



To improve or not to improve? The dilemma of “bat-friendly” farmland potentially becoming an ecological trap

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ABSTRACT

Conventional agriculture occupies a substantial portion of Earth's terrestrial surface and adversely affects biodiversity through pesticide spread, mechanisation, and loss of spatial and temporal heterogeneity of farmed landscapes. Consequently, conventional agriculture has become a primary target of many restoration projects operating at various scales, from habitat to landscape. While these restoration efforts aim to increase farmland biodiversity and promote the delivery of associated ecosystem services, unintended consequences may arise when important threats are not mitigated. For instance, animals may be led to make maladaptive choices, and lured to attractive sites with poor habitat quality (ecological traps), resulting in adverse effects on individual fitness and demography. We focus our review on European farmland as a case study because of its extensive presence on the continent and the particularly articulated legal framework regulating agriculture and biodiversity within the European Union. Europe's policy framework is dual-faced: one promotes farmland development regardless of management practices, while the other advocates for biodiversity protection measures that sometimes lack strong supporting evidence or overlook critical management aspects. Insectivorous bats contribute significantly to ecosystem service delivery through insectivory in agricultural landscapes, consuming large numbers of pest arthropods. However, when restoring habitats for bats in conventional farmland, potential unintended outcomes must be considered, particularly if restoration actions are not accompanied by mitigation of key threats. These threats include the persistent and widespread use of pesticides, road networks, the siting of wind turbines in farmed landscapes, and opportunistic predators, especially domestic cats. We argue that installing bat boxes and enhancing habitat and landscape features, such as increasing connectivity and diversity, potentially trap bats in attractive yet unsuitable environments if such threats are not mitigated. While environmental restoration in farmland is highly valued for supporting bat populations, it is crucial to avoid neglecting factors that could have the opposite effect, turning 'improved' farmland into a sink. Research is urgently needed to understand such potential unintended effects and inform farmland management and policymakers.

1. Background and objectives

1.1. What are ecological traps and why do they matter for wildlife occurring in conventional farmland?

Human-induced environmental change acts quickly on habitats and may alter the cues that animals use to assess habitat quality, luring them

to poor habitats and reducing individual fitness. Such situations are called “ecological traps” and are recognised as a key threat to many animal species jeopardised by human action (Schlaepfer et al., 2002; Battin, 2004; Robertson and Hutto, 2006; Hale and Swearer, 2016). Farmland may act as an ecological trap for many species. The number of studies demonstrating this effect has recently increased (Northrup et al., 2012; Hollander et al., 2017; Penteriani et al., 2018; Ganser et al., 2019;

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Nawrocki et al., 2019; Buderman et al., 2020; Courtois et al., 2021). For example, in such a context brown bears compete with humans for space and food, generating conflicts that often result in property damage, bear killing, population reduction initiatives, and bear relocation (Northrup et al., 2012; Penteriani et al., 2018; Santangeli et al., 2018;). In Canada, tree swallows (*Tachycineta bicolor*) are attracted to farmland because of the open habitats with abundant perennial forage crops, high spring insect biomass, and a high density of house sparrows, their main competitors for nest sites. They also prefer to nest in areas with a high density of breeders and a high mean number of fledglings from the previous year (Courtois et al., 2021). However, these habitat preferences and actual habitat quality show important mismatches, particularly regarding competitor density and social information. Traditional habitat cues are disrupted by human-induced environmental changes, potentially leading to maladaptive breeding choices. Furthermore, while tree swallows are drawn to areas with high spring insect biomass and dense perennial forage crops, these factors do not correlate with improved breeding success, adding complexity to their habitat selection (Courtois et al., 2021). In Finland, the mismatch between the advancing egg-laying of ground-nesting birds in response to climate warming and the lack of corresponding advancement in farming practices leads to nest destruction by sowing activities (Santangeli et al., 2018).

1.2. Insectivorous bats occur in conventionally managed fields where they suppress arthropod pests

“Conventional farmland”, or industrial agriculture, typically involves modern systems with heavy use of synthetic chemical fertilisers, fungicides, insecticides, herbicides, high-yielding crop varieties, monoculture, genetically modified organisms, large-scale machinery, intensive tillage, and mechanised irrigation (e.g., Le Campion et al., 2020). By avoiding synthetic pesticides and fertilisers, growth hormones, antibiotics, and genetically modified organisms, organic farming is typically more friendly to ‘natural enemies,’ i.e., organisms that suppress agricultural pests and promote their control (Puech et al., 2014). However, natural enemies still play an important role even in conventional agriculture, since despite the widespread use of pesticides, natural control still accounts for most pest suppression (Debach and Rosen, 1974; Naylor and Ehrlich, 1997). Bats are valuable top-down pest controllers, as many studies of bat activity (e.g., Heim et al., 2016; 2017; Ancillotto et al., 2023), diet (Mata et al., 2021), and experimental exclusion (Maas et al., 2016) have shown. Bats are among the natural enemies that also occur in agricultural habitats, including conventional farmland (Heim et al., 2016; 2017), where they are exposed to significant pesticide contamination (Stahlschmidt and Brühl, 2012; Stahlschmidt et al., 2017). The outstanding pest suppression accomplished by bats has highly positive economic effects (Boyles et al., 2011). Therefore, in principle, the presence of bats in farmland is highly desirable, and it should be promoted to favour ecosystem service delivery (Tuneu-Corral et al., 2023).

