 2023). These landscape elements provide essential resources for foraging, navigation, and access to roosts (Froidevaux et al., 2022b; Heim et al., 2015; Rodríguez-San Pedro et al., 2019).

Bat responses to agricultural practices are far from uniform and are shaped by species-specific ecological traits. Different foraging guilds, defined by echolocation range, wing morphology, and flight behaviour, show contrasting sensitivities to habitat change (Boughey et al., 2011; Tarcy et al., 2025). Open-space foragers such as *Nyctalus* or *Tadarida* species can cover large areas to locate prey, which may buffer them against local habitat simplification, yet they remain sensitive to prey depletion and loss of structural heterogeneity at the landscape scale. In contrast, edge and narrow-space foragers (e.g., *Myotis* and *Plecotus*

species) depend on landscape linear elements such as hedgerows, field margins, or riparian corridors for foraging and movement (Boughey et al., 2011). Beyond foraging guilds, traits such as diet, body size, and habitat specialization further shape species' responses to agricultural practices (Carballo-Morales et al., 2021; Farneda et al., 2020; Froidevaux et al., 2023; García-Morales et al., 2013; Loeb, 2020; Mendes and Srbeek-Araujo, 2021). This heterogeneity complicates the design of effective agri-environmental strategies and underscores the need for structured evidence syntheses examining how agricultural practices influence bat communities to clarify knowledge patterns, identify critical gaps, and better inform both research priorities and management decisions.

Previous syntheses have made important progress in linking bats, agriculture, and ecosystem services. Park, (2015) reviewed the benefits of lower-intensity farming systems such as organic farming, agroforestry, and agri-environment schemes for bats as potential bioindicators, but drew on a limited number of studies and without systematic scale-based mapping of the evidence. Similarly, Williams-Guillén et al. (2016) distinguished habitat conversion from agricultural intensification in a global multi-scale review, documenting predominantly negative effects on bat communities while highlighting the mitigating role of agroforestry systems. More recently, Tuneu-Corral et al. (2023) provided a global review on bat pest control, synthesizing dietary and economic evidence, while Xavier et al. (2023) developed a global systematic map of research on bats in agroecosystem, organising 309 studies by cropping systems (e.g., soybean, rice, cultivated pasture) across biomes and highlighting broad trends and gaps. However, these syntheses primarily organise evidence around broad land-use categories and cropping systems rather than agricultural practices. Consequently, it remains challenging to determine which practices (e.g., pesticide regimes, tillage intensity, grazing pressure, crop diversification, irrigation strategies) have received substantial research attention and where evidence is sufficiently concentrated to inform management. Moreover, their global scopes, spanning diverse climates, production systems, and policies limit their direct applicability to temperate agroecosystems, where farming systems, bat communities, and regulatory instruments such as agri-environment schemes show greater comparability.

Here, we present a systematic map of peer-reviewed research on agricultural practices affecting insectivorous bats in temperate regions. In line with the Collaboration for Environmental Evidence guidelines (Collaboration for Environmental Evidence, 2022), we applied a PICO-C (Population, Intervention, Comparator, Outcome, Context) framework as a guiding structure for the search strategy, screening criteria, and data extraction. We classified interventions into local-scale agricultural practices (specific management decisions at field or farm level, e.g., pesticide use, tillage, irrigation), integrated farming systems (e.g., organic vs. conventional), and landscape-scale management (habitat composition and configuration beyond individual fields). We also documented the diversity of bat response metrics (e.g., activity, taxonomic and functional diversity, physiological indicators, pest control) and monitoring approaches (e.g., acoustic surveys, telemetry, capture methods). By explicitly structuring the evidence base around agricultural practices within a coherent temperate context, this map provides a structured diagnosis of the evidence base, identifying where knowledge is concentrated, where it remains fragmented, and where critical gaps constrain inference. In doing so, it offers a practice-oriented overview that is directly usable for informing research prioritisation and agri-environmental decision-making, while establishing a comparative framework for future targeted quantitative syntheses. Hence, we addressed the following questions:

- (1) Which agricultural practices have been investigated across local, system, and landscape scales?
- (2) Which monitoring approaches and bat response variables have been used to assess these practices?

- (3) What mitigation or conservation measures are proposed in the literature?
- (4) Where are the main evidence clusters and critical knowledge gaps?

2. Material and methods

2.1. Literature search and pre-scoping

To address the objectives of this systematic map, we conducted a literature search to identify all relevant peer-reviewed articles published in English. All searches were performed on April 6, 2024, across Web of Science Core Collection (WOS), Scopus (via institutional access from the *Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement* - INRAE, France), and Google Scholar, with no restrictions applied to publication dates. The search in Google Scholar was limited to the first 400 results retrieved using Publish or Perish software (Harzing, 2017), with browser history and cookies cleared beforehand to reduce algorithmic biases from prior internet activity. Results were stored by relevance (default Google Scholar algorithm). The 400-result threshold follows established practice in systematic mapping and review studies, as Google Scholar ranks the most relevant studies first (Bonfanti et al., 2023; Haddaway et al., 2015; Triquet et al., 2024). The exact search strings used for literature search are presented in Table 1. The same Boolean structure was used across WOS and Scopus, with database-specific field tags applied (TS= in WOS; TITLE-ABS-KEY in Scopus). For Google Scholar, we applied a simplified version of the search string to account for platform limitations in query length and advanced Boolean operators.

The search terms used to reflect the PICO-C intervention component (agricultural practices) in our search strings were derived from a preliminary scoping of the literature. This phase allowed us to identify commonly used terms describing agricultural practices (Soil preparation, Fertilization, Sowing, Irrigation, Crop protection, Harvesting, Mowing, Intermediate crop, grazing). Broader search terms such as 'agriculture', 'agroecology', and 'landscape(s)' were also included to increase sensitivity and ensure comprehensive coverage.

The development of the final search string used for the literature search in WOS and Scopus (Table 1) resulted from an iterative process aimed at optimising both sensitivity and precision (Livoreil et al., 2017). This process, conducted in WOS, involved comparing the outputs of alternative search strings against a test list of 47 articles identified as highly relevant to the review question (Appendix A). We first tested a simplified baseline string that successfully retrieved 100% of the test list, confirming its high sensitivity. Despite this full retrieval rate, we decided

to enrich this baseline string by incorporating additional terms previously identified for the intervention component, in order to maximise comprehensiveness and minimize the risk of missing relevant studies. These additional terms were introduced stepwise, with each iteration tested as a distinct search string whose performance was evaluated against the benchmark list; all intermediate search strings and their outputs are reported in Appendix B.

All records retrieved from the different search engines were reported and merged into a single dataset. Duplicate records were removed prior to screening using the *remove_duplicates* function from the *litsearchr* R package (Grames et al., 2019), based on matching of titles and DOIs.

2.2. Study selection

We conducted a two-stage screening process on all records, systematically applying predefined eligibility criteria (Table 2) at each stage. In the first stage, titles and abstracts were screened using *Abstrackr* (Wallace et al., 2012) by several members of the systematic map team. To ensure consistency in applying the selection criteria, the screeners conducted a test on a shared sample of 100 articles. Reviewer agreement

Table 2

Eligibility criteria used in the screening process, arranged by PICO-C components.

PICO-C component	Definition
Eligible Population (s)	Studies must include at least one insectivorous bat taxon, either as a focal group or in combination with other bat trophic guilds or taxonomic groups.
Eligible Intervention(s)	Studies must examine agricultural practices or management within the agricultural landscapes. Eligible interventions include: (i) local-scale agricultural practices (e.g., pesticide application, tillage, irrigation, grazing); (ii) integrated farming systems combining multiple practices at the field or farm scale (e.g., organic farming systems, agroforestry, grassland-based systems); or (iii) landscape-scale management, including landscape complexity (compositional or configurational heterogeneity), and agroecological infrastructures (e.g., hedgerows, ponds, wooded patches).
Eligible Comparator(s)	Studies must include a comparator (control treatment) that provides a baseline for examining the bat responses in relation to agricultural practices. Eligible comparators include: (i) contrasts in management intensity (e.g., sprayed vs. unsprayed fields, grazed vs. ungrazed grasslands or pastures); (ii) comparisons between farming systems (e.g., organic vs. conventional); (iii) spatial contrasts across land-cover types or landscape heterogeneity (e.g., habitat diversity, proportions of semi-natural habitats, or hedgerow density); (iv) gradients of landscape heterogeneity; and (v) temporal contrasts (e.g., before–after changes in management).
Eligible Outcome (s)	Studies must report at least one measurable biological response of bats, such as activity, species richness or taxonomic/functional diversity, community composition, diet, habitat selection, or physiological indicators (e.g., pesticide residues in tissues).
Eligible Context	Studies must be conducted in temperate climatic regions, defined according to Köppen-Geiger climate classification. The included regions encompass: (i) temperate oceanic climates (Cfb, Cfc), (ii) temperate humid continental climates (Cfa), (iii) Mediterranean climates (Csa, Csb), and (iv) cool-summer continental climates (Dfb), which correspond to boreonemoral and other cool-temperate zones. The inclusion of Mediterranean zones ensures coverage of southern regions of Europe that share comparable agroecological characteristics, community compositions, and agricultural policy frameworks with the other temperate systems. For studies conducted in countries spanning multiple climatic zones (e.g., Sweden, Australia, Chile), inclusion was determined based on the specific study location reported in the article. If geographic coordinates were provided, they were verified against the Köppen-Geiger classification. If coordinates were unavailable, inclusion was based on the reported region (e.g., state or province), which was cross-checked against the Köppen-Geiger classification.

Table 1

Search strings used for the literature search in WOS, Scopus, and Google Scholar.

Search engine	Search string
WOS and Scopus	(bat OR bats OR chiroptera*) AND (agri* OR agro* OR farm* OR crop* OR cultivated OR arable OR landscape\$ OR "farming practice\$" OR "agricultural practice\$" OR wood* OR "semi-natural habitat\$" OR "semi-natural element\$" OR hedgerow\$ OR "field boundar*" OR "field margin\$" OR pasture\$ OR bush* OR wetland\$ OR marsh\$ OR pond\$ OR "water bod*" OR fallow\$ OR grassland\$ OR orchard\$ OR vineyard\$ OR "olive grove\$" OR rice OR alfalfa OR sorghum OR soybean OR vegetable\$ OR wheat OR barley OR rapeseed OR sunflower OR corn OR maize OR cotton OR till* OR plough* OR fertil* OR amendment\$ OR compost OR manur* OR sow* OR irrigat* OR "crop protection" OR "pest control" OR "pest management" OR pesticide\$ OR insecticide\$ OR fungicide\$ OR herbicide\$ OR harvest* OR "residue management" OR "crop residue\$" OR mow* OR cutting OR silage OR "cover crop*" OR grazing OR pasture\$ OR livestock\$ OR husbandr* OR cattle\$ OR "antiparasitic drug\$" OR ivermectin)
Google Scholar	(bat OR bats OR chiroptera*) AND (agri* OR agro* OR farm* OR crop* OR cultivated OR arable OR landscape OR "farming practice" OR "agricultural practice")

was assessed using Fleiss's Kappa coefficient (Fleiss, 1971), with values above 0.6 considered acceptable (Collaboration for Environmental Evidence, 2022; Frampton et al., 2017). We achieved a Kappa value of 0.86, indicating a high level of agreement. All remaining disagreements were discussed and resolved before proceeding with the screening process. A conservative approach was applied during this stage (i.e., articles were retained for full-text screening if eligibility could not be determined based on title and abstract alone). In the second stage, full texts of the remaining articles were reviewed by the first author, and in cases of uncertainty, inclusion or exclusion decisions were discussed with other team members.

2.3. Data extraction and coding

Data extraction was conducted by the first author using a standardised coding framework. The coding process was piloted on a subset of studies to refine category definitions and ensure consistency before full extraction was completed. Ambiguous cases were discussed with other team members to ensure consistent interpretation of coding criteria. For each included study, we extracted bibliographic information as well as study characteristics, including study location and design. Bat species studied or recorded in each study were documented. A synthesis showing the frequency of reported species per geographic region is presented in Appendix C (Fig. C1).

We systematically extracted data on the agricultural practices assessed in each study. Consistent with the classification introduced above, practices were grouped into three main categories (Table 3; Appendix D), partly inspired by the typology proposed by (Bonfanti et al., 2023): local-scale agricultural practices, referring to specific management decisions implemented at field or farm level (e.g., crop protection, fertilization, irrigation and water management, livestock grazing management, field margin management, harvesting); (ii) integrated farming systems, referring to coordinated management regimes combining multiple practices under a unified framework (e.g., organic farming systems, grassland-based systems, farming systems under agri-environment schemes); and (iii) landscape-scale management, referring to landscape composition and configuration beyond individual fields. Within the landscape-scale category, we further distinguished three subcategories: (a) landscape complexity, encompassing compositional heterogeneity, which refer to the diversity and proportion of land-cover types and configurational heterogeneity, which relates to their spatial arrangement (Fahrig et al., 2011); (b) land-use, describing the use and preferences of bats for different land-cover types; and (c) agroecological infrastructures, defined as intentionally maintained or restored semi-natural habitats embedded within agricultural landscapes but located outside cultivated fields (e.g., hedgerows, ponds, wooded

patches, flower strips). We also extracted data on bat monitoring methods (e.g., acoustic surveys, radio tracking, faecal sampling) and on the biological descriptors used to assess bat responses. These descriptors encompassed biodiversity measures (e.g., abundance, activity, species richness, taxonomic/functional diversity) as well as other ecological and physiological responses such as diet composition, habitat use and specialisation, and pesticide concentrations in bat tissues. A detailed description of agricultural practice categories, monitoring methods, and biological response descriptors is provided in Appendix D.

Additionally, we documented the conservation measures proposed in the studies to mitigate the impacts of agricultural practices on bats. Based on the collected data, these measures were grouped into the following categories (Appendix D): adjustment of livestock management; education of farmers, landowners, and the public; habitat conservation and restoration; enhancement of roost availability; promotion of landscape heterogeneity and habitat connectivity; implementation of monitoring and research; development of policy recommendations; and adoption of sustainable agricultural practices. All extracted data were recorded in a structured database (Appendix D). The relevant evidence was mapped using visual representations, including figures and heat-maps, to illustrate the volume of evidence and identify knowledge clusters and gaps.

3. Results

3.1. Literature searches and studies selection

The literature initially identified 12,804 records, of which 4388 duplicates were removed prior to screening. After deduplication, 8416 records (Appendix E) were screened, resulting in 164 studies that met the eligibility criteria and were included in this systematic map (Fig. 1; Appendix E).

3.2. Geographic distribution and temporal evolution

The studies included in this map were published between 1986 and 2023. Their temporal distribution (Fig. 2) shows a clear increase in research effort over time. After a period of sporadic publication during the late 1980s and 1990s, the number of studies began to rise in the early 2000s, followed by a more consistent growth from the late 2000s onward. Although annual outputs fluctuate, the general trend indicates sustained and expanding scientific interest in the effects of agricultural practices on insectivorous bats, with several peaks observed during the last decade.

Geographically, the evidence base is unevenly distributed (Fig. 3). Studies are strongly concentrated in Western Europe and North America. The United Kingdom (n = 29; 17.7%) and the United States of America (n = 26; 15.9%) stand out as major contributors, followed by Germany (n = 16; 9.8%), Italy (n = 13; 7.9%), Portugal (n = 13; 7.9%), and France (n = 12; 7.3%). In contrast, Eastern European countries are sparsely represented, with only isolated studies (e.g., Greece and Estonia; 1 study each). Outside Europe and North America, Australia (n = 5; 3%) and Chile (n = 5; 3%) contribute modestly, while other temperate regions remain weakly covered.

