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RESEARCH

Adhesive traps for suppressing pest insects represent a serious threat to bats across Europe

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Abstract
The use of biocides is one of the main threats to biodiversity worldwide, representing a significant driver of decline for several taxa. Mechanical devices for the control of pest insect populations are commonly considered as less impacting, and yet may also represent a serious threat to wildlife. Among such mechanical devices, adhesive traps meant to control pest insects are especially widespread, and anecdotal evidence suggests that several vertebrates are at risk of being trapped by adhesive traps as bycatch. Specifically, we here focus on bats as potential bycatch of adhesive traps across Europe, conducting a literature review and community science data collection to describe and quantify bat mortality due to such devices, followed by a trait-based approach to highlight potential biases in the frequency of bycatch. We retrieved 222 cases of bats caught by adhesive traps, involving 17 species, with the brown long-eared bat *Plecotus auritus* being the most heavily affected. Among European bat species, probability of being caught by adhesive traps is significantly trait-biased, with the risk of getting caught being higher for species featuring smaller size, a gleaning hunting style, and being associated with anthropogenic habitats. Our results shed light upon a so-far overlooked risk posed by mechanical remedies meant to control insect pests upon bats, and the ecosystem services they provide. Our findings thus clearly indicate that the use of such devices should be avoided, especially in proximity to important roosts of rare or sensitive species, besides providing insights into the risk of "eco-friendly" remedies in organic agriculture.

Keywords Bycatch · Ecosystem services · Glue traps · Pest control · *Plecotus auritus*

Introduction

The increase in the human population over the last 50 years and the continuous expansion of agricultural areas, settlements, and cities has increased the chances of encounters between humans and wildlife, triggering new opportunities for potential conflict (Bogin 2020; Brooks et al. 2020; König et al. 2020). Despite the number of national and international protection laws, acts of killing wildlife are still widespread as a result of such conflicts, either intentional or not (Cerri et al. 2017; Schell et al. 2021). Human-wildlife conflicts usually lead to the implementation of remedies that involve killing or removal of individuals, especially in the case of pest taxa, in response to yield loss in cropland. Efficient methods for controlling pest populations require low cost-results ratios, as well as ease of use and, more importantly from a conservation point of view, must be selective towards the targeted pest. The public perception and awareness of issues related to animal welfare are increasing worldwide, fostering higher attention on how wild species and pests are managed (Baker et al. 2020), as well as how food is produced in terms of environmental footprint (Knight 2008).

Different approaches are currently available for the suppression of insect pests in a range of human-modified habitats, ranging from the use of chemicals (Ridgway et al. 1978), to biological agents (Van Lenteren and Woets 1988),

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pheromones (Witzgall et al. 2010), and mechanical devices (Hokkanen 1991). While the use of biocides is recognised as one of the major threats to biodiversity worldwide, representing a significant driver of decline for several non-target taxa (Mineau 2005), mechanical devices for the control of insect populations - commonly considered as less impacting - may also represent a serious, and yet less noticed, threat to wildlife, especially as their specificity is low (Ferronato et al. 2014). Among mechanical devices for the suppression of insect populations, adhesive traps are especially widespread, as they are highly effective (Sulaiman et al. 1987), cheap, relatively long-lasting, and are often sold as "environmental friendly" or "non-toxic" remedies in comparison to biocides. Such devices, known as sticky or glue traps or fly paper, are generally made of a flat rectangular strip of paper or other smooth material of white or yellow colour, covered with adhesive substances such as rosin; these adhesive strips may be freely hung from a ceiling or other structure, or may be tied to a vertical surface such as a tree-trunk or a wall. Similar traps are also designed to kill rodents if installed horizontally on the ground, and generally positioned indoors (Corrigan 1998). Most trapping devices designed to capture animals in natural or semi-natural environments imply chances of bycatch i.e., the entrapment and consequent potential mortality of non-target species. Bycatch has been mostly investigated in marine ecosystems, where research efforts are focused on mortality rates of vertebrate bycatches such as turtles, marine mammals, and seabirds due to fishing activities (Anderson et al. 2011; Reeves et al. 2005; Wallace et al. 2010), and only fewest papers deal with the impact assessment of traps in terrestrial ecosystems (e.g. Carpaneto et al. 2011). The only studies that assessed bycatch during glue trap campaigns refer to insect non-target species, along with campaigns conducted for research or pest control management, and no study reports vertebrate bycatch (Schmid et al. 2006). Nonetheless, several vertebrates are at risk of getting trapped by this type of device, either because they occur at the same sites of the targeted insects (e.g., small terrestrial mammals), or as being even attracted by the trapped insects, such as in the case of insectivorous small terrestrial mammals, birds, and bats. Only two studies to date focus on wildlife mortality due to adhesive traps, with a focus on raptors admitted at rescue centres (Burton and Doblar 2004; Harden 2002; Rodríguez et al. 2010).