The presence of bats in conventional farmland may be favoured by acting at the field or landscape scales, or both. Deploying bat boxes may increase the carrying capacity of the bat species that use them, and this has locally been found to have highly positive implications for pest suppression (Puig-Montserrat et al., 2015). Likewise, increasing hedgerow networks provide important landscape elements for commuting or foraging bats of several species (Froidevaux et al., 2019; Ancillotto et al., 2023). Flower fields have been recently found to increase bat activity in conventional farmland (Krings et al., 2022), while field margins favour the activity of *Myotis* bats (Blary et al., 2021). Pools and canals may provide drinking water besides additional foraging opportunities (Korine et al., 2016). Increasing landscape diversity around conventionally managed fields may be an effective strategy to increase bat richness, activity, or both (Froidevaux et al., 2017).

1.3. Aims of this review

Why does this review focus on farmland? Bats face threats in natural habitats (Frick et al., 2020), but urban (Russo and Ancillotto, 2015) and farmed (Park, 2015) landscapes also present significant challenges. Urban areas filter out many species that do not adapt to their demands, resulting in low biodiversity (Santini et al., 2019). Farmland, instead, can offer resources and conditions that support greater biodiversity (Benton et al., 2003; Kleijn et al., 2011), including bats (Monck-Whipp et al., 2018). Therefore, threats associated with farmland management and agricultural practices are crucial for conservation efforts. Agriculture intensification impacts bats by reducing prey availability, diminishing survival due to loss of roosting sites, and degrading or reducing foraging areas. Additionally, bats face increased exposure to toxic compounds from agrochemicals (e.g., Park, 2015). Consequently, farmland becomes a focal point for initiatives aiming to enhance environmental conditions for bats, much more than other anthropogenic habitats or landscapes (Tuneu-Corral et al., 2023).

Russo et al. (2018) advocated avoiding structural improvement in conventional agriculture at both field and landscape scales without simultaneously reducing pesticide use. Such improvements could act as deceptive cues, exposing bats to both direct and indirect effects of pesticides. Despite this plea, this important topic has been neglected in scientific literature and policymaking. Furthermore, bats face numerous additional threats in conventionally farmed landscapes, and the combined effects of these threats at a population level are likely significant. However, such threats are often overlooked in both research and policy development.

Here, we expand upon this initial concept to analyse the factors that may transform conventional farmland into a significant ecological trap and highlight its potential implications for ecosystem service delivery and bat conservation. Based on current evidence about the role of farmland for bats and the feasibility of attracting bats to conventional farms through environmental improvements, we hypothesise that enhancing farmland without addressing certain threats could expose bats to additional risks and potential ecological trap dynamics. Studies on pesticides, wind turbines, and domestic cats highlight these threats. We show that pesticides, already a significant factor in bat decline across Europe, pose a substantial potential risk. Cat predation can be particularly harmful in farmed landscapes. We also predict that wind turbines, which already impact bats in farmland, would likely pose an even greater threat if bat populations were encouraged in areas with wind energy production. We emphasise critical gaps in scientific research and policy on this topic that require urgent attention.

Our goal is not to discourage habitat and landscape improvement for bats but to ensure that such efforts are always coupled with appropriate mitigation of potential threats in farmland. Moreover, while further research on the topic is warranted, our study goes beyond hypothetical speculation; we are connecting existing knowledge and advocating a precautionary approach to safeguard bat populations in agricultural landscapes.

We focused on Europe for two reasons. First, its extensive farmland coverage spans nearly half the total area. In the European Union (hereafter “EU”) alone, agricultural land comprises approximately 40 % of the total land surface. European farmland often intersects with protected areas and the Natura 2000 network. Therefore, effective farmland management is essential for biodiversity conservation. Second, Europe boasts an advanced policy framework dedicated to bat conservation. This includes the EUROBATs agreement, which safeguards all 55 European bat species through legislation, education, conservation actions, and international cooperation among Agreement Parties and non-parties. Additionally, in the EU, the 92/43/EEC Habitats Directive protects bat species and aims to preserve their habitats. The EU is renowned for its leadership in implementing policies whose goal is safeguarding and enhancing ecosystems and environmental quality (Zito, 2005). However, the efficacy and appropriateness of these

measures, despite their stringent nature (OECD, 2023), have been questioned (e.g., Kleijn and Sutherland, 2003; Trouwborst, 2010). Especially within the EU, there are complex dynamics whose efforts to promote biodiversity in farmland may contrast with policies encouraging the intensification and enlargement of medium-sized farms (Eurostat, 2020). This discrepancy can lead to conflicting choices, interests, and strategies that may undermine biodiversity conservation, including the conservation of bat populations.