3.3. Agricultural practices

The evidence base is strongly concentrated on landscape-scale management. Landscape complexity (n = 72; 31.3%), land use (n = 71; 30.9%), and agroecological infrastructures such as hedgerows or isolated trees (n = 22; 9.6%) together account 71.8% of the evidence base, forming the largest cluster of studies (Fig. 4). Studies in the landscape complexity category typically explore how landscape composition and spatial heterogeneity affect bat populations (e.g., Ancillotto et al., 2021, 2017; Tortosa et al., 2023). Within the land use

Table 3
Agricultural practice categories used to classify publications by Intervention.

Practices and management group	Practices and management category
local-scale agricultural practices	Crop protection
	Fertilization
	Harvesting
	Livestock grazing management
	Field margin
	Irrigation and water management
Integrated farming systems (Combination of various individual practices, studied under a unique system/method)	Agroforestry
	Organic farming system
	Conservation tillage system
	Grassland systems
	Farming systems under Agri-Environment Schemes
	Landscape complexity
Landscape-scale management	Land use
	Agroecological infrastructures

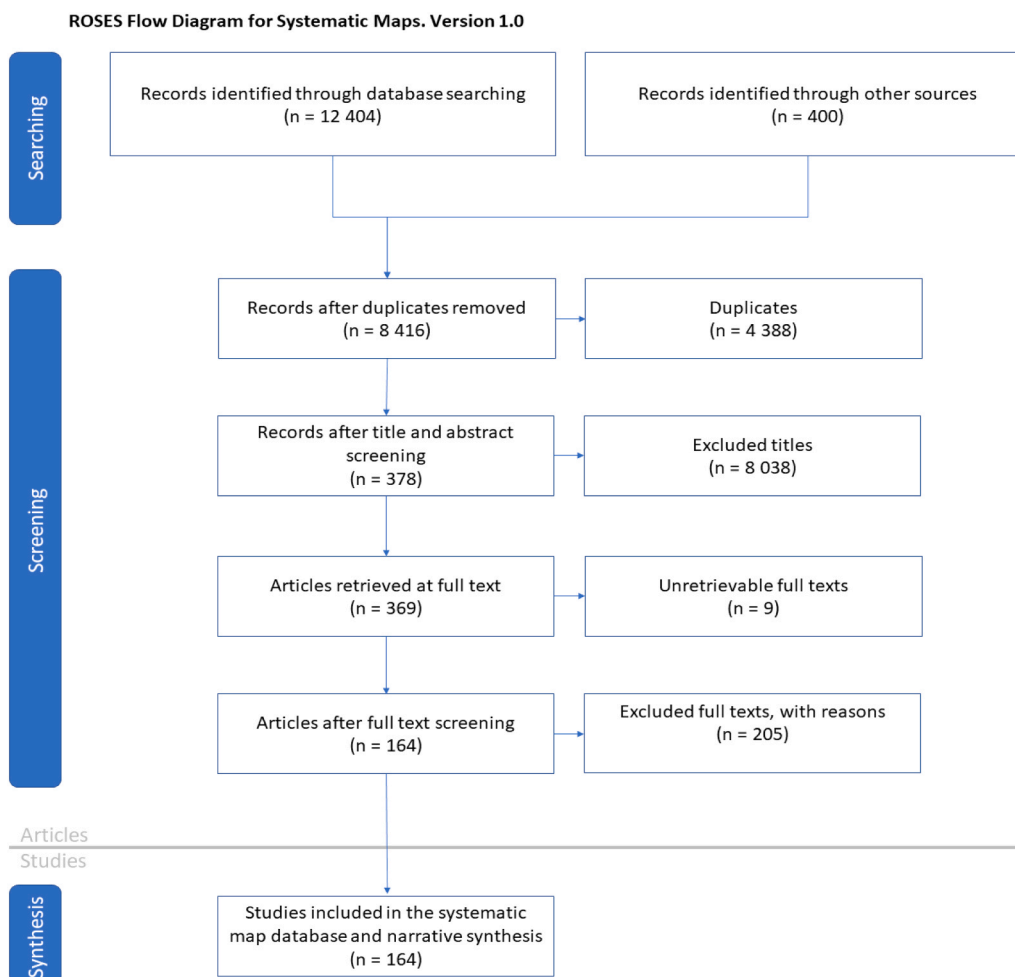


Fig. 1. ROSES flow diagram illustrating the study selection process for the systematic map (adapted from Haddaway et al., 2017).

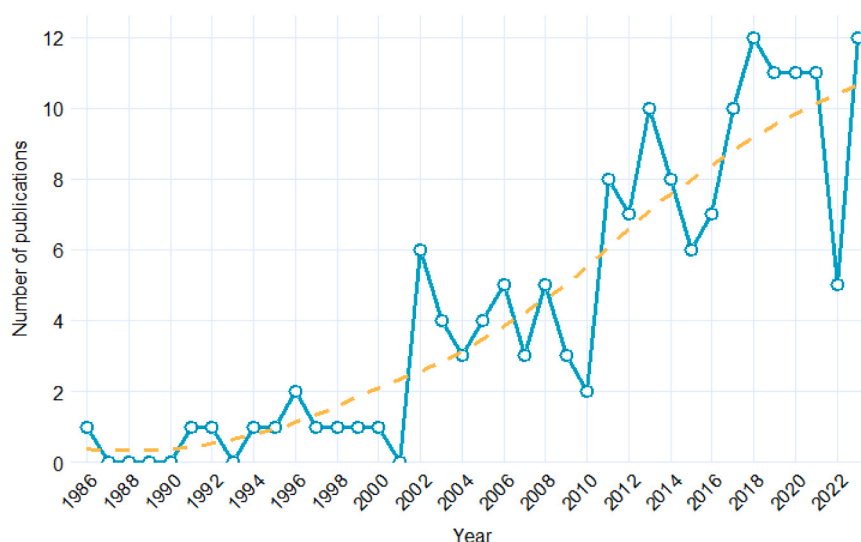


Fig. 2. Temporal evolution of studies included in the systematic map. Annual numbers (solid line) and trend (dashed line).

category, 45 studies focus on the habitat use and specialisation of one or a few bat species across different land-cover types, primarily using radio-tracking (e.g., Nelson and Gillam, 2017; Russo and Jones, 2003).

In contrast, local-scale practices ($n = 35$; 14.9%) and integrated farming systems ($n = 30$; 13.1%) are substantially underrepresented,

revealing important gaps in the evidence base.

Among local-scale agricultural practices, field margins are the most frequently investigated ($n = 21$; 9.1%), with studies often comparing presence versus absence margins (Kelly et al., 2016; Toffoli, 2016) or different margin types (Lentini et al., 2012; McHugh et al., 2019).

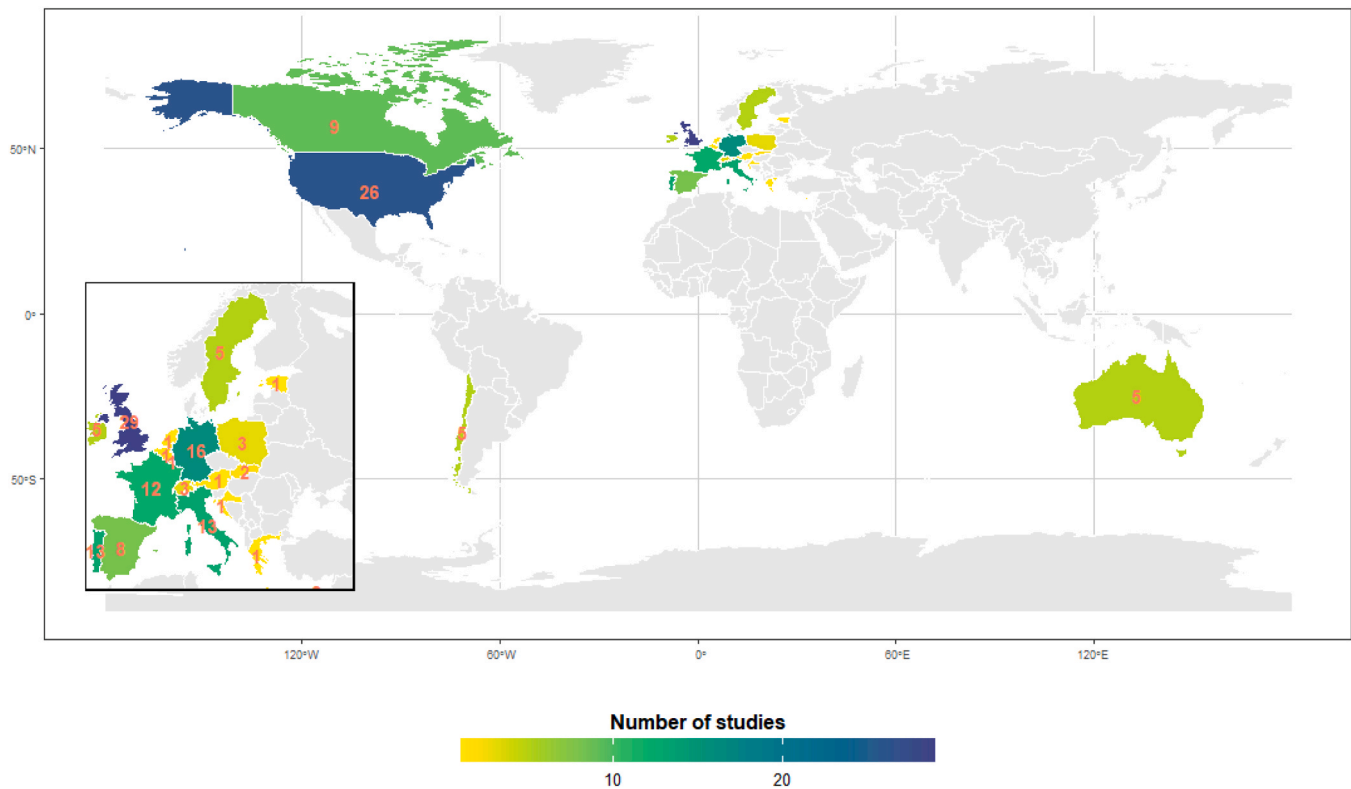


Fig. 3. Geographic distribution of the studies included in the systematic map. The mapped values correspond to the number of studies conducted in each country. For countries spanning multiple climatic zones (Canada, USA, Sweden, Australia, Chile), only studies conducted within temperate regions, as defined by the Köppen–Geiger classification and detailed in Table 2, were included and therefore are represented here.

Livestock grazing management ($n = 5$; 2.2%) is examined through comparisons of grazing intensity (Ancillotto et al., 2017), herd size (Costa et al., 2019), or livestock presence (Downs and Sanderson, 2010), with only one study assessing the impact of livestock water-trough modifications on bats (Tuttle et al., 2006). Crop protection practices are less addressed ($n = 4$; 1.7%) and covered heterogeneous dimensions of pesticide use and pest management, including comparisons of chemical input intensity (Jimenez-Navarro et al., 2023), AES schemes involving reduced pesticide use (MacDonald et al., 2012), experimentally testing the effect of herbivore-induced plant volatiles (Maynard et al., 2023), and pesticide residue analyses in bat tissues across gradients of spraying intensity (Guillén et al., 1994). Irrigation and water management studies ($n = 3$; 1.3%) emphasize the ecological role of ponds and channels in semiarid regions, which support bat activity and species richness by providing essential foraging habitats (Lison and Calvo, 2011; Stahlschmidt et al., 2012). Other local-scale practices such as fertilisation (MacDonald et al., 2012) and harvesting techniques (Pluciński et al., 2015) are addressed in less than 1% ($n = 1$) of studies each. Within the farming integrated system category, organic farming receives the greatest attention ($n = 14$; 7.4%), most often in contrast with conventional systems. Two studies extend this comparison: the first includes fields in transition to organic farming (Fialas et al., 2023), while the second incorporates the conservation tillage system (Barré et al., 2018). Farming systems under AES account for only 2.2% ($n = 5$) of studies, and typically compare farms adopting AES versus non-participating farms without detailing the specific management measures implemented (Angell et al., 2019; MacDonald et al., 2019). Other integrated farming systems, such as grassland ($n = 5$; 2.2%) and agroforestry ($n = 2$; 0.9%), also remain marginal in the evidence base. Only 33 (20%) studies combined landscape-scale variables with local-scale agricultural practices within the same framework, and only 10 statistically tested interaction effects between scales.

3.4. Monitoring methods

Acoustic surveys represent the predominant monitoring approach, used in 73% ($n = 119$) of the included studies (Fig. 5). They are applied across almost all categories of agricultural practices, with the highest concentration in studies addressing landscape complexity and land use. Radio tracking ($n = 45$; 27%) is the second most frequent method, primarily employed to study bat habitat use and specialisation by tracking individual movements and assessing how land-use changes influence bat behaviour. Capture-based methods, including mist netting and harp trapping, are used only occasionally ($n = 9$; 5%), primarily in studies addressing land-use changes. Importantly, the values reported here represent only studies in which capture methods were employed independently from radio-tracking procedures (i.e., not for attaching transmitters). These methods are mainly combined with acoustic surveys to refine species identification or to collect additional biological information. Tuttle et al., (2006) employed mist netting alongside infrared cameras to monitor bat activity at modified and unmodified livestock water troughs. In this study, black-and-white surveillance cameras with infrared illumination recorded nocturnal bat behaviour, while mist netting at the troughs allowed researchers to identify species and assess their reproductive status. Another study combined mist netting with direct observations (Krull et al., 1991), and a third did not specify the capture method used (Guillén et al., 1994). Faecal sampling ($n = 5$; 3%) is applied in studies addressing landscape-scale management, to evaluate diet composition or biological control potential. Roost surveys ($n = 3$; 2%) and camera monitoring ($n = 2$; 1%) are uncommon.