Bats are finely-tuned adapted to their environment, and yet many species are capable of rapidly adjusting to changing environmental conditions, coping with anthropogenic habitat changes, and thus being frequently found in close proximity to humans, e.g. in farmland and urban areas (Russo and Ancillotto 2015). Yet, most bats are sensitive to large-scale habitat alterations and suffer from the use of pesticides and direct persecution. Albeit being increasingly recognised as efficient suppressors of a wide range of nuisance and pest insects worldwide (Kemp et al. 2019; Baroja et al. 2019; Cleveland et al. 2006), little attention has been posed on the effects of mechanical devices for the control of insects on bats.

Here we conduct a review of scientific literature to collect occurrences of bats trapped by adhesive traps, also screening social media or directly contacting wildlife and bat rehabilitators, and apply a trait-based approach to testing whether such phenomenon affects species differently, according to their eco-morphological characteristics.

We hypothesise that both bats' traits and trap positioning affect bats' probability of being caught in flypaper, predicting that the most commonly trapped bat species will be those more frequently recorded in anthropogenic habitats, i.e. those more likely to encounter glue traps inside or in proximity of buildings (Russo and Ancillotto 2015); also, we expect that traps will more often catch bats that may be attracted by trapped insects as potential prey i.e., species that may catch prey from the substrate ("gleaners") in comparison to species that usually hunt on the wing ("hawkers" and "trawlers").

Materials and methods

Study area

We set our search on geographical Europe, as most countries recognize bats as conservation priorities e.g., by providing legal coverage via the EU Habitats Directive and the EUROBATS Agreement, and because the use of glue traps for pest control is generally legal, easily accessible and thus potentially ubiquitous. An exception to this is represented by Ireland, where the use of glue traps for pest control is banned (Baker et al. 2020).

Record collection

Search for records was conducted by searching the following keywords - and their combinations - on ISI Web of Science, Google Scholar, Google, Facebook, and X: "*bat*", "*fly paper*", "*sticky trap*", "*glue trap*", and "*adhesive trap*". We manually checked each retrieved paper, report or post to delete duplicates (e.g., the same retrieved bat posted on both X and Facebook). Moreover, we contacted Wildlife Rescue Centres and private rehabilitators to retrieve additional records of glued bats. From each record, we extracted the following information, whenever available: (i) year and location at country level, (ii) bat species or genus id, (iii) numbers of individuals found on the same trap, and (iv) adhesive trap location (indoor vs. outdoor).

Statistical analyses

We first explored the relationship between bat entrapment and trap positioning by running chi-squared tests on contingency tables reporting the numbers of trapped bats - or the proportions of events involving >1 individual - according to trap position (outdoor vs. indoor), considering as significant those results with $p<0.05$ and residual values $>|5|$.

We then investigated whether and which ecological traits are related to the probability of being trapped by adhesive traps by following a trait-based approach (Violle et al. 2007). To do this, we considered all bat species occurring in biogeographical Europe according to Hackländer and Zachos (2020) and classified *a posteriori* all species with evidence of trapping as '1' and all species without evidence of trapping as '0'. We then selected a set of traits that may potentially affect bat trappability, namely body size (approximated by forearm length), main foraging habitat (forest, edges, open areas, or wetland), hunting style (hawking, gleaning, or trawling), and response to urbanization (avoider, adapter, or exploiter). All these assignments were retrieved from - or supported by - available datasets (Cosentino et al. 2023; Froidevaux et al. 2023) and recent literature (Santini et al. 2019; Hackländer and Zachos 2020). When more measurements were available for the same species, we considered the mean values for numeric variables and one single category for categorical variables based on expert opinion. To exclude redundant ecological traits, we performed a principal coordinate analysis (FactoMineR R package; R 4.1.2) and calibrated a Random forest model (500 trees; Breiman 2001) using the ecological traits as explanatory variables (*randomForest* R package). We measured variable importance by using the percentage increase in mean squared error (% IncMSE), which measures the increase of error for each tree by permuting each variable in the out-of-bag sample of the data. We evaluated the predictive capacity of the traits model by using the root mean square error (RMSE) and calculating the area under the curve (AUC) of the receiver operating characteristic (ROC; Swets 1988). The used script for this analysis is available as supplementary material (document S1).