2. Direct and indirect effects of pesticides on bats

Insectivorous bats may ingest pesticide residues through oral, dermal, and inhalation routes (Fig. 1), with pups also at risk of contamination through maternal milk. The clustering and social grooming behaviours within bat colonies further increase the risk of contact exposure (EFSA Panel on Plant Protection Products and their Residues et al., 2019). Due to high energetic requirements imposed by flight, bats feed on large numbers of insects every night (Russo et al., 2018), which exposes them to high risks of biomagnification through their diet. Bats largely store fat they acquire and use when they are torpid, a strategy to cope with periods of insect scarcity when they do not actively forage, so lipophilic pesticides accumulate (EFSA Panel on Plant Protection Products and their Residues et al., 2019). Spraying pesticides at dusk or during the night may pose additional risks as they could directly interfere with foraging bats and increase the likelihood of inhalation and dermal contamination. Night spraying of pesticides is recommended to mitigate the impact on bee biodiversity (Decourtye et al., 2023) but is likely more harmful to bats, thus posing a conservation dilemma. Applying pesticides in the middle of the day is not recommended because it increases the chances of direct contact with pollinators. Still, different pollinators exhibit varying temporal activity and abundance patterns, thus no universal recipe exists for adjusting application timing accordingly (Karbassioon and Stanley, 2023). In scientific discussions and management policies, we emphasise the importance of considering vertebrates, particularly bats, and the need to adopt a broad ecological perspective.

EFSA (The European Food Safety Authority) has acknowledged that the current risk assessment approach does not effectively cover bats and that a bat-specific risk assessment protocol is needed (EFSA Panel on

Plant Protection Products and their Residues et al., 2019). Furthermore, a recent update to the risk assessment for birds and mammals (European Food Safety Authority et al., 2023) fails to adequately address bats due to the lack of a model available to estimate their total pesticide body burden, including dermal and inhalation routes. This significantly increases the risk that even pesticides deemed 'safe' for mammals could adversely affect bats. The situation becomes even more concerning when considering that only 5 % of all bat species have been studied regarding pesticide exposure, especially chronic exposure to sublethal doses (Torquetti et al., 2021).

There is little doubt that insectivorous bats suffer from pesticides' direct and indirect effects. Current knowledge supports the prediction that these impacts are considerable, also bringing about strong genotoxic effects (Sandoval-Herrera et al., 2021) reducing the survival capacity of bat populations and potentially leading to significant losses (Oliveira et al., 2020). Schanzer et al. (2022) analysed nearly 400 bats across five species from Germany for residues of 209 pesticides and pollutants, finding multiple residues in the bats, including banned organochlorine insecticides and newer pesticides like azole antifungals and fipronil. The study underscores the bats' widespread, persistent exposure to harmful chemicals and the urgent need for effective mitigation strategies.

In line with the prediction that pesticides harm bats in Europe, the IUCN project "European Red List 'Pulse' - Measuring the Pulse of European Biodiversity has revealed that agricultural and forestry effluents are a known risk factor for 27 bat species (Fig. 2). Among these, herbicides and pesticides adversely affect six endemic species (three assessed as "threatened") and 20 regional species (ten of which are "threatened"). Consequently, pesticides and herbicides are the second most significant threat to European bat species, following human intrusions and habitat disturbance (Fig. 2; IUCN, 2024).

The scarcity of natural roosts may force bats to make maladaptive choices, such as selecting bat boxes in poor habitats. Bat boxes in conventionally managed fields could pose additional risks, as pesticides sprayed in these areas might accumulate inside them, leading to further exposure for the bats. However, no studies have yet assessed the level of pesticide contamination in these structures within agricultural areas. We therefore urge that research be conducted on bat boxes in conventional farmland to explore this crucial issue. In tree swallows (*Tachycineta*