3.5. Measured outcomes

Bat activity (measured as acoustic passes per night) is the most frequently measured outcome, reported in 60% ($n = 99$) of included studies (Fig. 6). Species richness ($n = 64$; 39%) and habitat use or

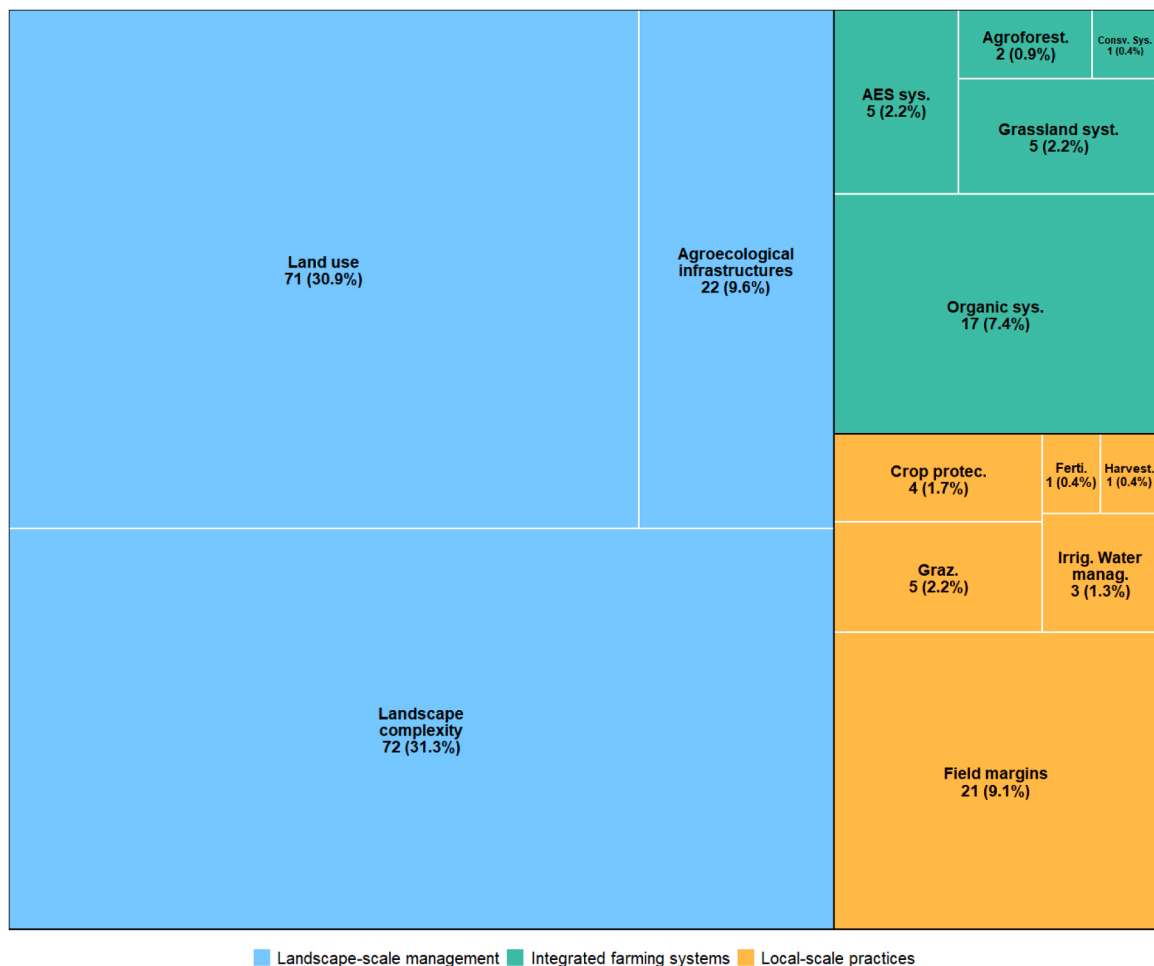


Fig. 4. Agricultural practices studied in temperate agroecosystem. Numbers and percentages respectively indicate the number of publications and relative proportions for each practice. Because individual studies may evaluate multiple practices, cell values represent the numbers of study–method–practice combinations, and totals therefore exceed the number of included studies. AES sys. = Farming systems under AES; Agroforest. = Agroforestry; Conserv. Sys. = Conservation tillage system; Crop protec. = Crop protection; Ferti. = Fertilization; Grassland syst. = Grassland systems; Graz. = Livestock grazing management; Harvest. = Harvesting; Irrig. water manag. = Irrigation and water management; Organic syst. = Organic farming system.

specialisation ($n = 55$; 34%) are also widely reported. Habitat use or specialisation is analysed through comparative assessments of bat occurrence or activity across habitat types, and through indices such as the *Species Specialization Index (SSI)* and *Community Specialization Index (CSI)*, which quantify species and community-level specialisation along habitat and landscape gradients (Blary et al., 2021; Lacoëuilhe et al., 2018). These three metrics form the central outcome cluster in the literature and are strongly associated with landscape-scale studies. Activity and species richness predominate in landscape complexity studies, while habitat use or specialisation is strongly associated with land-use studies (Fig. 6).

Community composition ($n = 16$; 10%) is commonly assessed using ordination methods such as *non-metric multidimensional scaling (NMDS)* or dissimilarity indices (e.g., Bray–Curtis, ANOSIM) to analyse shifts in bat communities between habitats. Taxonomic diversity ($n = 13$; 8%) is less frequently assessed using indices such as Shannon or Simpson, while functional diversity ($n = 8$; 5%) remains poorly integrated. Only a few studies employ functional diversity metrics such as *Functional Richness (FRic)*, *Functional Evenness (FEve)*, *Functional Divergence (FDiv)*, or *Rao's Quadratic Entropy (Rao's Q)* to evaluate the ecological roles of different bat species (Jakobsson et al., 2020). These diversity-based outcomes are mainly associated with studies on landscape complexity. Outcomes directly linked to demographic performance, ecosystem functioning or physiological exposure are rare. Diet composition ($n = 6$; 4%) is

primarily assessed in studies addressing land use, and seldom combined with bat activity or species richness. Pest control service, pesticide residues in tissues, and colony size are each reported in only one study (Froidevaux et al., 2017; Puig-Montserrat et al., 2015).

3.6. Conservation measures to mitigate agricultural impacts on bats

Most studies proposed conservation measures (157 of 164 studies; Appendix D). These proposals (Fig. 7) largely reflect the landscape-oriented structure of the evidence base, with comparatively limited operational guidance for local-scale management adjustments.

Habitat conservation and restoration (29%) and the promotion of landscape heterogeneity and habitat connectivity (28%) are the most frequently recommended actions, with studies emphasizing the need to maintain and enhance suitable foraging and roosting environments within agricultural landscapes (Froidevaux et al., 2022, 2019; Heim et al., 2015).

The adoption of sustainable agricultural practices (12%), including organic farming and reduced pesticide use, is less frequently highlighted. Within this category, promoting diverse on-farm and within-field vegetation (e.g., wildflower strips to support beneficial insect populations) is proposed as a means of enhancing foraging habitats and ensuring consistent food resources for bats (McHugh et al., 2019; Peter et al., 2021).

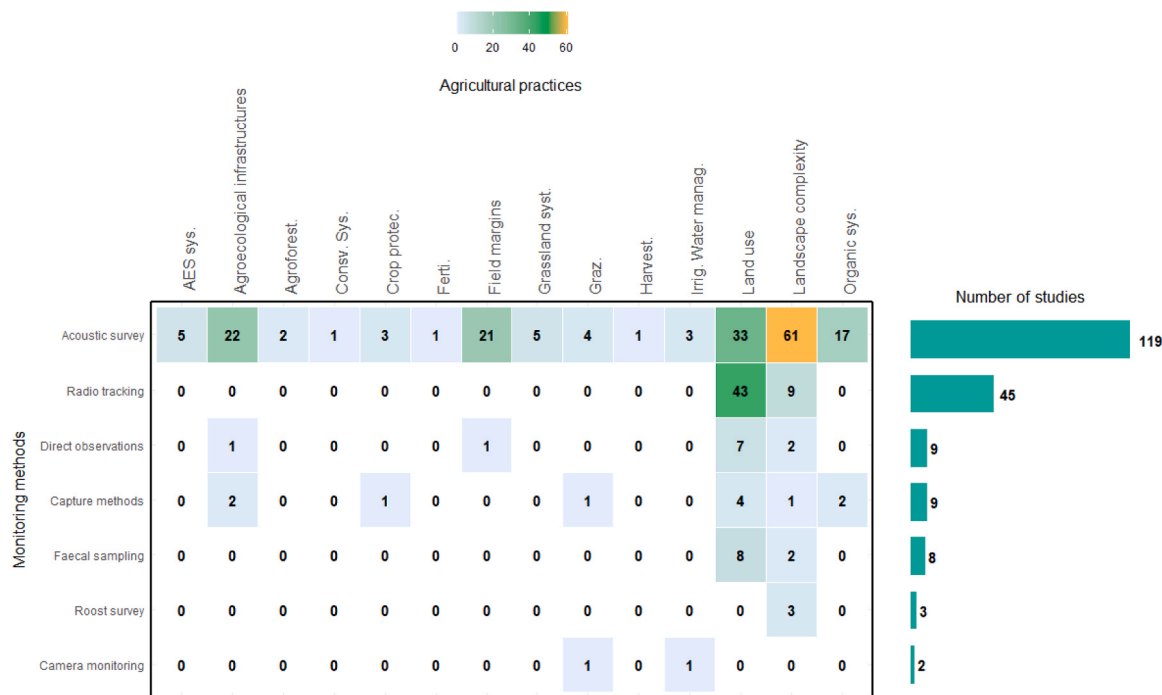


Fig. 5. Distribution of bat monitoring methods used in studies assessing the effects of agricultural practices in temperate agroecosystem. The heatmap shows the number of times each monitoring method was applied within each agricultural practice category. Because individual studies may evaluate multiple practices, cell values represent the numbers of study–method–practice combinations, and totals therefore exceed the number of included studies. The barplot on the right indicates the total number of studies using each monitoring method. AES sys. = Farming systems under AES; Agroforest. = Agroforestry; Conserv. Sys. = Conservation tillage system; Crop protec. = Crop protection; Ferti. = Fertilization; Grassland syst. = Grassland system; Graz. = Grazing; Harvest. = Harvesting; Irrig. water manag. = Irrigation and water management; Organic sys. = Organic system.

Implementation of monitoring and research (16%) constitutes a notable component of the proposed actions, stressing the necessity of long-term ecological studies to evaluate the effectiveness of conservation strategies. The importance of long-term monitoring is emphasized, with calls for citizen science programs to better track bat population dynamics and assess the impact of agricultural policies (Olivier et al., 2020).

In contrast, policy recommendations (7%) are relatively underrepresented. Some proposals emphasize the need for stronger integration of biodiversity conservation within the EU's Common Agricultural Policy, notably through the promotion of organic farming and agri-environmental measures aimed at enhancing landscape complexity and foraging opportunities (Toffoli and Rugghetti, 2020). Zoning regulations and development guidelines around key bat habitats are also suggested to mitigate urban expansion (Duchamp et al., 2004). The need for management guidelines under AES is also highlighted to ensure that conservation measures are effectively targeted to benefit bat populations (McHugh et al., 2019; Razgour et al., 2011).

Finally, a small minority of studies (3%) emphasize the need for better education of farmers, landowners, and the public about the ecological role of bats, particularly their contribution to pest control (Anderson et al., 2020; Monck-Whipp et al., 2018).

4. Discussion

This systematic map provides the first structured synthesis of agricultural practices affecting bat populations in temperate farmland across spatial scales. Beyond cataloguing the distribution of studies, our analysis reveals pronounced imbalances in research focus, methodological approaches, and response metrics. By reorganising the evidence around four main ecological pathways, structural habitat availability, trophic resource dynamics, toxicological exposure, and spatial configuration of landscapes, we distinguish relatively consistent behavioural patterns

from persistent empirical blind spots. Importantly, by explicitly disentangling behavioural responses from demographic inference and ecosystem service claims, this map clarifies both the strengths and the limits of the current evidence base supporting bat-friendly agricultural transitions. We therefore examine not only mechanistic pathways but also interpretative constraints, methodological robustness, and policy implications shaping the translation of ecological evidence into agricultural action.

4.1. Mechanistic pathways structuring the evidence base

4.1.1. Structural habitat availability within agricultural landscapes

Agroecological infrastructures are among the most studied components at various spatial scales. Field margins represent the most frequently studied ($n = 21$) local-scale management component, though they still account for a modest share of the total evidence (9.1%). Studies primarily examine the presence, type, and management of margins, most often hedgerows, less frequently grassy or wildflower strips (e.g., Kelly et al., 2016; Lentini et al., 2012; McHugh et al., 2019; Toffoli, 2016). Across studies, hedgerows and other agroecological infrastructures along field edges consistently support higher bat activity and greater species richness, particularly for edge- and narrow-space foragers that use linear landscape elements for commuting and prey detection (Boughy et al., 2011; Lacoëuilhe et al., 2018). The ecological role of hedgerows, alongside other agroecological infrastructures (woodlands, isolated trees, water bodies, etc.), is also examined at landscape scales (9.6% of the evidence), highlighting their contribution to heterogeneity and structural habitat availability (Davy et al., 2007; Froidevaux et al., 2022b; Heim et al., 2018). However, most studies assess bat activity rather than roost availability or demographic outcomes. This distinction matters because increased activity indicates habitat use, but not necessarily increased fitness or population growth (Hayes, 1997; Jones et al., 2009). Despite the potential importance of

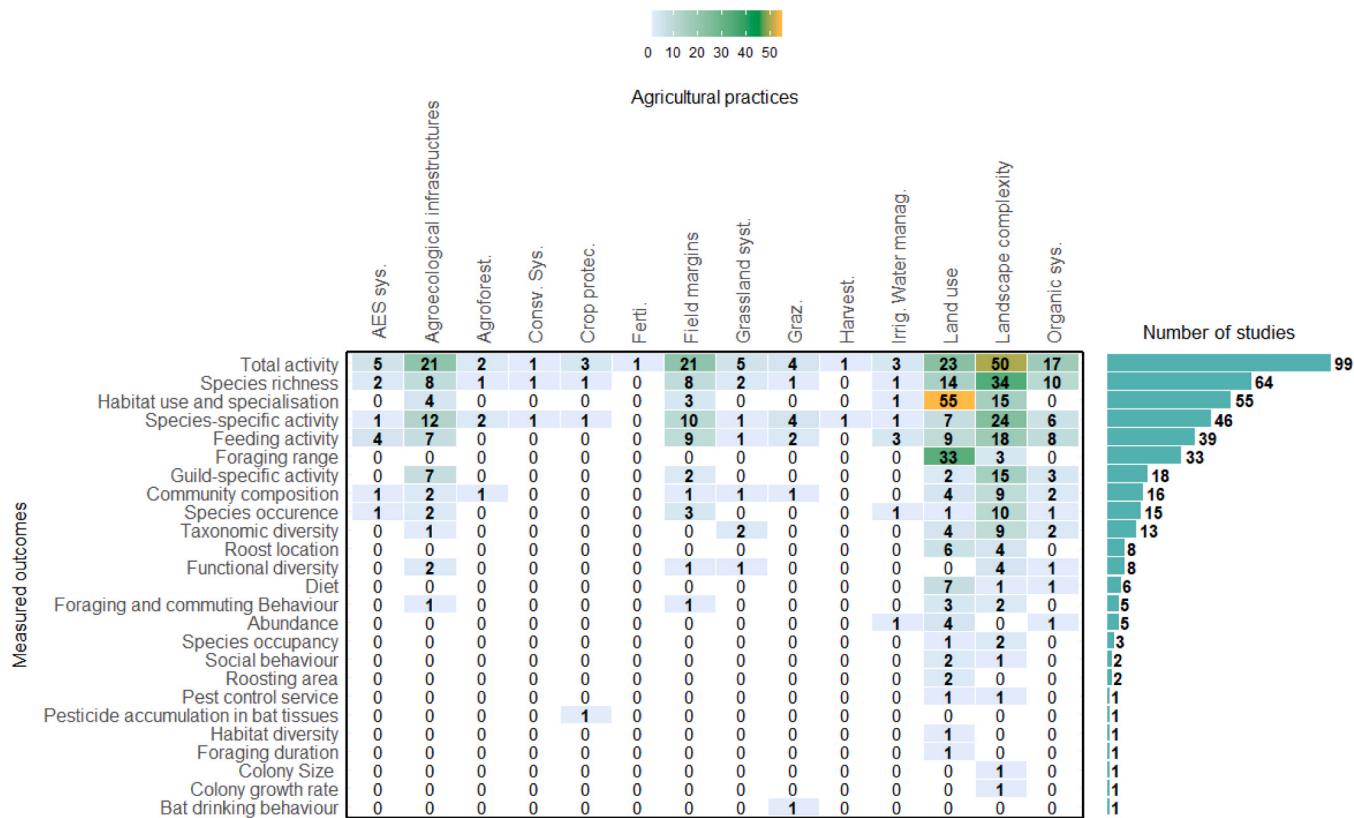


Fig. 6. Distribution of outcomes measured in studies assessing the effects of agricultural practices on insectivorous bats in temperate agroecosystem. The heatmap shows the number of times each ecological outcome was assessed within each agricultural practice category. Because individual studies may evaluate multiple practices, cell values represent the numbers of study–outcome–practice combinations, and totals exceed the number of included studies. The barplot on the right indicates the total number of studies reporting each outcome. AES sys. = Farming systems under AES; Agroforest. = Agroforestry; Conserv. Sys. = Conservation tillage system; Crop protec. = Crop protection; Ferti. = Fertilization; Grassland syst. = Grassland system; Graz. = Grazing; Harvest. = Harvesting; Irrig. water manag. = Irrigation and water management; Organic syst. = Organic system.