Results

Overall, we retrieved 222 records of bats glued to adhesive traps documented between 1998 and 2023, totalling 302 individuals belonging to 17 species. Most records come directly from rehabilitators and social networks, while only one scientific paper specifically covered the topic of bats caught in adhesive traps (Von Florian 2008). A large proportion of records come from the UK, yet we retrieved occurrences also from several central, northern, and southern European countries (Fig. 1). Among the recorded species, the brown long eared bat *Plecotus auritus* was the most frequently reported as trapped in flypaper, with >120 individuals recorded as trapped in 95 events, followed by the common pipistrelle *Pipistrellus pipistrellus*, and *Myotis* bats (Fig. 2).

Only 8 out of 81 records for which trap position was available refer to adhesive strips put on tree trunks, while all others refer to strips hanging freely from branches, porches or ceilings. In 69 cases, information on whether flypaper was hanging indoor or outdoor was retrieved, these conditions being similarly frequent (indoor: $n=36$; outdoor: $n=33$). Captured bats per record ranged from 1 to 16 individuals (one case involving *M. mystacinus*), with multiple captures - usually involving 2 or 3 bats - occurring in 15.5% of cases. Multiple captures were significantly more frequent in *P. auritus* than any other species (57% of multiple capture events referred to this species; chi-squared: 1.23, $p<0.05$). Multiple capture events were significantly more frequent when traps were hanging outdoors ($p<0.01$), with no difference among species.

The traits model showed a good performance with RMSE = 0.408 and AUC = 0.836. The most important trait in predicting the probability of a species to be glued was forearm length (22.2% IncMSE), followed by foraging habitat (open 7.9% IncMSE), and hunting strategy (gleaning 5.9% and hawking 5.1% IncMSE). In particular, the probability for a bat of getting glued was lower for species with longer forearm and species foraging in open habitats, or that mainly adopt a hawking foraging strategy. Conversely, the same probability was higher for species foraging with a gleaning strategy, as well as for species more associated with urban areas (adapters and exploiters).

Discussion

We here document the phenomenon of bat bycatch by adhesive traps meant to control pest insects in anthropogenic habitats, evidencing how such cause of mortality is geographically widespread across Europe, and biased towards species characterised by specific sets of traits. The risk of being trapped in flypaper was significantly higher for smaller bats i.e., species featuring shorter forearm length. Such bias may be due to the lower proportion of body or wing surface in contact with the adhesive trap in case of impact with a larger bat, thus allowing larger species to detach more easily than smaller-bodied ones that instead end up glued to the trap. Besides, our sample was dominated by bat species that hunt prey by gleaning i.e., by catching arthropods from the substrate, in comparison to hawkers and trawling species.