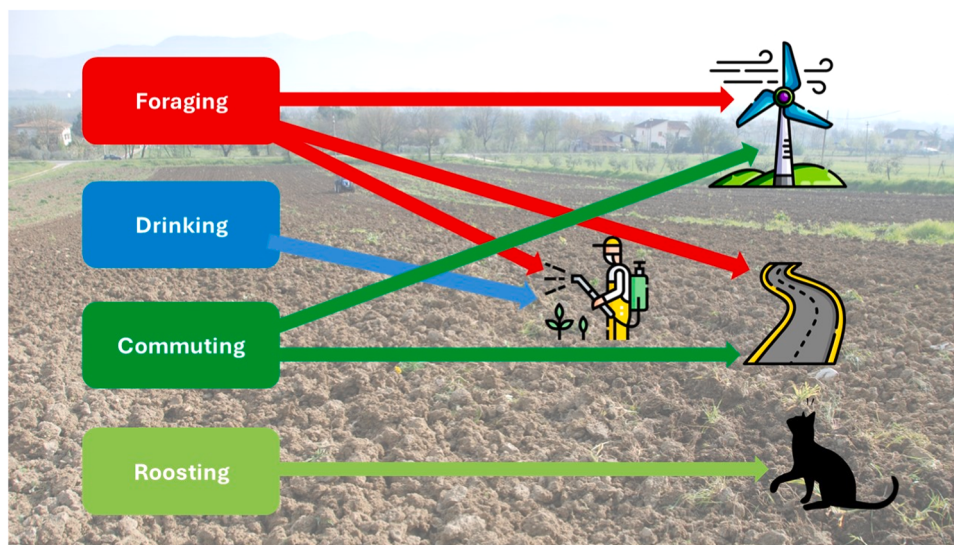


Fig. 1. Primary pathways through which bat behaviours may expose these mammals to risks in conventional farms, potentially creating ecological traps. Foraging bats may inadvertently ingest pesticides from contaminated insects and face additional threats from wind turbines or vehicle traffic. Water sources also pose a risk of pesticide ingestion. Commuting bats, potentially benefiting from landscape connectivity restoration efforts such as hedgerows, treelines, and woodland patches, may also be killed by wind turbines and road accidents. Roosting bats in bat boxes or farm buildings face predation risks from domestic cats or opportunistic birds and may become contaminated by accumulated pesticides. Secondary threats, like dermal pesticide absorption during flight or human-induced roost exclusion, are not shown for simplicity. The icons were sourced from www.flaticons.com.

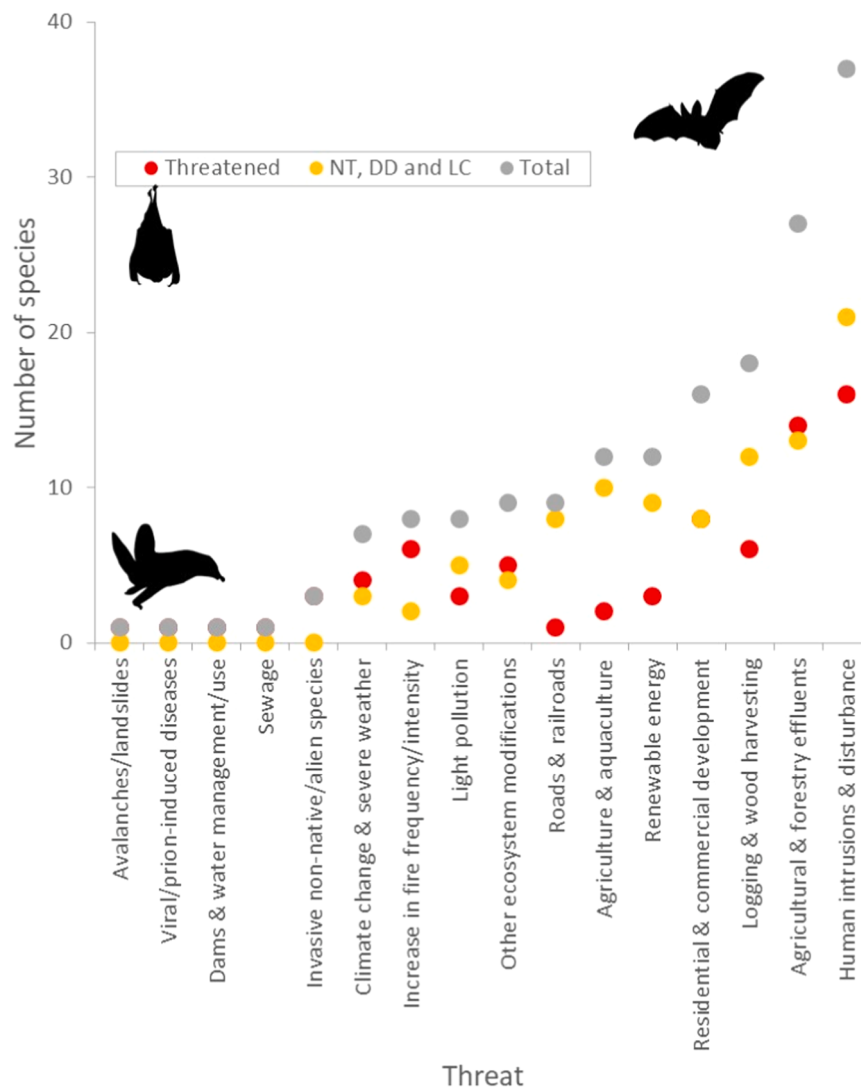


Fig. 2. The number of European bat species exposed to various threat categories, as determined by the IUCN reassessment conducted under the project 'European Red List of Mammals - Measuring the pulse of European biodiversity using the IUCN Red List' (to be published in 2024). The "threatened" category includes all European bat species assessed as Vulnerable, Endangered, or Critical Endangered. NT = Near Threatened; LC = Least Concern; DD = Data Deficient.

bicolor), nest boxes set in farmland expose settlers to a range of suboptimal factors, including phenological mismatches, nonideal habitat selection, super-optimal density, and greater costs from house sparrow competition, which do result in lower numbers of hatchlings and fledging success (Courtois et al., 2021).