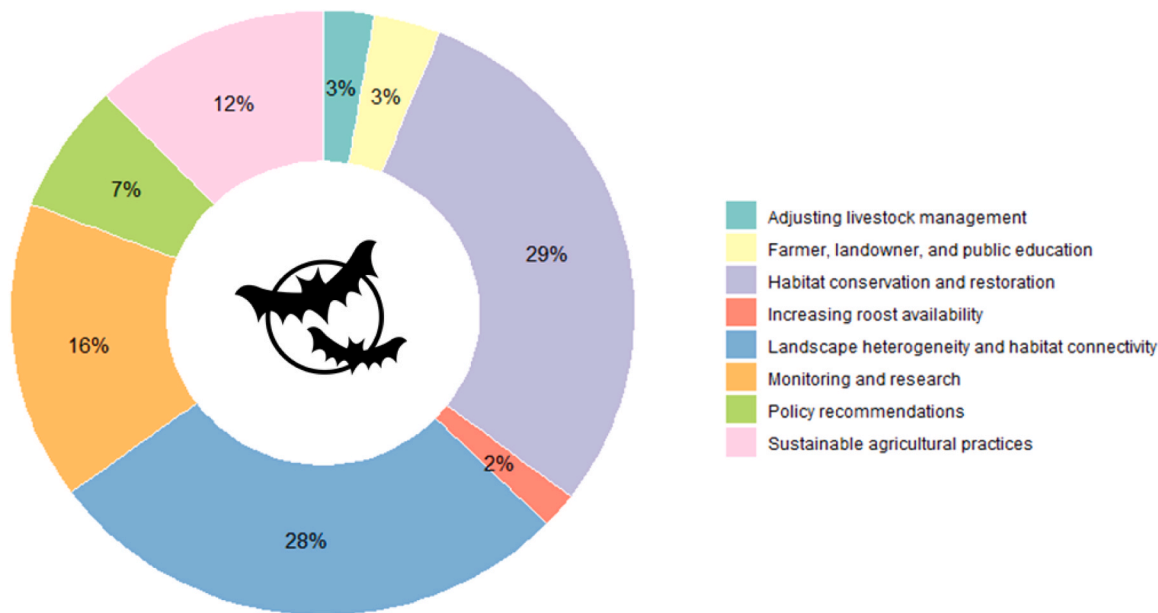


Fig. 7. Proposed conservation measures identified in the reviewed literature to mitigate the effects of agricultural practices on bats. Measures are grouped into eight categories: habitat conservation and restoration, promotion of landscape heterogeneity and habitat connectivity, adoption of sustainable agricultural practices, adjustment of livestock management, enhancement of roost availability, implementation of monitoring and research, development of policy recommendations, and education of farmers, landowners, and the public. Percentages indicate the proportion of publications recommending each category.

roost loss under livestock intensification (Kunz and Lumsden, 2003), no study in our database explicitly links changes in farm buildings to roost

loss and subsequent demographic responses in bat populations. This represents a critical blind spot as intensive livestock systems increasingly rely on enclosed, sealed structures that exclude bats (Kunz and Lumsden, 2003).

Future research should integrate roost monitoring, reproductive output, and colony persistence metrics to test whether structural habitat enhancements translate into population-level benefits. In livestock systems, experimental evaluations of bat-friendly building adaptations (e.g., preserved roof spaces, access points in renovated barns) would be particularly valuable for assessing farm infrastructure as a conservation lever within landscapes.

4.1.2. Trophic resource dynamics: bottom-up mechanisms remain weakly quantified

Agricultural practices operate mainly through bottom-up effects on insect communities (Paniccia et al., 2025; Tuneu-Corral et al., 2023), yet this pathway, central to both bat conservation and biological control, remains strikingly underexplored. Pesticides are known to reduce insect biomass and diversity in agroecosystems (Douglas and Tooker, 2016; Goulson, 2013), but only three studies among those explicitly examined crop protection practices, addressed the effects of pesticide intensity on bats (Guillén et al., 1994; Jiménez-Navarro et al., 2023; MacDonald et al., 2012). Organic-conventional comparisons ($n = 17$; 7.4%) consistently report higher bat activity in organic systems (e.g., Ancillotto et al., 2023; Put et al., 2018), likely reflecting greater prey availability. However, few studies (e.g., Long and Kurta, 2014; Olimp and Philpott, 2018) adopt a multi-trophic design by simultaneously monitoring bat activity and insect abundance. In these cases, the relationship between bats and prey is generally assessed through correlative analyses of acoustic activity and insect biomass or abundance. While such studies provide support for prey-mediated responses, they rarely distinguish agricultural pests from non-pest taxa, and none experimentally demonstrate reductions in crop damage or improvements in yield attributable to bat predation. Consequently, the mechanistic chain linking pesticide reduction to insect community recovery, and measurable pest control remains largely untested. The use of veterinary pharmaceuticals, especially antiparasitic agents like ivermectin, can have downstream ecological effects by contaminating dung, harm dung beetles (Ambrožová et al., 2021), which serve as prey for some bats (Downs and Sanderson, 2010). Despite the ecological significance of this pathway, we note the absence of studies on the impact of antiparasitic drugs on bat populations. Evidence for other agricultural practices is limited: Irrigation regimes and water management ($n = 3$; 1.3%), fertilisation ($n = 1$; 0.4%), and harvesting ($n = 1$; 0.4%) are marginally represented, while soil management was not investigated at all. Given their potential influence on insect availability (Guariento et al., 2023; Holland, 2004; Kohles et al., 2024), their underrepresentation constitutes a persistent blind spot.

Dietary metabarcoding confirms that many bat species consume agricultural pests (Mata et al., 2021b; Tuneu-Corral et al., 2023), but activity alone cannot determine whether increased foraging translates into measurable pest control (Kunz et al., 2011; Russo et al., 2018). Thus, while behavioural responses to structurally diverse or organic systems appear relatively robust, direct quantification of bottom-up trophic mediation remains limited. Multi-trophic study designs integrating insect monitoring, dietary metabarcoding (Charbonnier et al., 2021; Tuneu-Corral et al., 2023), and pest abundance tracking are needed to clarify causal pathways.

4.1.3. Toxicological exposure and ecological trap risk

Beyond indirect trophic effects through prey depletion, bats may also experience direct exposure to pesticides via contaminated prey and environmental contact. Despite substantial ecotoxicological literature documenting residue accumulation and sublethal physiological effects (Sandoval-Herrera et al., 2025; Torquetti et al., 2021), only one study quantified pesticide residues in bat tissues (Guillén et al., 1994). This

disconnect between bat ecology and ecotoxicology has important implications. Recent studies have explicitly highlighted the risk that habitat enhancement in farmland may inadvertently create ecological traps when broader anthropogenic pressures associated with agricultural intensification, including pesticide exposure, are not simultaneously mitigated (Russo et al., 2024; Tanalgo et al., 2025). This concern is particularly relevant for agroecological infrastructures such as hedgerows and flower strips, which enhance habitat attractiveness and prey availability for bats (Frey-Ehrenbold et al., 2013). However, when embedded within intensively managed croplands, these otherwise suitable features simultaneously expose bats to multiple stressors, including pesticide contamination, reduced prey quality and diversity, increase temporal instability of resource availability, habitat fragmentation, and recurrent agricultural disturbances. The co-occurrence of habitat attractiveness and chronic environmental stressors may therefore attract bats to habitats perceived as suitable for foraging while ultimately reducing survival or reproductive success, thereby potentially creating population sinks (Robertson and Hutto, 2006; Russo et al., 2024, 2018; Tanalgo et al., 2025). This mechanism highlights an underexplored risk in agroecological design: habitat restoration alone cannot be assumed to benefit bat populations if broader pressures associated with agricultural intensification persist (Hallmann et al., 2017; Russo et al., 2024, 2018).

Because most studies rely on activity-based metrics and rarely measure contaminant loads or fitness parameters concurrently, this risk may remain largely undetected. Bridging bat ecology with ecotoxicology through integrated designs combining contaminant analyses, physiological biomarkers, behavioural responses, and demographic monitoring is therefore essential to determine whether agroecological infrastructures contribute to population persistence and reproductive success or instead function as attractive sinks within intensified agricultural landscapes.

4.1.4. Spatial configuration and functional connectivity of agricultural landscapes

Landscape complexity studies constitute the largest evidence cluster ($n = 72$; 31.3%). This prominence reflects broader patterns in agroecological research, where landscape-scale variables are frequently prioritised because of both their well-documented influence on the distribution, diversity, and community composition of highly mobile organisms such as bats, birds, and pollinators (Frey-Ehrenbold et al., 2013; Priyadarshana et al., 2024; Vallé et al., 2023) and the relative accessibility of land-cover data. However, studies predominantly rely on descriptive metrics of landscape heterogeneity and don't incorporate agricultural management at the landscape scale, such as crop succession, pesticide use, or farming systems (Brusse et al., 2024).

Most studies quantify landscape composition, for example, habitat diversity and percentage of semi-natural habitats, while comparatively few assess configuration, such as corridor continuity, network cohesion, or permeability. This distinction is critical because a high amount of semi-natural habitats does not necessarily ensure landscape connectivity, as these habitats may remain fragmented when poorly connected or spatially isolated (Fahrig, 2013; Zeller et al., 2012). Furthermore, landscape-bat relationships are predominantly analysed using static, correlational metrics. Such approaches rarely incorporate temporal dynamics, such as seasonal crop phenology or canopy development, that can modify corridor quality and matrix permeability across the year (Tschamtké et al., 2012b). Consequently, compositional proxies may capture broad habitat gradients but fail to detect finer-scale constraints shaping bat movement and habitat use. For bats as highly mobile central-place foragers, spatial configuration likely influences energetic expenditure, commuting efficiency, and ultimately reproductive investment (Flaquer et al., 2008; Rainho and Palmeirim, 2011). Yet few studies integrate landscape metrics with energetic proxies, or demographic indicators, limiting inference about the functional consequences of landscape structure.

As a result, evidence consistently supports positive associations

between habitat amount and bat activity or species richness, but the functional consequences of configuration for long-term population viability remain underexplored. Integrating fine-scale movement data, graph-based connectivity indices, energetic proxies, and hierarchical modelling frameworks would help determine how spatial configuration shapes not only behavioural responses but also demographic outcomes in agricultural landscapes.

4.2. Inference limitations and systemic biases

4.2.1. Monitoring and detectability biases

Acoustic surveys dominate the literature ($n = 119$; 73%), reflecting logistical efficiency (O'Farrell and Gannon, 1999). However, detectability varies across guilds and habitats, with clutter-adapted species such as *Myotis* or *Plecotus* likely underestimated in dense vegetation (Ferreira et al., 2022; Russo et al., 2018). More fundamentally, bat activity provides only a partial representation of ecological processes (Park, 2015; Zhu et al., 2024).

Call data rarely allow reliable discrimination between commuting, foraging, and social interactions (Russo and Voigt, 2016). Activity indices therefore capture presence and relative use rather than energetic profitability or resource acquisition. Moreover, bat activity correlates only weakly with their abundance and does not directly predict reproductive success or population growth (Hayes, 1997; Jones et al., 2009, 2023). As a result, much of the literature documents behavioural responses without resolving demographic consequences. This interpretative limitation shapes the entire evidence base and constrains inference regarding long-term conservation effectiveness.

4.2.2. Ecosystem service inference versus direct evidence strength

Only one study (Puig-Montserrat et al., 2015) estimated the economic value of pest control in terms of avoided pesticide expenditure per hectare. In contrast, nearly all other studies infer ecosystem service potential from bat activity or species richness. However, bat activity correlates only moderately with prey consumption, and species richness does not necessarily reflect pest control capacity (Park, 2015; Zhu et al., 2024). Functional diversity metrics are rarely applied, despite evidence from other taxa that functional diversity components, such as functional richness (*FRic*) or the dominance of a few key species, often predict ecosystem processes, including predation on prey, better than species richness alone (Mouillot et al., 2011; Rouabah et al., 2024). Consequently, a structural gap persists between ecosystem service promotion and empirical demonstration. While behavioural responses suggest potential service provision, direct quantification linking diet, pest population dynamics, and crop outcomes remains exceptionally scarce.

4.2.3. Cross-scale and bundled management effects

Farming systems operate through interacting management bundles rather than isolated practices (Beillouin et al., 2019; Deguine et al., 2023). Yet most studies analyse agricultural practices separately and rarely incorporate cumulative-effects. As a result, nonlinear responses and threshold dynamics predicted by ecological theory (Didham et al., 2007) remain insufficiently documented. This reductionist framing contrasts with the reality of agroecosystems as complex socio-ecological networks in which multiple practices interact (Deguine et al., 2023) and may generate cumulative impacts on bat populations. While studies focusing on pesticide use, fertilisation, or tillage provide important insights, systemic approaches are needed to assess their combined effects across management dimensions (Beillouin et al., 2019; Deguine et al., 2023).

Multi-scale integration also remains limited. Although 33 studies included both local and landscape variables, only 10 explicitly tested interaction effects between scales (e.g., Millon et al., 2021; Olimpí and Philpott, 2018). This restricts detection of context dependency and hierarchical dynamics central to agroecological farming systems (Tscharnatke et al., 2012a; Tyllianakis and Martin-Ortega, 2021). For

instance, landscape heterogeneity may shape species richness, while local agroecological infrastructures such as hedgerows or field margins influence foraging efficiency and roost access (Froidevaux et al., 2022a, 2019). Furthermore, the expected positive effects of non-cropped habitats on biological pest control may be modulated by pesticide application (Ricci et al., 2019), soil tillage and farming system (Chabert and Sarthou, 2017; Martin et al., 2020), and within-field plant diversity (Chaplin-Kramer and Kremen, 2012). Integrating these spatial levels within coherent analytical frameworks is therefore essential to capture the cumulative and scale-dependent drivers of bat population dynamics and ecosystem service provision.

4.2.4. Geographic biases

The evidence base shows marked geographic clustering in Western Europe and North America, limiting the transferability of findings to underrepresented temperate regions. This pattern mirrors broader biases in ecological and agroecological research, where a large proportion of studies are concentrated in high-income temperate countries of the Global North (Di Marco et al., 2017; Skaldina and Blande, 2025).

Such concentration is problematic because agroecosystems in dominant study regions, often characterised by intensive monocultures, consolidated landholdings, and established hedgerow networks, differ markedly from Eastern Europe's fragmented post-socialist landscapes, smaller farm sizes (Frelih Larsen et al., 2024), or Australia's drier temperate systems. These contextual differences may moderate bat responses to landscape-scale management, consistent with evidence that species responses to habitat structure are context dependent (Boughy et al., 2011; Froidevaux et al., 2019). Expanding standardized monitoring efforts in underrepresented regions would be essential to test the generality of identified patterns and to identify context-dependent drivers of bat responses to agricultural management (Bonfanti et al., 2025).