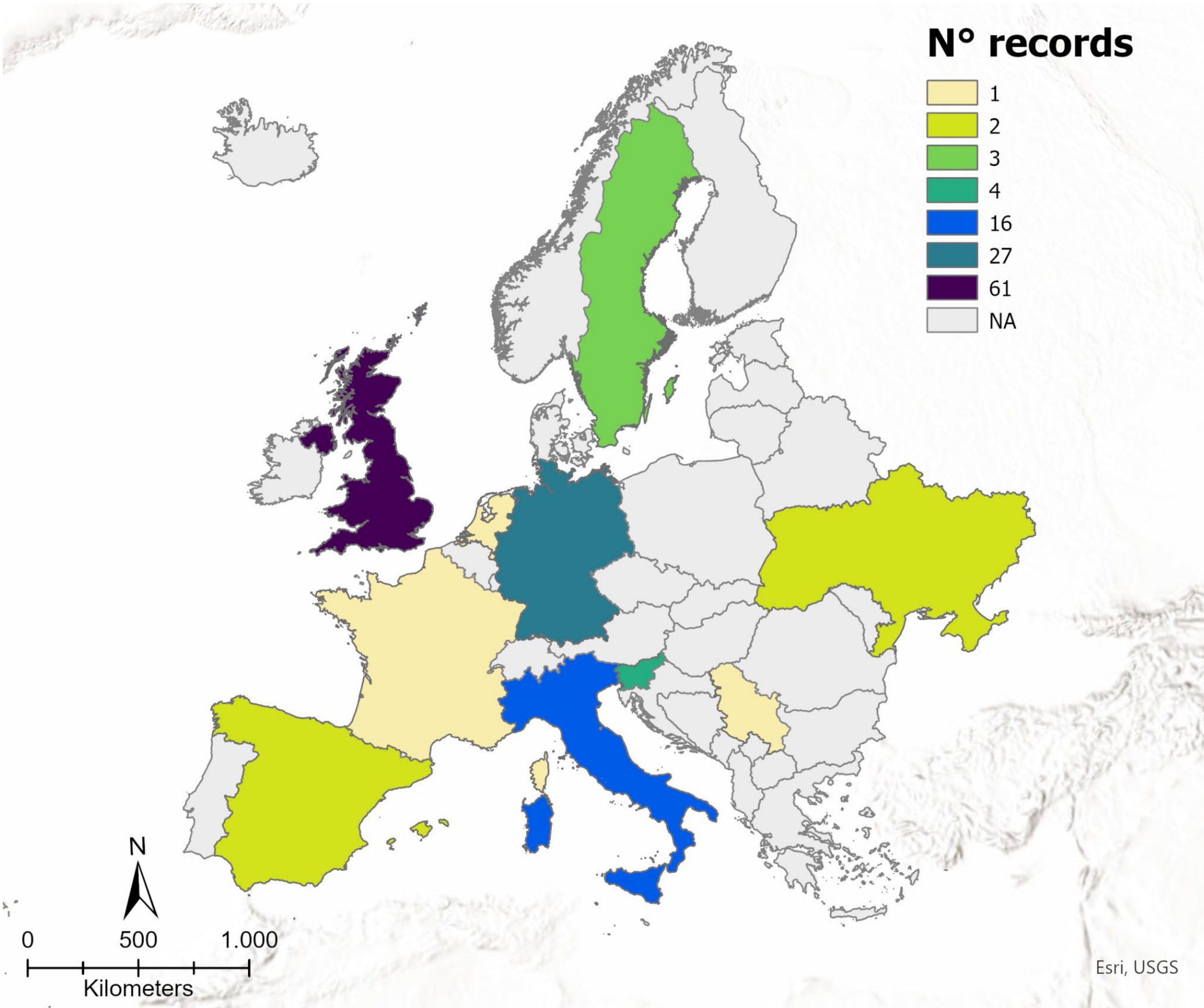

Fig. 1 Map of retrieved records ($N=222$) of bats entrapped in adhesive traps ("flypaper") in Europe, per country