In 2018, the Agreement on the Conservation of Populations of European Bats (EUROBATS), currently signed by 38 range states, recognised the issue of direct and indirect effects of pesticides on bats through the adoption of Resolution 8.13 on "Insect Decline as a Threat to Bat Populations in Europe" (<https://www.eurobats.org/node/1422#3>). Specifically, Resolution 8.13 recommends that Parties and non-party Range States promote scientific research on the impact of insect decline on bat populations, avoid using problematic pesticides near bat conservation areas, implement action programs for insect conservation, include bats in pesticide risk assessments, and adopt a precautionary approach concerning the use of pesticides. Research in this area is therefore urgently needed.

3. Other farmland-associated ecological traps

3.1. Dying at roosts

Although not directly related to conventional agriculture, bat boxes in farmland are often situated in open spaces, exposing them to temperature peaks in summer. This poses a significant risk, especially during hot seasons, which are increasingly common due to climate change in areas such as the Mediterranean. In these conditions, bats may succumb to dehydration and overheating (Flaquer et al., 2014; Martin Bideguren et al., 2019; Crawford and O'Keefe, 2021). There is mounting evidence that overheating is a key cause of mortality in bats during hot summers, particularly when the roost microclimate is not buffered from temperature extremes (Ancillotto et al., 2021; Salinas-Ramos et al., 2023). Bat boxes are probably the most frequently adopted "Nature-Based Solution" in conventional farmland, but advice on how to place them to avoid overheating is seldom provided to farmers. When placing bat boxes in open habitats (including farmland), their design and appropriate location should be carefully considered to prevent overheating (Flaquer et al., 2014; Martin Bideguren et al., 2019; Crawford and O'Keefe, 2021; Crawford et al., 2022).

Agricultural areas also host bat predators absent from natural

habitats, such as forests or wetlands, which may opportunistically kill bats inside or near their overground roosts (Figs. 1, 3). Predation by birds is likely negligible, with few local exceptions. Corvids, including crows, carrion crows, and magpies, are among the most common birds in European agroecosystems (ECCB, 2018; Gianpasquale and Alberto, 2019). Although the main conservation issue arises from predation on songbird eggs and nestlings (Capstick and Madden, 2021), there is evidence that such species may also opportunistically prey on bats but the importance of their impact on these mammals is unknown. At least 19 corvid species prey on bats: these birds' cognitive and ecological flexibility allows them to feed on bats when they are available and accessible (e.g., when bat pups fall from the roost, or by adopting a "sit-and-wait" strategy and seize bats when these leave their roost), also adopting communal hunting to increase their success (Mikula et al., 2016; 2024). Likewise, gulls, common in agricultural areas (Isaksson et al., 2016; Martín-Vélez et al., 2021), are dietary generalists that may occasionally prey upon bats (Speakman, 1991; Mikula et al., 2016).

Free-roaming domestic cats (including pets, strays, and feral cats) pose a more serious issue. They occur at high densities in agricultural areas of many European countries, regardless of how these areas are managed. Although domestic cats are also present in European urban areas (where many of them are kept indoors) the number of free-roaming cats in farmland is much higher, since they are often seen as needed to control rodent numbers and minimise crop damage (Trouwborst and Somsen, 2020). Based on current scientific and legal standards, all EU Member States must prevent cats from roaming freely outdoors but no enforcement exists. Authorities should therefore communicate to the public that allowing cats to roam is either already prohibited under existing nature conservation laws or will be explicitly banned through new legislation (Trouwborst and Somsen, 2020).

Cats tend to stay near farm buildings to exploit human-associated food resources (Lázaro et al., 2024), but they also prey on small wildlife species (Kitts-Morgan et al., 2015), including bats (Ancillotto et al., 2013; Oedin et al., 2021; Salinas-Ramos et al., 2021a). Cats have a significant impact on farmland wildlife. For example, domestic cats are estimated to kill millions of small vertebrates in Polish farmland

(Krauze-Gryz et al., 2019). Cat predation may jeopardise the survival of entire bat colonies in apparently suitable overground roosts, which act as ecological traps (Ancillotto et al., 2019; Vlaschenko et al., 2019). In Italy, cat predation on adult bats is significantly associated with land cover and occurs most frequently in rural areas (Ancillotto et al., 2013).