4.3. Evidence robustness and study quality limitations

Consistent with systematic map methodology, we did not conduct a formal risk-of-bias assessment (Pullin and Stewart, 2006). Nevertheless, recurring methodological features constrain inference strength and should inform interpretation of the evidence base. First, correlational designs predominate. Most studies rely on observational comparisons across land-use types or habitat configurations without experimental manipulation or randomisation. Paired or quasi-experimental approaches (e.g., Barré et al., 2018; Put et al., 2018) and gradients of landscape heterogeneity (e.g., Ancillotto et al., 2023; Tortosa et al., 2023) are common but remain vulnerable to unmeasured confounding, limiting causal inference. Second, replication is often limited. Many studies include fewer than ten sites per treatment or are geographically restricted, constraining statistical power and generalisability. Broadly replicated, multi-scale designs (e.g., Heim et al., 2015; Monck-Whipp et al., 2018) remain comparatively rare. Third, landscape covariates are inconsistently integrated. Although some analyses explicitly test cross-scale interactions (e.g., Millon et al., 2021; Olimpí and Philpott, 2018), many assess local management effects without incorporating surrounding landscape composition or connectivity, increasing the risk of contextual confounding. Fourth, reliance on bat activity, often without detectability correction (Teets et al., 2019), may conflate ecological responses with variation in habitat structure, weather, or sampling design. Finally, temporal scope is typically short. Single-season monitoring with limited interannual replication restricts detection of lagged or cumulative responses and rarely captures demographic outcomes.

Collectively, these characteristics indicate that the evidence base primarily documents patterns of association rather than high-certainty causal relationships. Future systematic reviews or meta-analyses incorporating structured quality appraisal criteria, including study design, replication level, landscape integration, detectability correction, and

demographic metrics, would strengthen inference and better distinguish robust from provisional findings.

4.4. From ecological evidence to agricultural action

4.4.1. Translating mechanistic evidence into operational management levers

The distribution of proposed conservation measures closely mirrors the dominant evidence clusters identified. Landscape complexity and its structural habitat availability, representing the largest and most consistent evidence bases, are directly reflected in the predominance of habitat conservation and restoration (29%) and promotion of landscape heterogeneity and connectivity (28%) among recommended actions. Frequently recommended actions include maintaining and restoring semi-natural habitats, particularly hedgerow and other linear landscape elements, reinforcing landscape connectivity, and protecting roosting structures within farm buildings (Froidevaux et al., 2019; Millon et al., 2021). These structural measures build on well-established positive associations between habitat amount, heterogeneity, and bat activity and species richness (Frey-Ehrenbold et al., 2013; Froidevaux et al., 2022a; Monck-Whipp et al., 2018) and therefore represent the most defensible starting point for bat-friendly agricultural transitions, even if responses remain primarily activity-based rather than demographic.

Sustainable agricultural management such as organic systems, pesticide reduction, conservation tillage, and floristically diverse AES account for 12% of proposed measures, yet direct quantifications of pest control, dietary shifts, or contaminant exposure remain scarce (4.2). Despite the imbalance between the strong empirical support for landscape management and the weaker evidence for chemical thresholds or validated biological control claims, this does not undermine the importance of chemical reduction or agroecological transitions. Rather, it calls for precautionary and integrated strategies. Systemic approaches combining multi-scale habitat enhancement with progressive chemical reduction better reflect this multi-pathway reality (Beillouin et al., 2019; Deguine et al., 2023). Such systemic integration of practices also reflects farming realities, where combinations of practices are implemented rather than single measures (Jones et al., 2023). For example, coupling hedgerow restoration or agroforestry with reduced chemical inputs may enhance both connectivity and the availability of less contaminated prey.

Overall, the evidence supports prioritising structural landscape habitat measures at local and landscape scales. By contrast, evidence supporting specific chemical thresholds, irrigation regimes, or tillage prescriptions remains limited, and therefore insufficient to justify precise management targets. However, durable bat conservation and reliable pest control service require embedding these within integrated management strategies that also address trophic and toxicological pressures, dimensions still underrepresented in the evidence base.

4.4.2. Aligning conservation objectives with policy instruments

Despite the growing evidence on the effects of agricultural practices on bats, explicit policy recommendations appear in only 7% of studies, highlighting a persistent gap between ecological research and governance. Where discussed, implications focus on integrating bat conservation into AES and the EU Common Agricultural Policy, particularly through support for organic systems, landscape complexity, and spatial targeting of floristically diverse habitats (Toffoli and Rugghetti, 2017).

Policy instruments can operationalise the strongest evidence clusters identified in this systematic map, which primarily concern landscape complexity. Incentives for hedgerow maintenance, agroforestry establishment, restoration of semi-natural habitats, and preservation of landscape heterogeneity directly translate these structural findings into practice. In parallel, regulatory and incentive-based instruments targeting pesticide reduction, Integrated Pest Management, and organic transitions may address toxicological pressures (Deguine et al., 2023).

Embedding bat conservation within broader frameworks such as the

EU Biodiversity Strategy (European Commission, 2020) and the Kunming–Montreal Global Biodiversity Framework (CBD, 2022) may strengthen cross-sectoral coherence and increase political uptake. However, feasibility ultimately depends on farmer decision-making dynamics. Economic constraints, perceived risk, and short-term profitability shape adoption of biodiversity-friendly practices (Brown et al., 2021; van Dijk et al., 2016, van Dijk et al., 2015). Without adequate financial incentives or compensation for opportunity costs, uptake may remain limited (Deguine et al., 2023; Moon and Cocklin, 2011). Aligning conservation objectives with agronomic viability is therefore central to policy effectiveness.

However, translating evidence into policy instruments is not sufficient; their ecological effectiveness must also be demonstrated. Evaluation design is therefore central to policy credibility. Yet few AES assessments use before–after designs, long-term monitoring, or demographic indicators capable of detecting sustained population-level responses. Most rely on short-term acoustic metrics, which may overestimate effectiveness if ecological traps or landscape context remain unaccounted for (Russo et al., 2018). More broadly, existing AES evaluations provide mixed evidence of effectiveness and rarely incorporate demographic or long-term population indicators, limiting robust conclusions about sustained ecological benefits. As a result, schemes may align with structural evidence while lacking robust validation of long-term outcomes. Predictive ecological modelling can strengthen both targeting and evaluation. By simulating how alternative practices, such as pesticide reduction or habitat restoration, affect bat populations, modelling frameworks allow policymakers to anticipate ecological consequences before implementation and assess expected benefits more rigorously (Beillouin et al., 2019). Integrated into decision-support tools, such approaches support scenario testing and adaptive refinement of biodiversity-oriented schemes.

4.4.3. Strengthening the science–practice interface for adaptive implementation

Sixteen percent of studies call for improved monitoring and knowledge transfer, underscoring the need to reinforce the science–practice interface (e.g., Monck-Whipp et al., 2018; Toffoli and Rugghetti, 2017). Translating ecological patterns into durable agricultural outcomes requires better data integration, participatory pathways, and adaptive governance.

Citizen science programmes such as Vigie-Chiro in France (Kerbirou et al., 2015) and the National Bat Monitoring Programme in the UK (Barlow et al., 2015) generate extensive biodiversity datasets. Integrating these with fine-scale agricultural data would substantially strengthen causal inference and adaptive management (Isaac et al., 2020; Jetz et al., 2012). However, detailed information on pesticide use, irrigation timing, livestock treatments, or mowing regimes often remains inaccessible or insufficiently resolved. Improving interoperability between biodiversity monitoring and agricultural databases is therefore strategic.

Adoption also depends on social and institutional dynamics. Farmer uptake is shaped not only by ecological effectiveness but by economic, cultural, and psychological drivers (Dessart et al., 2019; Mills et al., 2017). Participatory approaches, including living Labs, provide platforms for co-designing locally adapted management bundles with farmers and advisors (Yousefi and Ewert, 2023). Such co-produced approaches enhance legitimacy, feasibility, and long-term uptake.

Key messages

- Evidence is heavily concentrated on landscape complexity (i.e. compositional and configurational heterogeneity), while direct assessments of local management practices remain comparatively scarce.
- Most studies measure bat activity or species richness; demographic, physiological, and functional indicators are rarely assessed.

- Pest control service claims often rely on behavioural proxies rather than direct links between diet, pest dynamics, and crop outcomes.
- Advancing bat-friendly agriculture requires systemic, cross-scale approaches and more rigorous experimental designs.

5. Conclusion

This systematic map shows that evidence linking agricultural practices and insectivorous bats in temperate regions is strongly concentrated on descriptive metrics of compositional and configurational landscape heterogeneity, with comparatively limited investigation of specific local-scale practices such as pesticide regimes, fertilisation, tillage, irrigation, or grazing management. Most studies rely on bat activity and species richness, whereas functional, physiological, dietary, and demographic endpoints remain rare. Consequently, while behavioural responses to landscape management are consistently documented, inference about long-term population viability and ecosystem service delivery remains constrained.

The evidence base therefore supports cautious but not definitive claims regarding bat-mediated pest control in agroecosystems. Landscape heterogeneity emerges as the most consistently associated factor with bat activity and species richness, yet empirical validation of trophic regulation, pesticide exposure pathways, and fitness consequences remains limited. Translating bat-friendly farming into robust policy thus requires aligning ecological mechanisms, measurement approaches, and management scales.

By structuring the evidence around clearly defined intervention categories and response metrics, this map provides a transparent foundation for targeted meta-analyses and future empirical work. Strengthening the evidence base will require more explicit testing of specific management practices, improved integration across spatial scales, and greater attention to functional responses and service delivery. Such advances are essential to inform evidence-based agricultural policies and agri-environment schemes aimed at reconciling production and biodiversity conservation in temperate agroecosystems.

CRedit authorship contribution statement

Kevin Barré: Writing – review & editing, Validation. **Julie Marmet:** Writing – review & editing, Validation, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Abdelhak Rouabah:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Isabelle Le Viol:** Writing – review & editing, Validation. **Joseph Langridge:** Writing – review & editing, Validation, Methodology. **Florence Matutini:** Writing – review & editing, Validation, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Karine Princé:** Writing – review & editing, Validation. **Fabien Claireau:** Writing – review & editing, Validation, Investigation. **François Chiron:** Writing – review & editing, Validation. **Christian Kerbiriou:** Writing – review & editing, Validation, Investigation. **Jérémy S.P. Froidevaux:** Writing – review & editing, Validation, Investigation.

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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.

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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.2026.110554](https://doi.org/10.1016/j.agee.2026.110554).

Data availability

No data was used for the research described in the article.

References

- Ambrozová, L., Sládeček, F.X.J., Zitek, T., Perlík, M., Kozel, P., Jirků, M., Čížek, L., 2021. Lasting decrease in functionality and richness: Effects of ivermectin use on dung beetle communities. *Agric. Ecosyst. Environ.* 321, 107634. <https://doi.org/10.1016/j.agee.2021.107634>.
- Ancillotto, L., Ariano, A., Nardone, V., Budinski, I., Rydell, J., Russo, D., 2017. Effects of free-ranging cattle and landscape complexity on bat foraging: Implications for bat conservation and livestock management. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2017.03.001>.
- Ancillotto, L., Festa, F., De Benedetta, F., Cosentino, F., Pejic, B., Russo, D., 2021. Free-ranging livestock and a diverse landscape structure increase bat foraging in mountainous landscapes. *Agrofor. Syst.* <https://doi.org/10.1007/s10457-021-00591-0>.
- Ancillotto, L., Scaramella, C., Dartora, F., Migliozi, A., Russo, D., 2023. Organic farming sustains bats in Mediterranean farmland. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2022.108230>.
- Anderson, M., Norton, L., Mathews, F., 2020. Grassland management affects vegetation structure, bats and their beetle prey. *Divers.* <https://doi.org/10.3390/d12100406>.
- Angell, R.L., Langton, S.D., MacDonald, M.A., Skates, J., Haysom, K.A., 2019. The effect of a Welsh agri-environment scheme on bat activity: A large-scale study. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2018.12.011>.
- Barlow, K.E., Briggs, P.A., Haysom, K.A., Hutson, A.M., Lechiara, N.L., Racey, P.A., Walsh, A.L., Langton, S.D., 2015. Citizen science reveals trends in bat populations: The National Bat Monitoring Programme in Great Britain. *Biol. Conserv.* 182, 14–26. <https://doi.org/10.1016/j.biocon.2014.11.022>.
- Barré, K., Le Viol, I., Julliard, R., Chiron, F., Kerbiriou, C., 2018. Tillage and herbicide reduction mitigate the gap between conventional and organic farming effects on foraging activity of insectivorous bats. *Ecol. Evol.* 8, 1496–1506. <https://doi.org/10.1002/ece3.3688>.
- Batáry, P., Dicks, L.V., Kleijn, D., Sutherland, W.J., 2015. The role of agri-environment schemes in conservation and environmental management. *Conserv. Biol.* 29, 1006–1016. <https://doi.org/10.1111/cobi.12536>.
- Beilke, E.A., O'Keefe, J.M., 2023. Bats reduce insect density and defoliation in temperate forests: An exclusion experiment. *Ecology* 104, e3903. <https://doi.org/10.1002/ecy.3903>.
- Beillouin, D., Ben-Ari, T., Makowski, D., 2019. Evidence map of crop diversification strategies at the global scale. *Environ. Res. Lett.* 14, 123001. <https://doi.org/10.1088/1748-9326/ab4449>.
- Blary, C., Kerbiriou, C., Le Viol, I., Barre, K., 2021. Assessing the importance of field margins for bat species and communities in intensive agricultural landscapes. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2021.107494>.
- Bonfanti, J., Langridge, J., Beillouin, D., 2023. A global database to catalogue the impacts of agricultural management practices on terrestrial biodiversity. *Data Brief.* 50, 109555. <https://doi.org/10.1016/j.dib.2023.109555>.
- Bonfanti, J., Langridge, J., Avadí, A., Casajus, N., Chaudhary, A., Damour, G., Estrada-Carmona, N., Jones, S.K., Makowski, D., Mitchell, M., Seppelt, R., Beillouin, D., 2025. Geographic, Taxonomic and Metric Gaps in Biodiversity Research Limit Evidence-Based Conservation in Agricultural Landscapes: An Umbrella Review. *Ecol. Lett.* 28, e70220. <https://doi.org/10.1111/ele.70220>.