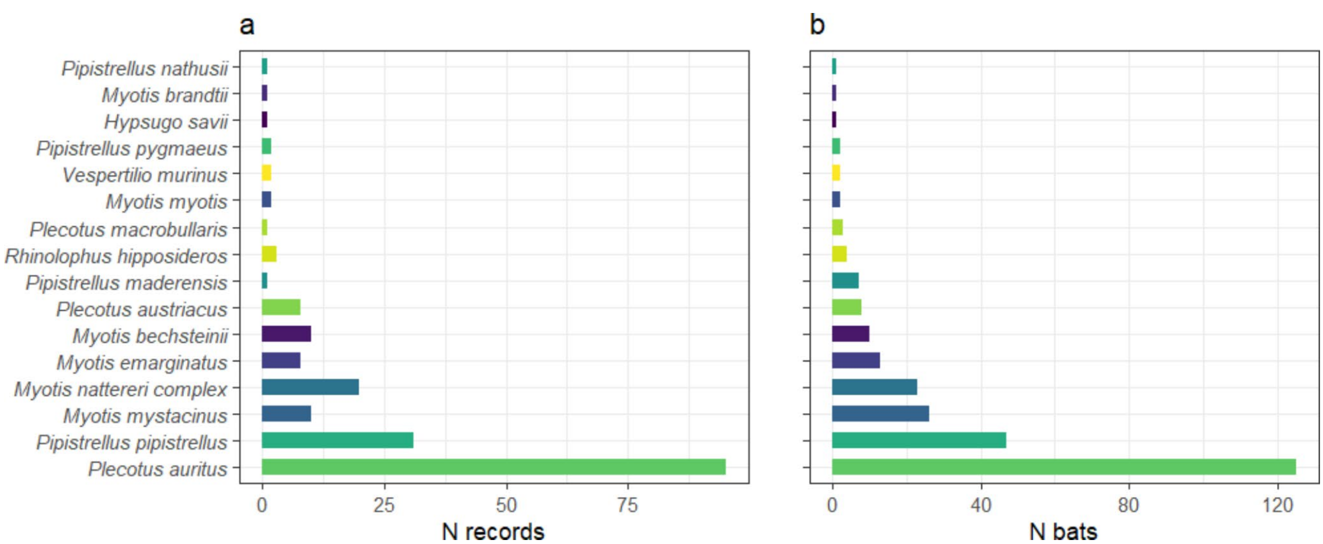

Fig. 2 Numbers of records (**a**; $N=222$) and individual bats (**b**; $N=302$) trapped in flypaper, between years 1998 and 2023

Such bias strongly suggests that bats mainly are trapped as being attracted by the occurrence of glued insects on the trap. In fact, gleaners, and particularly long-eared bats - the most abundant bats in our sample - extensively hunt by passive hearing, locating prey by tracking sounds emitted by moving arthropods (wing beats or rustling during locomotion) (Anderson and Racey 1993), making adhesive traps dangerous lures to these species. Finally, bat species that usually live in close proximity to urban areas and use buildings as roosts, such as pipistrelles and– again– long-eared bats, also proved to more likely fall victim to adhesive traps than species that avoid urban habitats. Nonetheless, our sample also featured many forest species, as these also occur in anthropogenic habitats such as orchards and managed woodlots, and thus close to human infrastructures. Close proximity to humans is known to offer bats both opportunities and challenges (Russo and Ancillotto 2015), usually imposing higher mortality (e.g., Ancillotto et al. 2013), and our results add to the evidence that - at least in some contexts - attraction to anthropogenic habitats may represent an ecological trap to bats (Vlaschenko et al. 2019).

The small size, and ease of purchase and application of glue traps allow their adoption as pest suppressor devices by a wide range of users, from private citizens to large companies, who may use them both indoor and outdoor. Such flexibility makes adhesive traps capillary widespread around the world, frequently occurring indoor in roofs, lofts, cellars, and stables, where these are mostly used to control populations of nuisance pests such as house and livestock flies (e.g. genera *Musca*, *Calliphora*, and *Stomoxys*: Sulaiman et al. 1987; Sundar et al. 2018; Williams 1973) or moths (e.g. *Tineola bisselliella* and *Plodia interpunctella*: Krüger-Carstensen and Plarre 2011; Nansen et al. 2004). Adhesive traps are also frequently used outdoor in agroforestry and cropland systems e.g., in vineyards, orchards, and vegetable gardens, where their use is meant to mainly suppress crop pests, or monitor the efficacy of control/eradication campaigns (Van Timmeren and Isaacs 2013; Cid et al. 2010; Yee 2015). In our sample, bat entrapment was evenly common between traps hanging indoor and outdoor, suggesting that both conditions represent a threat to bats in different contexts and for different species.

Adhesive traps meant to capture pests are anecdotally recognized as a threat to wildlife and to bats in particular e.g., by Bat Conservation International (http://www.batcon.org/resources/media-education/bats-magazine/bat_article/165*)*, Bat Conservation Trust (https://www.bats.org.uk/about-bats/threats-to-bats*)*, and by the British Pest Control Association (https://bpca.org.uk/news-and-blog/Feature/pest-control-while-protecting-our-bats/187876*)*. Nonetheless, beside the paper by Von Florian (2008) reporting bats glued to insect traps for the first time, no attempt to quantify and describe the phenomenon was ever conducted before on a European-wide scale.