Humans may kill or exclude bats from buildings when bat colonies interfere with people's activities (Russo and Ancillotto, 2015; Voigt et al., 2016). These conflicts sometimes result in eradicating entire reproductive colonies, with potentially serious implications at the population level, transcending the local scale of the event. House-dwelling bats are known to roost in both urban and agricultural areas. However, European farmland frequently harbours species of higher conservation importance, such as rhinolophids and *Myotis* spp., listed under Annexes II and IV of the EU's Habitats Directive (92/43/EEC). Bat exclusion from roosts can also occur in urban buildings but in such cases, bats often belong to more common species and frequently inhabit crevices. Their presence may therefore be overlooked or not seen as a major interference with human activities. In farmland, conservation-priority species like rhinolophids tend to occupy larger spaces such as attics and barns. People often demand these spaces, leading to more frequent conflicts and the potential exclusion of bat colonies.

While some regions, like the EU countries, have established legal protections against bat killing or colony exclusion (92/43/EEC "Habitats Directive"), this is not universally adopted, with neglect or even legal allowance in other countries. Moreover, even in countries where such actions are strictly forbidden, the exclusion of bat colonies from private properties remains common and often overlooked or does not lead to real prosecution due to a lack of enforcement.

3.2. Transportation and energy infrastructures in farmed landscapes

Landscape-scale issues associated with luring bats to conventional farmland include additional risks of wind turbines and vehicle traffic fatalities (Figs. 1, 3), and photovoltaic panels might also negatively affect bats. Wind turbines are a recognised threat to several bat species,

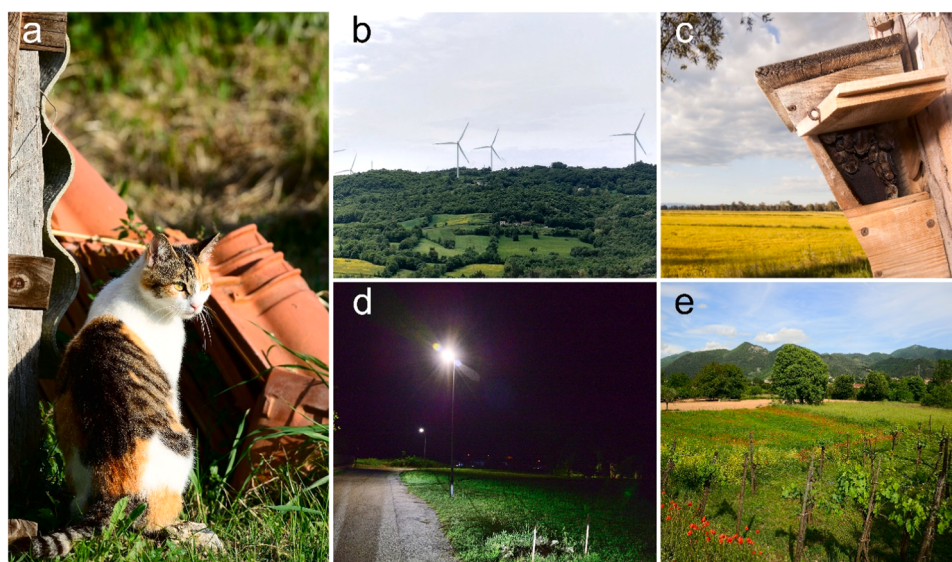


Fig. 3. Main factors that may turn conventional farmland into an ecological trap. a) Free-roaming cats in farmland pose a significant threat to bats roosting in buildings, as they may prey on them, sometimes driving entire colonies to extinction. b) Wind turbines in farmland may kill many bats, especially if they are situated in "bat-friendly" landscapes rich with hedgerows, treelines, and woodland patches. These landscape structures, which bats use for commuting and foraging, may bring them dangerously close to the turbines. c) Bat boxes are often proposed in conventional farmland to exploit bat insectivory and help decrease pest populations. However, unforeseen threats such as pesticide contamination at roosts and overheating may turn such roosts into ecological traps. d) Roads that crisscross farmland often have artificial illumination, attracting positive phototactic insects and, in turn, light-opportunistic bats. This increases the risk of bats being killed by vehicle traffic. e) Increasing diversity in conventional farmland may, in principle, support wildlife, including bats. However, attracting bats to apparently favourable sites where they face high mortality risks may turn farmed landscapes into sinks. Image c) courtesy of Adrià Lopez-Baucells.

especially when they are sited along commuting routes or near foraging or drinking sites (Arnett et al., 2016; O'Shea et al., 2016; Cabrera-Cruz et al., 2020; Choi et al., 2020; Davy et al., 2021; Voigt et al., 2022). There is a mounting tendency to locate wind turbines in agricultural landscapes (e.g., Sardaro et al., 2019; Global Wind Energy Council, 2024). Many of the European bat species that fall victim to wind turbines, including noctules (*Nyctalus* spp.) and pipistrelles (*Pipistrellus* spp.) are frequent foragers in agricultural landscapes (Rodrigues et al., 2015). As seen in common noctules (*Nyctalus noctula*) in Germany, bat mortality caused by wind turbines implies a considerable loss of trophic interactions in agroecosystems, substantially reducing the associated ecosystem service bats provide (Scholz and Voigt, 2022).