- Boughey, K.L., Lake, I.R., Haysom, K.A., Dolman, P.M., 2011. Improving the biodiversity benefits of hedgerows: How physical characteristics and the proximity of foraging habitat affect the use of linear features by bats. *Biol. Conserv.* 144, 1790–1798. <https://doi.org/10.1016/j.biocon.2011.02.017>.
- Boyles, J.G., Cryan, P.M., McCracken, G.F., Kunz, T.H., 2011. Economic Importance of Bats in Agriculture. *Science* 332, 41–42. <https://doi.org/10.1126/science.1201366>.
- Brown, C., Kovács, E., Herzon, I., Villamayor-Tomas, S., Albizua, A., Galanaki, A., Grammatikopoulou, I., McCracken, D., Olsson, J.A., Zinngrebe, Y., 2021. Simplistic understandings of farmer motivations could undermine the environmental potential of the common agricultural policy. *Land. Use Policy* 101, 105136. <https://doi.org/10.1016/j.landusepol.2020.105136>.
- Brusse, T., Tougeron, K., Barbottin, A., Henckel, L., Dubois, F., Marrec, R., Caro, G., 2024. Considering farming management at the landscape scale: descriptors and trends on biodiversity. A review. *Agron. Sustain. Dev.* 44, 30. <https://doi.org/10.1007/s13593-024-00966-4>.
- Carballo-Morales, J.D., Saldaña-Vázquez, R.A., Villalobos, F., 2021. Trophic guild and forest type explain phyllostomid bat abundance variation from human habitat disturbance. *Glob. Ecol. Conserv.* 25, e01425. <https://doi.org/10.1016/j.gecco.2020.e01425>.
- CBD, 2022. Kunming-Montreal Global Biodiversity Framework. *Secr. Conv. Biol. Divers.*
- Chabert, A., Sarthou, J.-P., 2017. Practices of conservation agriculture prevail over cropping systems and landscape heterogeneity in understanding the ecosystem service of aphid biocontrol. *Agric. Ecosyst. Environ.* 249, 70–79. <https://doi.org/10.1016/j.agee.2017.08.005>.
- Chaplin-Kramer, R., Kremen, C., 2012. Pest control experiments show benefits of complexity at landscape and local scales. *Ecol. Appl.* 22, 1936–1948. <https://doi.org/10.1890/11-1844.1>.
- Charbonnier, Y., Papura, D., Touzot, O., Rhouy, N., Sentenac, G., Rusch, A., 2021. Pest control services provided by bats in vineyard landscapes. *Agric. Ecosyst. Environ.* 306, 107207. <https://doi.org/10.1016/j.agee.2020.107207>.
- Clough, Y., Kirchweber, S., Kantelehardt, J., 2020. Field sizes and the future of farmland biodiversity in European landscapes. *Conserv. Lett.* 13, e12752. <https://doi.org/10.1111/conl.12752>.
- Collaboration for Environmental Evidence, 2022. Guidelines for Authors – Environmental Evidence. URL (<https://environmentalevidence.org/information-for-authors/>) (accessed 10.21.25).
- Costa, P., Medinas, D., Silva, B.M., Mira, A., Guimar, N., Sales-Baptista, E., Ferraz-de-Oliveira, M.I., Simões, M.P., Belo, A.D.F., Herrera, J.M., 2019. Cattle-driven forest disturbances impact ensemble composition and activity levels of insectivorous bats in Mediterranean wood pastures. *Agrofor. Syst.* 93, 1687–1699. <https://doi.org/10.1007/s10457-018-0275-x>.
- Di Marco, M., Chapman, S., Althor, G., Kearney, S., Besancon, C., Butt, N., Maina, J.M., Possingham, H.P., Rogalla von Bieberstein, K., Venter, O., Watson, J.E.M., 2017. Changing trends and persisting biases in three decades of conservation science. *Glob. Ecol. Conserv.* 10, 32–42. <https://doi.org/10.1016/j.gecco.2017.01.008>.
- Díaz, S.M., Settele, J., Brondizio, E., Ngo, H., Guéze, M., Agard, J., Arneeth, A., Balvanera, P., Brauman, K., Butchart, S., Chan, K.M.A., Garibaldi, L.A., Ichii, K., Liu, J., Subramanian, S., Midgley, G., Milosavljević, P., Molnár, Z., Obura, D., Pfaff, A., Polasky, S., Purvis, A., Razzaque, J., Reyers, B., Roy Chowdhury, R., Shin, Y.-J., Visseren-Hamakers, I., Willis, K., Zayas, C., 2019. global assessment report biodiversity ecosystem services Summary policy makers. *Intergovernmental Science-Policy Platform Biodiversity Ecosystem Services*.
- Dainese, M., Martin, E.A., Aizen, M.A., Albrecht, M., Bartomeus, I., Bommarco, R., Carvalheiro, L.G., Chaplin-Kramer, R., Gagic, V., Garibaldi, L.A., Ghazoul, J., Grab, H., Jonsson, M., Karp, D.S., Kennedy, C.M., Kleijn, D., Kremen, C., Landis, D.A., Letourneau, D.K., Marini, L., Poveda, K., Rader, R., Smith, H.G., Tschamke, T., Andersson, G.K.S., Badenhausser, I., Baensch, S., Bezerra, A.D.M., Bianchi, F.J.J.A., Boreux, V., Bretagnolle, V., Caballero-Lopez, B., Cavigliasso, P., Četković, A., Chacoff, N.P., Classen, A., Cusser, S., da Silva e Silva, F.D., de Groot, G.A., Dudenhöffer, J.H., Ekroos, J., Fijen, T., Franck, P., Freitas, B.M., Garratt, M.P.D., Gratton, C., Hipólito, J., Holzschuh, A., Hunt, L., Iverson, A.L., Jha, S., Keasar, T., Kim, T.N., Kishinevsky, M., Klatt, B.K., Klein, A.-M., Krewenka, K.M., Krishnan, S., Larsen, A.N., Lavigne, C., Liere, H., Maas, B., Mallinger, R.E., Martinez Pachon, E., Martínez-Salinas, A., Meehan, T.D., Mitchell, M.G.E., Molina, G.A.R., Nesper, M., Nilsson, L., O'Rourke, M.E., Peters, M.K., Plečáček, M., Potts, S.G., Ramos, D. de L., Rosenheim, J.A., Rundlöf, M., Rusch, A., Sáez, A., Scheper, J., Schleuning, M., Schmack, J.M., Sciligo, A.R., Seymour, C., Stanley, D.A., Stewart, R., Stout, J.C., Sutter, L., Takada, M.B., Taki, H., Tamburini, G., Tschumi, M., Viana, B.F., Westphal, C., Willcox, B.K., Wratten, S.D., Yoshioka, A., Zaragoza-Trello, C., Zhang, W., Zou, Y., Steffan-Dewenter, I., 2019. A global synthesis reveals biodiversity-mediated benefits for crop production. *Sci. Adv.* 5, eaax0121. <https://doi.org/10.1126/sciadv.aax0121>.
- Davy, C.M., Russo, D., Fenton, M.B., 2007. Use of native woodlands and traditional olive groves by foraging bats on a Mediterranean island: consequences for conservation. *J. Zool.* 273, 397–405. <https://doi.org/10.1111/j.1469-7998.2007.00343.x>.
- Deguine, J.-P., Aubertot, J.-N., Bellon, S., Côte, F., Lauri, P.-E., Lescouret, F., Ratnadass, A., Scopel, E., Andrieu, N., Bärberi, P., Becker, N., Bouyer, J., Brévault, T., Cerdan, C., Cortesoro, A.-M., Dangles, O., Delatte, H., Dinh, P.T.Y., Dreyer, H., Duru, M., Flor, R.J., Gardarin, A., Husson, O., Jacquot, M., Javelle, A., Justes, E., Lam, M.T.X., Launay, M., Le, V.V., Longis, S., Martin, J., Munier-Jolain, N., Nguyen, N.T.T., Nguyen, T.T.N., Penvern, S., Petit, S., Poissot, A.-S., Robin, M.-H., Rolland, B., Rusch, A., Sabourin, E., Sanguin, H., Sarthou, J.-P., Sester, M., Simon, S., Sourisseau, J.-M., Steinberg, C., Tchamitchian, M., Thoumazeau, A., Tibi, A., Tivet, F., Tixier, P., Trinh, X.T., Vialatte, A., Wyckhuys, K., Lamichhane, J.R., 2023. Chapter One - Agroecological crop protection for sustainable agriculture. In: Sparks, D.L. (Ed.), *Advances in Agronomy*. Academic Press, pp. 1–59. <https://doi.org/10.1016/bs.agron.2022.11.002>.
- Dessart, F.J., Barreiro-Hurlé, J., van Bavel, R., 2019. Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. *Eur. Rev. Agric. Econ.* 46, 417–471. <https://doi.org/10.1093/erae/jbz019>.
- Didham, R.K., Tylanakis, J.M., Gemmell, N.J., Rand, T.A., Ewers, R.M., 2007. Interactive effects of habitat modification and species invasion on native species decline. *Trends Ecol. Evol.* 22, 489–496. <https://doi.org/10.1016/j.tree.2007.07.001>.
- Dietzer, M.T., Keicher, L., Kohles, J.E., Hurme, E.R., Ruczyński, I., Borowik, T., Zegarek, M., Chojński, M., Dechmann, D.K.N., 2024. High temporal resolution data reveal low bat and insect activity over managed meadows in central Europe. *Sci. Rep.* 14, 7498. <https://doi.org/10.1038/s41598-024-57915-0>.
- Douglas, M.R., Tooker, J.F., 2016. Meta-analysis reveals that seed-applied neonicotinoids and pyrethroids have similar negative effects on abundance of arthropod natural enemies. *PeerJ* 4, e2776. <https://doi.org/10.7717/peerj.2776>.
- Downs, N.C., Sanderson, L.J., 2010. Do Bats Forage Over Cattle Dung or Over Cattle? *Acta Chiropterologica* 12, 349–358. <https://doi.org/10.3161/150811010X537936>.
- Duchamp, J.E., Sparks, D.W., Whitaker Jr., J.O., 2004. Foraging-habitat selection by bats at an urban–rural interface: comparison between a successful and a less successful species. *Can. J. Zool.* 82, 1157–1164. <https://doi.org/10.1139/z04-095>.
- European Commission, 2020. EU Biodiversity Strategy for 2030: Bringing nature back into our lives. European Commission, Brussels.
- European Environment Agency, 2020. State of nature in the EU: results from reporting under the nature directives 2013–2018. EEA report. Publications Office of the European Union, Luxembourg.
- Fahrig, L., 2013. Rethinking patch size and isolation effects: the habitat amount hypothesis. *J. Biogeogr.* 40, 1649–1663. <https://doi.org/10.1111/jbi.12130>.
- Fahrig, L., Baudry, J., Brotons, L., Burel, F.G., Crist, T.O., Fuller, R.J., Sirami, C., Siriwardena, G.M., Martin, J.-L., 2011. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecol. Lett.* 14, 101–112. <https://doi.org/10.1111/j.1461-0248.2010.01559.x>.
- Farneda, F.Z., Meyer, C.F.J., Grelle, C.E.V., 2020. Effects of land-use change on functional and taxonomic diversity of Neotropical bats. *Biotropica* 52, 120–128. <https://doi.org/10.1111/btp.12736>.
- Ferreira, D.F., Gibb, R., López-Baucells, A., Nunes, N.J., Jones, K.E., Rocha, R., 2022. Species-specific responses to land-use change in island insectivorous bats. *J. Nat. Conserv.* 67, 126177. <https://doi.org/10.1016/j.jnc.2022.126177>.
- Fialas, P.C., Froidevaux, J.S.P., Jones, G., Batary, P., 2023. Transition to organic farming negatively affects bat activity. *J. Appl. Ecol.* <https://doi.org/10.1111/1365-2664.14468>.
- Flaquer, C., Puig-Montserrat, X., Burgas, A., Russo, D., 2008. Habitat selection by Geoffroy's bats (*Myotis emarginatus*) in a rural Mediterranean landscape: implications for conservation. *Acta Chiropterologica* 10, 61–67. <https://doi.org/10.3161/150811008X331090>.
- Fleiss, J.L., 1971. Measuring nominal scale agreement among many raters. *Psychol. Bull.* 76, 378–382. <https://doi.org/10.1037/h0031619>.
- Forister, M.L., Jahner, J.P., Casner, K.L., Wilson, J.S., Shapiro, A.M., 2011. The race is not to the swift: Long-term data reveal pervasive declines in California's low-elevation butterfly fauna. *Ecology* 92, 2222–2235. <https://doi.org/10.1890/11-0382.1>.
- Frampton, G.K., Livoreil, B., Petrokofsky, G., 2017. Eligibility screening in evidence synthesis of environmental management topics. *Environ. Evid.* 6, 27. <https://doi.org/10.1186/s13750-017-0102-2>.
- Frank, E.G., 2024. The economic impacts of ecosystem disruptions: Costs from substituting biological pest control. *Science* 385, eadg0344. <https://doi.org/10.1126/science.adg0344>.
- Freihil Larsen, A., Riedel, A., Scheid, A., Jägle, J., Springer, K., Bognar, J., Wiltshire, J., Freeman, D., Crotty, F., Kiresiwa, Z., Rouillard, J., Bibu, T., Landgrebe-Trinkunait, R., Malek, Z., Pepkowska-Król, A., Morkvėnas, Ž., Nyárai, O., Karoglan, S., Hološková, A., Zemeckis, R., Záhradník, M., 2024. Towards climate friendly and resilient agri-food systems in Central Eastern Europe: the role of agroecological practices, sustainable diets, and holistic policies. *Ecologic Institute, Berlin*. ISBN 978-3-937085-37-1.
- Frey-Ehrenbold, A., Bontadina, F., Arlettaz, R., Obrist, M.K., 2013. Landscape connectivity, habitat structure and activity of bat guilds in farmland-dominated matrices. *J. Appl. Ecol.* <https://doi.org/10.1111/1365-2664.12034>.
- Frick, W.F., Kingston, T., Flanders, J., 2020. A review of the major threats and challenges to global bat conservation. *Ann. N. Y. Acad. Sci.* 1469, 5–25. <https://doi.org/10.1111/nyas.14045>.
- Froidevaux, J.S.P., Boughey, K.L., Barlow, K.E., Jones, G., 2017. Factors driving population recovery of the greater horseshoe bat (*Rhinolophus ferrumequinum*) in the UK: implications for conservation. *Biodivers. Conserv.* <https://doi.org/10.1007/s10531-017-1320-1>.
- Froidevaux, J.S.P., Boughey, K.L., Hawkins, C.L., Broyles, M., Jones, G., 2019. Managing hedgerows for nocturnal wildlife: Do bats and their insect prey benefit from targeted agri-environment schemes? *J. Appl. Ecol.* <https://doi.org/10.1111/1365-2664.13412>.
- Froidevaux, J.S.P., Laforge, A., Larrieu, L., Barbaro, L., Park, K., Fialas, P.C., Jones, G., 2022b. Tree size, microhabitat diversity and landscape structure determine the value of isolated trees for bats in farmland. *Biol. Conserv.* <https://doi.org/10.1016/j.biocon.2022.109476>.
- Froidevaux, J.S.P., Duarte, G., Fonseca, A., Zina, V., Conde, S., Ferreira, M.T., Fernandes, M.R., 2022a. The location and vegetation physiognomy of ecological infrastructures determine bat activity in Mediterranean floodplain landscapes. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2022.107929>.