Among European bats, the brown long-eared bat *P. auritus* seems to be particularly vulnerable to the threat of adhesive traps, representing the most commonly reported species by far. Such high susceptibility may be the result of the synergistic effects of the traits we considered, i.e. relatively small size, gleaning hunting strategy, and the frequent proximity of the species to human settlements. In fact, despite *P. auritus* is strongly dependent upon forest habitats (Ancillotto et al. 2022a), it is also widely documented to exploit anthropogenic structures for roosting such as bat-boxes and buildings (Moussy 2011; Zeus et al. 2017). Several species of conservation concern featured among those we retrieved in our sample e.g., three species listed within Annex II of the Habitats Directive (*M. emarginatus*, *R. hipposideros*, and *M. bechsteinii*), and two classified as Vulnerable by the European Redlist by IUCN (*M. bechsteinii* and *P. macrobullaris*). Bats are occasionally reported to fall accidentally victim also of natural traps such as spiny plants (Norquay et al. 2010; Jacomassa et al. 2017) and cobwebs (Nyffeler and Knornschild 2013), and of human made devices such as barbed wire (Wisely 1978; Van Der Ree 1999; Jacomassa et al. 2017), small mammal traps (Jung and Slough 2005), and fishing hooks (Sleeman 2013), albeit the causal mechanisms that lead to such entrapments are mostly unclear. Nonetheless, man-made adhesive traps occur at much higher densities in anthropogenic habitats, and thus likely impose an unsustainable loss to local bat populations.

Conclusions

The accidental fatalities of bats due to adhesive traps may not only represent a threat to species conservation, but also entail a potentially dramatic - and ironically counter-productive - toll to the ecosystem services that bats provide to suppress the same pests meant to be controlled by adhesive traps. Insights into such potential effects are hard to provide, yet the recent advances in the study of ecosystem services provided by bats indicate a rather relevant loss (Russo et al. 2018; Ancillotto et al. 2024). As an example, Murphy and Ament (2022) found that *P. auritus* predation upon a single major crop pest (*Cydia pomonella*) translates into a GBP 307.59/604.95 per hectare value. Considering that each *P. auritus* usually forages over 1 to 3 exclusive core areas, each of ca. 1 ha in size (Froidevaux et al. 2023), and that this bat frequently hunts also in orchards (Murphy and Ament 2022) - the loss of even single individual bats, not to mention multiple fatalities, may have significant economic implications to local agricultural activities. Besides, single bat species usually feed upon several numbers of pests at the same time (e.g., Ancillotto et al. 2022b; Mata et al. 2021), so that decreasing in bat abundance and diversity is likely to cause significant losses in the ecosystem services provided by these mammals.

Our results, albeit being far from exhaustively quantifying the phenomenon of bat mortality due to adhesive traps, shed light upon a so-far overlooked risk posed by mechanical remedies meant to control insect pests upon bats in agricultural landscapes. Our methodological approach does not allow us to quantitatively assess the impact of adhesive traps to bats, yet community science approaches have proved to provide valuable data to infer key information on wildlife ecology and threats (e.g., Nyffeler and Knörnschild 2013; Maritz and Maritz 2020). From a practical perspective, our findings clearly indicate that the use of such devices should be avoided, especially in proximity to important roosts of rare or sensitive bat species, and that otherwise sticky traps should be equipped with protection against impact with vertebrates (e.g., wire cages). Besides, we here also provide insights into the risk of "eco-friendly" remedies for pest control in organic agriculture and urban areas that should be considered when screening and managing threats to wild species and the ecosystem services they provide.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10344-024-01872-6.

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Author contributions L.A. and E.M. conceived the work, F.C. performed formal analyses and provided figures F.F, F. C., and L. A. wrote the main manuscriptall authors reviewed and approved the final version of the manuscript.

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Data availability Data and script of the analyses will be made available upon reasonable request to the corresponding author.

Declarations

Competing interests The authors declare no competing interests.

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