While placing wind turbines in low-bat diversity agricultural areas is, in principle, a good approach to limit casualties of species at risk, structural improvements that increase roosting opportunities and the presence of woody vegetation near wind turbines likely increase mortality. This possibility is supported by recent research (Barré et al., 2022a; Leroux et al., 2022) and covered by EUROBATS recommendations (Rodrigues et al., 2015). Both emphasise the importance of limiting bat attraction to turbines in open spaces, thereby reducing bat mortality, by keeping turbines at least 200 m away from woodland edges, treelines, and hedgerows (Rodrigues et al., 2015).

Like wind turbines, photovoltaic panels are taking up agricultural soil (including bat foraging habitat), and solutions are being sought to mitigate the conflict between food and energy production (e.g., Miskin et al., 2019). Relatively few studies have explored the influence of photovoltaic panels on bats, with results ranging from reductions (Tinsley et al., 2023; Barré et al., 2024) to the absence of effects (Szabadi et al., 2023) in bat activity. Since bats mistake horizontal smooth surfaces for water (Greif and Siemers, 2010; Russo et al., 2012), there is a general concern that smooth photovoltaic panels might act as sensory traps resembling water to bats, potentially inciting them to attempt drinking (Tinsley et al., 2023; Barré et al., 2024). Testing of mitigation strategies is underway (Rahman et al., 2024), although there is currently no hard evidence to confirm this issue.

Conventionally farmed landscapes also imply the expansion of road networks for car and mechanical mobility (Li et al., 2020). While most bat species are repelled by artificial illumination at night, some bat species concentrate foraging activity near lights to feed on insects lured by light (Rydell, 1992; Stone et al., 2009, 2012, 2015; Barré et al., 2021; Salinas-Ramos et al., 2021b; Voigt et al., 2021). Landscape composition affects bat activity at artificially illuminated sites, with certain species, such as *Pipistrellus pygmaeus*, increasing activity in farmland compared to other land use types (Barré et al., 2022b). Bats that increase foraging activity at lights bordering roads face a higher risk of being involved in roadkill events (O'Shea et al., 2016; Huang et al., 2021). In Portugal, road verges in agricultural areas attract bats for feeding and serve as habitat edges or corridors due to their higher vegetation complexity compared to surrounding habitats. Improving the surrounding farmland increases the risk of roadkill (Medinas et al., 2013; 2019).

3.3. Landscape patterns

Assessing the real risk ecological traps pose to wildlife requires comprehension of their impact on a landscape scale, potentially influencing metapopulation dynamics significantly (Hale et al., 2015).

The complexity of trap effects considerably escalates once landscapes, rather than local contexts, are analysed, requiring a more comprehensive examination of animal movement across their broad home ranges (Hale et al., 2015). Conventionally farmed areas adjacent to restoration sites may invalidate the intended benefit of such conservation practices and lead animals to make maladaptive choices, resulting in reduced fitness (Nawrocki et al., 2019).

The substantial scientific evidence indicating higher bat activity in heterogeneous farm areas (Frey-Ehrenbold et al., 2013; Monck-Wipp et al., 2018) and agricultural sites surrounded by diverse landscapes

(Heim et al., 2015; Froidevaux et al., 2017; 2019; Blary et al., 2021; Ancillotto et al., 2023) suggests a strategy to promote the presence of bats in agroecosystems by managing landscape structure (Fig. 3). This includes increasing crop type diversity across the landscape, favouring the presence of hedgerows, forest patches and other valuable landscape elements, and promoting more complex agricultural mosaics in the surrounding matrix (Tuneu-Corral et al., 2023). While this approach is potentially useful, it should go hand in hand with mitigating potential risks associated with conventional farmland. Luring bats to agricultural sites highly contaminated with pesticides or where they may encounter ecological traps associated with infrastructures could have detrimental impacts on a broad scale. Failure to mitigate these risks could transform agricultural fields into sinks, depleting bat populations in the natural matrix. Such depletion could also have repercussions for rare species like forest bats, known to use farmland for feeding, as activity (Stahlschmidt et al., 2017) and dietary (Ancillotto et al., 2022) studies demonstrate. The complexity of trap effects considerably escalates once landscapes, rather than local contexts, are analysed, requiring a broader examination of animal movement across their large home ranges (Hale et al., 2015).

The potential adverse effects of conventional agricultural management on bats in diverse landscape mosaics, characterised by patches of natural habitat interspersed with cultivations, are especially concerning in geographic systems such as islands. Here, bats occur at low densities due to the inherent scarcity of resources, which may result in serious problems. This is exemplified by the situation on Pantelleria Island, in southern Italy, where the famous wine production has come at the cost of significant pesticide use for decades. As a result, bats are now rare on the island (personal observation). Although frugivorous rather than insectivorous, the European population of Egyptian fruit bats (*Rousettus aegyptiacus*) confined to the island of Cyprus has experienced a decline of over 90 % in the last three generations, leading to its classification as 'critically endangered' on the continent (Russo and Cistrone, 2023). While the factors behind this alarming decline remain unclear, pesticides are suspected to be among the main causes.