- Froidevaux, J.S.P., Toshkova, N., Barbaro, L., Benítez-López, A., Kerbiriou, C., Le Viol, I., Pacifici, M., Santini, L., Stawski, C., Russo, D., Dekker, J., Alberdi, A., Amorim, F., Ancillotto, L., Barré, K., Bas, Y., Cantú-Salazar, L., Dechmann, D.K.N., Devaux, T., Eldegard, K., Fereidouni, S., Furmankiewicz, J., Hamidovic, D., Hill, D.L., Ibáñez, C., Julien, J.-F., Juste, J., Kaňuch, P., Korine, C., Laforge, A., Legras, G., Leroux, C., Lesiński, G., Mariton, L., Marmet, J., Mata, V.A., Mifsud, C.M., Nisteanu, V., Novella-Fernandez, R., Rebelo, H., Roche, N., Roemer, C., Ruczyński, I., Sorås, R., Uhrin, M., Vella, A., Voigt, C.C., Razgour, O., 2023. A species-level trait dataset of bats in Europe and beyond. *Sci. Data* 10, 253. <https://doi.org/10.1038/s41597-023-02157-4>.
- García-Morales, R., Badano, E.I., Moreno, C.E., 2013. Response of Neotropical Bat Assemblages to Human Land Use. *Conserv. Biol.* 27, 1096–1106. <https://doi.org/10.1111/cobi.12099>.
- Goulson, D., 2013. REVIEW: An overview of the environmental risks posed by neonicotinoid insecticides. *J. Appl. Ecol.* 50, 977–987. <https://doi.org/10.1111/1365-2664.12111>.
- Grames, E.M., Stillman, A.N., Tingley, M.W., Elphick, C.S., 2019. An automated approach to identifying search terms for systematic reviews using keyword co-occurrence networks. *Methods Ecol. Evol.* 10, 1645–1654. <https://doi.org/10.1111/2041-210X.13268>.
- Guariento, E., Rüdiger, J., Fiedler, K., Panizza, C., Stifter, S., Tappeiner, U., Seebler, J., Hilpold, A., 2023. From diverse to simple: butterfly communities erode from extensive grasslands to intensively used farmland and urban areas. *Biodivers. Conserv.* 32, 867–882. <https://doi.org/10.1007/s10531-022-02498-3>.
- Guillén, A., Ibáñez, C., Pérez, J.L., Hernández, L.M., González, M.J., Fernández, M.A., Fernández, R., 1994. Organochlorine residues in Spanish common pipistrelle bats (*Pipistrellus pipistrellus*). *Bull. Environ. Contam. Toxicol.* 52, 231–237. <https://doi.org/10.1007/BF00198493>.
- Haddaway, N. R., Woodcock, P., Macura, B., Collins, A., 2015. Making literature reviews more reliable through application of lessons from systematic reviews. *Conserv. Biol.* 29, 1596–1605. <https://doi.org/10.1111/cobi.12541>.
- Haddaway, N.R., Macura, B., Whaley, P., Pullin, A.S., 2017. ROSES Flow Diagram for Systematic Maps. Version 1.0 [WWW Document]. figshare. (<https://doi.org/10.6084/m9.figshare.6085940.v2>).
- Hallmann, C.A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D., Kroon, H. de, 2017. More than 75 % decline over 27 years in total flying insect biomass in protected areas. *PLOS ONE* 12, e0185809. <https://doi.org/10.1371/journal.pone.0185809>.
- Harzing, A.-W., 2017. Publish or Perish [WWW Document]. Harzing.com. URL (<https://harzing.com/resources/publish-or-perish/>) (accessed 6.16.25).
- Hayes, J.P., 1997. Temporal Variation in Activity of Bats and the Design of Echolocation-Monitoring Studies. *J. Mammal.* 78, 514–524. <https://doi.org/10.2307/1382902>.
- Heim, O., Treitler, J.T., Tschapka, M., Knörnschild, M., Jung, K., 2015. The Importance of Landscape Elements for Bat Activity and Species Richness in Agricultural Areas. *PLOS ONE* 10, e0134443. <https://doi.org/10.1371/journal.pone.0134443>.
- Heim, O., Lenski, J., Schulze, J., Jung, K., Kramer-Schadt, S., Ecard, J.A., Voigt, C.C., 2018. The relevance of vegetation structures and small water bodies for bats foraging above farmland. *Basic. Appl. Ecol.* 27, 9–19. <https://doi.org/10.1016/j.baae.2017.12.001>.
- Holland, J.M., 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. *Agric. Ecosyst. Environ.* 103, 1–25. <https://doi.org/10.1016/j.agee.2003.12.018>.
- Isaac, N.J.B., Jarzyna, M.A., Keil, P., Dambly, L.L., Boersch-Supan, P.H., Browning, E., Freeman, S.N., Golding, N., Guillera-Arroita, G., Henrys, P.A., Jarvis, S., Lahoz-Monfort, J., Pagel, J., Prescott, O.L., Schmucki, R., Simmonds, E.G., O'Hara, R.B., 2020. Data Integration for Large-Scale Models of Species Distributions. *Trends Ecol. Evol.* 35, 56–67. <https://doi.org/10.1016/j.tree.2019.08.006>.
- Jakobsson, S., Wood, H., Ekroos, J., Lindborg, R., 2020. Contrasting multi-taxa functional diversity patterns along vegetation structure gradients of woody pastures. *Biodivers. Conserv.* <https://doi.org/10.1007/s10531-020-02037-y>.
- Janousek, W.M., Douglas, M.R., Cannings, S., Clément, M.A., Delphia, C.M., Everett, J.G., Hatfield, R.G., Keinath, D.A., Koch, J.B.U., McCabe, L.M., Mola, J.M., Ogilvie, J.E., Rangwala, I., Richardson, L.L., Rohde, A.T., Strange, J.P., Tronstad, L.M., Graves, T. A., 2023. Recent and future declines of a historically widespread pollinator linked to climate, land cover, and pesticides. *Proc. Natl. Acad. Sci.* 120, e2211223120. <https://doi.org/10.1073/pnas.2211223120>.
- Jetz, W., McPherson, J.M., Guralnick, R.P., 2012. Integrating biodiversity distribution knowledge: toward a global map of life. *Trends Ecol. Evol.* 27, 151–159. <https://doi.org/10.1016/j.tree.2011.09.007>.
- Jiménez-Navarro, G., Rodríguez-Pérez, J., Melguizo-Ruiz, N., Silva, B., Vasconcelos, S., Beja, P., Moreira, F., Morgado, R., Barreiro, S., Herrera, J.M., 2023. Disentangling the seasonal effects of agricultural intensification on birds and bats in Mediterranean olive groves. *Agric. Ecosyst. Environ.* 343, 108280. <https://doi.org/10.1016/j.agee.2022.108280>.
- Jimenez-Navarro, G., Rodríguez-Pérez, J., Melguizo-Ruiz, N., Silva, B., Vasconcelos, S., Beja, P., Moreira, F., Morgado, R., Barreiro, S., Herrera, J.M., 2023. Disentangling the seasonal effects of agricultural intensification on birds and bats in Mediterranean olive groves. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2022.108280>.
- Jones, G., Jacobs, D.S., Kunz, T.H., Willig, M.R., Racey, P.A., 2009. Carpe noctem: the importance of bats as bioindicators. *Endanger. Species Res.* 8, 93–115. <https://doi.org/10.3354/esr00182>.
- Jones, S.K., Sánchez, A.C., Beillouin, D., Juventia, S.D., Mosnier, A., Remans, R., Estrada Carmona, N., 2023. Achieving win-win outcomes for biodiversity and yield through diversified farming. *Basic. Appl. Ecol.* 67, 14–31. <https://doi.org/10.1016/j.baae.2022.12.005>.
- Kelly, R.M., Kitzes, J., Wilson, H., Merenlender, A., 2016. Habitat diversity promotes bat activity in a vineyard landscape. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2016.03.010>.
- Kerbiriou, C., Julien, J.-F., Bas, Y., Marmet, J., Le Viol, I., Lorrilliere, R., Azam, C., Gasc, A., Lois, G., 2015. Vigie-Chiro: 9 ans de suivi des tendances des espèces communes. *Symbioses Nos.* 34–35.
- Kohles, J.E., Page, R.A., Wikelski, M., Dechmann, D.K.N., 2024. Seasonal shifts in insect ephemerality drive bat foraging effort. *Curr. Biol.* 34, 3241–3248.e3. <https://doi.org/10.1016/j.cub.2024.05.074>.
- Kremen, C., Merenlender, A.M., 2018. Landscapes that work for biodiversity and people. *Science* 362, eaau6020. <https://doi.org/10.1126/science.aau6020>.
- Krull, D., Schumm, A., Metzner, W., Neuweiler, G., 1991. Foraging areas and foraging behavior in the notch-eared bat, *Myotis emarginatus* (Vespertilionidae). *Behav. Ecol. Sociobiol.* 28, 247–253. <https://doi.org/10.1007/BF00175097>.
- Kunz, T.H., Lumsden, L.F., 2003. Ecology of cavity and foliage roosting bats. *Bat Ecol.* 3–89. <https://doi.org/10.5281/zenodo.4655329>.
- Kunz, T.H., Braun de Torrez, E., Bauer, D., Lobova, T., Fleming, T.H., 2011. Ecosystem services provided by bats. *Ann. N. Y. Acad. Sci.* 1223, 1–38. <https://doi.org/10.1111/j.1749-6632.2011.06004.x>.
- Lacoeuilhe, A., Machon, N., Julien, J.-F., Kerbiriou, C., 2018. The relative effects of local and landscape characteristics of hedgerows on bats. *Divers. -Basel.* <https://doi.org/10.3390/d10030072>.
- Lentini, P.E., Gibbons, P., Fischer, J., Law, B., Hanspach, J., Martin, T.G., 2012. Bats in a Farming Landscape Benefit from Linear Remnants and Unimproved Pastures. *PLOS ONE* 7, e48201. <https://doi.org/10.1371/journal.pone.0048201>.
- Lison, F., Calvo, J.F., 2011. The significance of water infrastructures for the conservation of bats in a semiarid Mediterranean landscape. *Anim. Conserv.* <https://doi.org/10.1111/j.1469-1795.2011.00460.x>.
- Livoreil, B., Glanville, J., Haddaway, N.R., Bayliss, H., Bethel, A., de Lachapelle, F.F., Robalino, S., Savilaakso, S., Zhou, W., Petrokofsky, G., Frampton, G., 2017. Systematic searching for environmental evidence using multiple tools and sources. *Environ. Evid.* 6, 23. <https://doi.org/10.1186/s13750-017-0099-6>.
- Loeb, S.C., 2020. Qualitative synthesis of temperate bat responses to silvicultural treatments—where do we go from here? *J. Mammal.* 101, 1513–1525. <https://doi.org/10.1093/jmammal/gyaa089>.
- Long, B.L., Kurta, A., 2014. Activity and diet of bats in conventional versus organic apple orchards in southern Michigan. *Can. Field-Nat.* 128, 158–164. <https://doi.org/10.22621/cfn.v128i2.1580>.
- Maas, B., Clough, Y., Tschamtké, T., 2013. Bats and birds increase crop yield in tropical agroforestry landscapes. *Ecol. Lett.* 16, 1480–1487. <https://doi.org/10.1111/ele.12194>.
- MacDonald, M.A., Cobbold, G., Mathews, F., Denny, M.J.H., Walker, L.K., Grice, P.V., Anderson, G.Q.A., 2012. Effects of agri-environment management for cirl buntings on other biodiversity. *Biodivers. Conserv.* <https://doi.org/10.1007/s10531-012-0258-6>.
- MacDonald, M.A., Angell, R., Dines, T.D., Dodd, S., Haysom, K.A., Hobson, R., Johnstone, I.G., Matthews, V., Morris, A.J., Parry, R., Shellsell, C.H., Skates, J., Tordoff, G.M., Wilberforce, E.M., 2019. Have Welsh agri-environment schemes delivered for focal species? Results from a comprehensive monitoring programme. *J. Appl. Ecol.* <https://doi.org/10.1111/1365-2664.13329>.
- Maine, J.J., Boyles, J.G., 2015. Bats initiate vital agroecological interactions in corn. *Proc. Natl. Acad. Sci.* 112, 12438–12443. <https://doi.org/10.1073/pnas.1505413112>.
- Martin, A.E., Collins, S.J., Crowe, S., Girard, J., Naujokaitis-Lewis, I., Smith, A.C., Lindsay, K., Mitchell, S., Fahrig, L., 2020. Effects of farmland heterogeneity on biodiversity are similar to—or even larger than—the effects of farming practices. *Agric. Ecosyst. Environ.* 288, 106698. <https://doi.org/10.1016/j.agee.2019.106698>.
- Mata, V.A., da Silva, L.P., Verissimo, J., Horta, P., Raposeira, H., McCracken, G.F., Rebelo, H., Beja, P., 2021b. Combining DNA metabarcoding and ecological networks to inform conservation biocontrol by small vertebrate predators. *Ecol. Appl.* 31, e02457. <https://doi.org/10.1002/eap.2457>.
- Mata, V.A., da Silva, L.P., Verissimo, J., Horta, P., Raposeira, H., McCracken, G.F., Rebelo, H., Beja, P., 2021a. Combining DNA metabarcoding and ecological networks to inform conservation biocontrol by small vertebrate predators. *Ecol. Appl.* 31, e02457. <https://doi.org/10.1002/eap.2457>.
- Maynard, L.D., Ford, W.M., Parker, J.D., Whitehead, S.R., 2023. Biotic and abiotic factors shaping bat activity in Maryland soybean fields. *Ecosphere* 14, e4575. <https://doi.org/10.1002/ecs2.4575>.
- McHugh, N.M., Bown, B.L., Hemsley, J.A., Holland, J.M., 2019. Relationships between agri-environment scheme habitat characteristics and insectivorous bats on arable farmland. *BASIC Appl. Ecol.* <https://doi.org/10.1016/j.baae.2019.09.002>.
- Mendes, P., Srbeek-Araujo, A.C., 2021. Effects of land-use changes on Brazilian bats: a review of current knowledge. *Mammal. Rev.* 51, 127–142. <https://doi.org/10.1111/mam.12227>.
- Millon, L., Barre, K., Julliard, R., Compere, P., Kerbiriou, C., 2021. Calculation of biodiversity level between different land-uses to improve conservation outcomes of biodiversity offsetting. *LAND USE POLICY.* <https://doi.org/10.1016/j.landusepol.2020.105161>.
- Mills, J., Gaskell, P., Ingram, J., Dwyer, J., Reed, M., Short, C., 2017. Engaging farmers in environmental management through a better understanding of behaviour. *Agric. Hum. Values* 34, 283–299. <https://doi.org/10.1007/s10460-016-9705-4>.
- Monck-Whipp, L., Martin, A.E., Francis, C.M., Fahrig, L., 2018. Farmland heterogeneity benefits bats in agricultural landscapes. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2017.11.001>.

- Moon, K., Cocklin, C., 2011. A Landholder-Based Approach to the Design of Private-Land Conservation Programs. *Conserv. Biol.* 25, 493–503. <https://doi.org/10.1111/j.1523-1739.2010.01639.x>.
- Mouillot, D., Villéger, S., Scherer-Lorenzen, M., Mason, N.W.H., 2011. Functional Structure of Biological Communities Predicts Ecosystem Multifunctionality. *PLOS ONE* 6, e17476. <https://doi.org/10.1371/journal.pone.0017476>.
- Nelson, J.J., Gillam, E.H., 2017. Selection of foraging habitat by female little brown bats (*Myotis lucifugus*). *J. Mammal.* 98, 222–231. <https://doi.org/10.1093/jmammal/gwv181>.
- O'Farrell, M.J., Gannon, W.L., 1999. A Comparison of Acoustic Versus Capture Techniques for the Inventory of Bats. *J. Mammal.* 80, 24–30. <https://doi.org/10.2307/1383204>.
- Olimpi, E.M., Philpott, S.M., 2018. Agroecological farming practices promote bats. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2018.06.008>.
- Olivier, T., Thébaud, E., Elias, M., Fontaine, B., Fontaine, C., 2020. Urbanization and agricultural intensification destabilize animal communities differently than diversity loss. *Nat. Commun.* 11, 2686. <https://doi.org/10.1038/s41467-020-16240-6>.
- Paniccia, C., Scott, M.J., Bellé, A., Marsoner, T., Ladurner, E., Angelini, L., Reichegger, F., Tomelleri, E., Tappeiner, U., Hilpold, A., 2025. Balancing bats and agriculture: Investigating the effects of agricultural management practices on bat species diversity in mountain ecosystems. *Agric. Ecosyst. Environ.* 387, 109620. <https://doi.org/10.1016/j.agee.2025.109620>.
- Park, K.J., 2015. Mitigating the impacts of agriculture on biodiversity: bats and their potential role as bioindicators. *Mamm. Biol. Spec. Issue. Bats Bioindic.* 80, 191–204. <https://doi.org/10.1016/j.mambio.2014.10.004>.
- Peter, F., Brucia, L., Carstens, F., Götsche, M., Diekötter, T., 2021. Sown wildflower fields create temporary foraging habitats for bats in agricultural landscapes. *Biol. Conserv.* 264, 109364. <https://doi.org/10.1016/j.biocon.2021.109364>.
- Plucinski, T., Zmihorski, M., Plucinski, P., 2015. Impact of night-time crop harvesting on bat activity in agricultural landscape. *Zool. Ecol.* 25, 1–7. <https://doi.org/10.1080/21658005.2014.999501>.
- Priyadarshana, T.S., Martin, E.A., Sirami, C., Woodcock, B.A., Goodale, E., Martínez-Núñez, C., Lee, M.-B., Pagani-Núñez, E., Raderschall, C.A., Brotons, L., Rege, A., Ouin, A., Tschamtké, T., Slade, E.M., 2024. Crop and landscape heterogeneity increase biodiversity in agricultural landscapes: A global review and meta-analysis. *Ecol. Lett.* 27, e14412. <https://doi.org/10.1111/ele.14412>.
- Puig-Montserrat, X., Torre, I., Lopez-Baucells, A., Guerrieri, E., Monti, M.M., Rafols-Garcia, R., Ferrer, X., Gisbert, D., Flaquer, C., 2015. Pest control service provided by bats in Mediterranean rice paddies: linking agroecosystems structure to ecological functions. *Mamm. Biol.* <https://doi.org/10.1016/j.mambio.2015.03.008>.
- Pullin, A.S., Stewart, G.B., 2006. Guidelines for systematic review in conservation and environmental management. *Conserv. Biol.* 20, 1647–1656. <https://doi.org/10.1111/j.1523-1739.2006.00485.x>.
- Put, J.E., Mitchell, G.W., Fahrig, L., 2018. Higher bat and prey abundance at organic than conventional soybean fields. *Biol. Conserv.* <https://doi.org/10.1016/j.biocon.2018.06.021>.
- Rainho, A., Palmeirim, J.M., 2011. The Importance of Distance to Resources in the Spatial Modelling of Bat Foraging Habitat. *PLoS ONE* 6, e19227. <https://doi.org/10.1371/journal.pone.0019227>.
- Rasmussen, L.V., Grass, I., Mehrabi, Z., Smith, O.M., Bezner-Kerr, R., Blesh, J., Garibaldi, L.A., Isaac, M.E., Kennedy, C.M., Wittman, H., Batary, P., Buchori, D., Cerda, R., Chará, J., Crowder, D.W., Darras, K., DeMaster, K., Garcia, K., Gómez, M., Gonthier, D., Guzman, A., Hidayat, P., Hipólito, J., Hiron, M., Hoey, L., James, D., John, I., Jones, A.D., Karp, D.S., Kebede, Y., Kerr, C.B., Klassen, S., Kotowska, M., Kreft, H., Llanque, R., Levers, C., Lizcano, D.J., Lu, A., Madsen, S., Marques, R.N., Martins, P.B., Melo, A., Nyantakyi-Frimpong, H., Olimpi, E.M., Owen, J.P., Pantevez, H., Qaim, M., Redlich, S., Scherber, C., Sciligo, A.R., Snapp, S., Snyder, W. E., Steffan-Dewenter, I., Stratton, A.E., Taylor, J.M., Tschamtké, T., Valencia, V., Vogel, C., Kremen, C., 2024. Joint environmental and social benefits from diversified agriculture. *Science* 384, 87–93. <https://doi.org/10.1126/science.adj1914>.
- Raven, P.H., Wagner, D.L., 2021. Agricultural intensification and climate change are rapidly decreasing insect biodiversity. *Proc. Natl. Acad. Sci.* 118, e2002548117. <https://doi.org/10.1073/pnas.2002548117>.
- Razgour, O., Hanmer, J., Jones, G., 2011. Using multi-scale modelling to predict habitat suitability for species of conservation concern: The grey long-eared bat as a case study. *Biol. Conserv.* 144, 2922–2930. <https://doi.org/10.1016/j.biocon.2011.08.010>.
- Ricci, B., Lavigne, C., Alignier, A., Aviron, S., Biju-Duval, L., Bouvier, J.C., Choisis, J.-P., Franck, P., Joannon, A., Ladet, S., Mezerette, F., Plantegenest, M., Savary, G., Thomas, C., Vialatte, A., Petit, S., 2019. Local pesticide use intensity conditions landscape effects on biological pest control. *Proc. R. Soc. B Biol. Sci.* 286, 20182898. <https://doi.org/10.1098/rspb.2018.2898>.
- Robertson, B.A., Hutto, R.L., 2006. A Framework for Understanding Ecological Traps and an Evaluation of Existing Evidence. *Ecology* 87, 1075–1085. [https://doi.org/10.1890/0012-9658\(2006\)87%255B1075:AFUET%255D2.0.CO;2](https://doi.org/10.1890/0012-9658(2006)87%255B1075:AFUET%255D2.0.CO;2).
- Rodriguez-San Pedro, A., Rodriguez-Herbach, C., Luis Allendes, J., Chaperon, P.N., Beltran, C.A., Grez, A.A., 2019. Responses of aerial insectivorous bats to landscape composition and heterogeneity in organic vineyards. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2019.03.009>.
- Rouabah, A., Lasserre-Joulin, F., Planteux, S., Taugourdeau, S., Amiaud, B., 2024. Functional trait composition of carabid beetle communities predicts prey suppression through both mass ratio and niche complementarity mechanisms. *Insect Sci.* 31, 562–574. <https://doi.org/10.1111/1744-7917.13261>.
- Russo, D., Jones, G., 2003. Use of foraging habitats by bats in a Mediterranean area determined by acoustic surveys: conservation implications. *ECOGRAPHY*. <https://doi.org/10.1034/j.1600-0587.2003.03422.x>.
- Russo, D., Voigt, C.C., 2016. The use of automated identification of bat echolocation calls in acoustic monitoring: A cautionary note for a sound analysis. *Ecol. Indic.* 66, 598–602. <https://doi.org/10.1016/j.ecolind.2016.02.036>.
- Russo, D., Bosso, L., Ancillotto, L., 2018. Novel perspectives on bat insectivory highlight the value of this ecosystem service in farmland: Research frontiers and management implications. *Agric. Ecosyst. Environ.* 266, 31–38. <https://doi.org/10.1016/j.agee.2018.07.024>.
- Russo, D., Tanalgo, K., Rebelo, H., Cistrone, L., 2024. To improve or not to improve? The dilemma of “bat-friendly” farmland potentially becoming an ecological trap. *Agric. Ecosyst. Environ.* 375, 109215. <https://doi.org/10.1016/j.agee.2024.109215>.
- Sandoval-Herrera, N., Lara-Jacobo, L., Faure, P.A., Simmons, D., Welch Jr, K., 2025. Systemic Effects of Pesticides on Insectivorous Bats: A Proteomics Approach. *Integr. Comp. Biol.* 65, 1810–1825. <https://doi.org/10.1093/icb/ica121>.
- Skaldina, O., Blande, J.D., 2025. Global biases in ecology and conservation research: insight from pollinator studies. *Ecol. Lett.* 28, e70050. <https://doi.org/10.1111/ele.70050>.
- Stahlschmidt, P., Paetzold, A., Ressler, L., Schulz, R., Bruehl, C.A., 2012. Constructed wetlands support bats in agricultural landscapes. *BASIC Appl. Ecol.* <https://doi.org/10.1016/j.baae.2012.02.001>.
- Stanton, R.L., Morrissey, C.A., Clark, R.G., 2018. Analysis of trends and agricultural drivers of farmland bird declines in North America: A review. *Agric. Ecosyst. Environ.* 254, 244–254. <https://doi.org/10.1016/j.agee.2017.11.028>.
- Tanalgo, K.C., Dela Cruz, K.C., Russo, D., 2025. Susceptibility of bats to ecological and evolutionary traps. *Biol. Conserv.* 305, 111110. <https://doi.org/10.1016/j.biocon.2025.111110>.
- Tarcy, N., Froidevaux, J.S.P., Kerbiriou, C., Leroux, C., Matutini, F., 2025. Managing hedgerows for biodiversity: Disentangling the effects of trimming, structure and connectivity on the use of linear features by bats. *J. Appl. Ecol.* 62, 3300–3313. <https://doi.org/10.1111/1365-2664.70205>.
- Teets, K.D., Loeb, S.C., Jachowski, D.S., 2019. Detection Probability of Bats Using Active Versus Passive Monitoring. *Acta Chiropterologica* 21, 205–213. <https://doi.org/10.3161/15081109ACC2019.21.1.017>.
- Toffoli, R., 2016. The importance of linear landscape elements for bats in a farmland area: The influence of height on activity. *J. Landsc. Ecol.* 9, 49–62. <https://doi.org/10.1515/jlecol-2016-0004>.
- Toffoli, R., Rugghetti, M., 2017. Bat activity in rice paddies: Organic and conventional farms compared to unmanaged habitat. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2017.08.022>.
- Toffoli, R., Rugghetti, M., 2020. Effect of water management on bat activity in rice paddies. *Paddy Water Environ.* 18, 687–695. <https://doi.org/10.1007/s10333-020-00811-w>.
- Torquetti, C.G., Guimarães, A.T.B., Soto-Blanco, B., 2021. Exposure to pesticides in bats. *Sci. Total. Environ.* 755, 142509. <https://doi.org/10.1016/j.scitotenv.2020.142509>.
- Tortosa, A., Giffard, B., Barbaro, L., Froidevaux, J.S.P., Ladet, S., Delhomel, J., Vialatte, A., 2023. Diverse agricultural landscapes increase bat activity and diversity: Implications for biological pest control. *Agric. Ecosyst. Environ.* <https://doi.org/10.1016/j.agee.2022.108318>.
- Triquet, C., Perennes, M., Séchaud, R., van der Meer, M., Fabian, Y., Jeanneret, P., 2024. What evidence exists on the effect of the main European lowland crop and grassland management practices on biodiversity indicator species groups? a systematic map. *Environ. Evid.* 13, 20. <https://doi.org/10.1186/s13750-024-00347-0>.
- Tschamtké, T., Clough, Y., Wanger, T.C., Jackson, L., Motzke, I., Perfecto, I., Vandermeer, J., Whitbread, A., 2012a. Global food security, biodiversity conservation and the future of agricultural intensification (ADVANCING ENVIRONMENTAL CONSERVATION: ESSAYS IN HONOR OF NAVJOT SODHI). *Biol. Conserv.* 151, 53–59. <https://doi.org/10.1016/j.biocon.2012.01.068>.
- Tschamtké, T., Tylianakis, J.M., Rand, T.A., Didham, R.K., Fahrig, L., Batary, P., Bengtsson, J., Clough, Y., Crist, T.O., Dormann, C.F., Ewers, R.M., Fründ, J., Holt, R. D., Holzschuh, A., Klein, A.M., Kleijn, D., Kremen, C., Landis, D.A., Laurance, W., Lindenmayer, D., Scherber, C., Sodhi, N., Steffan-Dewenter, I., Thies, C., van der Putten, W.H., Westphal, C., 2012b. Landscape moderation of biodiversity patterns and processes - eight hypotheses. *Biol. Rev.* 87, 661–685. <https://doi.org/10.1111/j.1469-185X.2011.00216.x>.
- Tuneu-Corral, C., Puig-Montserrat, X., Riba-Bertolín, D., Russo, D., Rebelo, H., Cabeza, M., López-Baucells, A., 2023. Pest suppression by bats and management strategies to favour it: a global review. *Biol. Rev.* 98, 1564–1582. <https://doi.org/10.1111/brev.12967>.
- Tuttle, S.R., Chambers, C.L., Theimer, T.C., 2006. Potential Effects of Livestock Water-Trough Modifications on Bats in Northern Arizona. *Wildl. Soc. Bull.* 34, 602–608. [https://doi.org/10.2193/0091-7648\(2006\)34%255B602:PEOLWM%255D2.0.CO;2](https://doi.org/10.2193/0091-7648(2006)34%255B602:PEOLWM%255D2.0.CO;2).
- Tylianakis, E., Martin-Ortega, J., 2021. Agri-environmental schemes for biodiversity and environmental protection: How we are not yet “hitting the right keys. *Land. Use Policy* 109, 105620. <https://doi.org/10.1016/j.landusepol.2021.105620>.
- Vallé, C., Le Viol, I., Kerbiriou, C., Bas, Y., Jiguet, F., Prince, K., 2023. Farmland biodiversity benefits from small woody features. *Biol. Conserv.* 286, 110262. <https://doi.org/10.1016/j.biocon.2023.110262>.
- van Dijk, W.F.A., Lokhorst, A.M., Berendse, F., de Snoo, G.R., 2015. Collective agri-environmental schemes: How can regional environmental cooperatives enhance farmers' intentions for agri-environment schemes? *Land. Use Policy* 42, 759–766. <https://doi.org/10.1016/j.landusepol.2014.10.005>.
- van Dijk, W.F.A., Lokhorst, A.M., Berendse, F., de Snoo, G.R., 2016. Factors underlying farmers' intentions to perform unsubsidised agri-environmental measures. *Land. Use Policy* 59, 207–216. <https://doi.org/10.1016/j.landusepol.2016.09.003>.
- Wallace, B.C., Small, K., Brodley, C.E., Lau, J., Trikalinos, T.A., 2012. Deploying an interactive machine learning system in an evidence-based practice center: abstrackr. *Proceedings of the 2nd ACM SIGMINT International Health Informatics Symposium*,

- IHI '12. Association for Computing Machinery, New York, NY, USA, pp. 819–824. <https://doi.org/10.1145/2110363.2110464>.
- Williams-Guillén, K., Olimpi, E., Maas, B., Taylor, P.J., Arlettaz, R., 2016. Bats in the Anthropogenic Matrix: Challenges and Opportunities for the Conservation of Chiroptera and Their Ecosystem Services in Agricultural Landscapes. In: Voigt, C.C., Kingston, T. (Eds.), *Bats in the Anthropocene: Conservation of Bats in a Changing World*. Springer International Publishing, Cham, pp. 151–186. https://doi.org/10.1007/978-3-319-25220-9_6.
- Xavier, B.S., Rainho, A., Santos, A.M.C., Vieira, M.V., Carvalho, W.D., 2023. Global systematic map of research on bats in agricultural systems. *Front. Ecol. Evol.* 11. <https://doi.org/10.3389/fevo.2023.1214176>.
- Yousefi, M., Ewert, F., 2023. Protocol for a systematic review of living labs in agricultural-related systems. *Sustain. Earth Rev.* 6, 11. <https://doi.org/10.1186/s42055-023-00060-9>.
- Zeller, K.A., McGarigal, K., Whiteley, A.R., 2012. Estimating landscape resistance to movement: a review. *Landsc. Ecol.* 27, 777–797. <https://doi.org/10.1007/s10980-012-9737-0>.
- Zhu, D., Liu, Y., Gong, L., Si, M., Wang, Q., Feng, J., Jiang, T., 2024. The Consumption and Diversity Variation Responses of Agricultural Pests and Their Dietary Niche Differentiation in Insectivorous Bats. *Animals* 14, 815. <https://doi.org/10.3390/ani14050815>.