Forest islands surrounded by conventionally cultivated farmland may harbour important bat colonies. For example, in Italy, a small forest remnant situated within a landscape dominated by intensive corn and poplar cultivations hosts large colonies of common (*Nyctalus noctula*) and greater (*Nyctalus lasiopterus*) noctule bats (Russo et al., 2023). These bats likely play a crucial role in ecosystem functioning by spreading across the surrounding agricultural matrix at night for feeding. However, the long-term exposure of such bats to the widespread use of pesticides is currently unknown but is unlikely to be negligible.

4. Conclusions and implications for conservation

Bat populations are declining for several reasons, among which pesticide spread and agriculture intensification likely play a major role (Park, 2015; Frick et al., 2020). The IUCN has recently reassessed the conservation status of all 47 European bat species (Russo and Cistrone, 2023), and the situation is far from positive. Of such species, 38 % are threatened (three are now listed as critically endangered, three as endangered, and 12 as vulnerable). In contrast to the assessment conducted in 2008, the evaluation in 2023 showed that 11 bat species were moved to higher conservation categories, while three species were downlisted. The conservation status of 25 species remained unchanged. Moreover, the evaluation included eight newly assessed species. Concerns about the future of European bats are amplified by population trends, with 26 species experiencing declines. Only eight species show population increases, while seven have stable trends. Population trends for six species are still unknown.

As we have seen, few bat species have been studied in detail regarding the impact of pesticides. While some effects are acute and may imply rapid lethal responses, sublethal effects arising from chronic exposure are far less known and probably more difficult to detect at the

population level, at least in the short term, despite being detrimental to bat fitness (Torquetti et al., 2021). Research on the effects of pesticides on bats is urgently needed, and a pesticide risk assessment tailored to the peculiar biology of these mammals is also imperative (EFSA Panel on Plant Protection Products and their Residues et al., 2019).

When promoting bat presence in agricultural areas highly contaminated with pesticides, there is a significant chance that the positive effects of bat predation on pest species will be noticed much more quickly than the long-ranging effects of chronic pesticide exposure. This likely also holds for other threats in conventional farmland, including wind turbines, roadkill, and predation. Short- to middle-term monitoring following operations such as landscape restoration or bat box deployment might convey a misleading idea that a win-win result is achieved, with bats returning to farmland and pest arthropods declining. In contrast, only a long-term assessment would provide a realistic picture.

We have reviewed the primary potential factors, such as pesticides, and other significant threats like wind turbines, roads, predation by domestic cats, and heat-affected artificial roosts, which can transform a seemingly 'bat-friendly' farmed landscape into an ecological trap. Bats are highly mobile species, which increases the likelihood of encountering and selecting ecological traps. Their long lifespan, slow reproduction, and unique life history potentially expose them to particularly high fitness costs (Hale et al., 2015).

Restoration actions in farmed landscapes may have unexpected effects on species intended to benefit from such practices, but few studies have addressed this important issue. For example, restored grasslands adjacent to agricultural fields lead eastern cottontails (*Sylvilagus floridanus*) to make maladaptive habitat choices, perceiving the fields to be safer than the grassland during the crop-up season, which implies a higher mortality risk (Nawrocki et al., 2019). We fear that bats may also be highly exposed to maladaptive choices in conventional farmland following improvement or restoration actions, and such consequences should not be overlooked.

Our intention is not to discourage efforts for improvement but to emphasise the importance of considering the risks bats face once these mammals are attracted to conventionally cultivated fields where major threats are not mitigated. We strongly urge research into the potential interactions between habitat and landscape improvement and the risks bats face in conventional farmland, especially with the increasing adoption of nature-based solutions in agriculture, emphasising its critical significance. We caution against naively adopting partial measures that could ultimately harm bats at the landscape level, or worse, implementing "greenwashing" tactics – for instance, placing bat boxes in conventional farmland to appear more "environmentally friendly" without addressing the threats to which the bats colonising such roosts would be exposed. Recently, the European Commission withdrew the controversial Sustainable Use Regulation (SUR), which aimed to halve pesticide usage by 2030. This decision suggests that changes in pesticide use and their impact on biodiversity, particularly in the EU, are unlikely. This weakens the anticipated benefits of the recently approved "Restoration Law". Such a scenario does not bode well for the adoption of more sustainable farming practices in agriculture. Adopting conflicting policies that promote biodiversity and expose it to extra risks is not viable. In such cases, the cure might be worse than the disease.

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Danilo Russo: Writing – review & editing, Writing – original draft, Visualization, Supervision, Conceptualization. **Krizler Tanalgo:** Writing – review & editing, Visualization, Conceptualization. **Luca Cistrone:** Writing – review & editing, Visualization, Conceptualization.

Hugo Rebelo: Conceptualization, Visualization, Writing – review & editing.

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 article.

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Data availability

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