Preventing unintentional bat captures in canopy traps used for insect surveys

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Author contributions

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Conflict of interest statement

The authors declare no conflicts of interest.

Abstract

There is growing interest in deploying insect traps in forest canopies for ecological research, invasive species surveillance, and biodiversity monitoring. However, forest canopies also harbor a diverse and abundant bat community. In this study, we investigated the impact of flight interception traps and multi-funnel traps deployed in oak canopies on incidental bat captures, and evaluated whether trap modifications could reduce this bycatch. We also examined how these modifications influenced the species richness, abundance, and mean body size of several beetle taxa, including Buprestidae, Cerambycidae, Cetoniinae, and Scolytinae. Both trap types captured bats. Flight interception traps collected seven species - *Myotis bechsteinii*, *Myotis daubentonii*, *Myotis mystacinus*, *Nyctalus noctula*, *Nyctalus leisleri*, *Plecotus auritus*, and *Pipistrellus pipistrellus* - with an average of 0.38 to 0.45 bats per trap. Multi-funnel traps primarily captured males of *P. pipistrellus*, with an average of 0.24 to 0.33 bats per trap. Adding a 13-mm mesh above the collection container significantly reduced bat bycatch to 0.02 to 0.05 bats per trap. This modification had no significant effect on insect species richness or mean body size, although it did reduce beetle abundance in Cerambycidae in black multi-funnel traps, and Scolytinae in flight interception traps, likely due to more frequent clogging by twigs and leaves. We recommend modifying flight interception and multi-funnel traps deployed in forest canopies to prevent unintentional harm to protected bat species.

Keywords

Lindgren trap, multi-funnel, flight interception trap, ecological trap, bycatch

Introduction

Insects are routinely sampled in forests for purposes related to biodiversity monitoring, invasive species surveillance and pest management. A variety of survey techniques - often involving traps - have been developed for the detection, monitoring, or inventory of either broad insect communities or specific target species (Brockerhoff et al., 2023). However, these traps are rarely taxon-specific and frequently capture a wide range of non-target organisms. Most reported bycatch consists of invertebrates (e.g., Zumr and Stary, 1991; Rojas-Nossa et al., 2018; Hafsi et al., 2020; Sukovata et al., 2022), and in some cases, it provides an opportunity to detect rare or previously unrecorded native and exotic species (Vincent et al., 2020; Le Souchu et al., 2024a; Mas et al., 2023). However, certain trap designs can also unintentionally capture and occasionally kill vertebrates. For example, conventional pitfall traps, commonly used to sample ground-dwelling invertebrates, may also cause mortality in small mammals and amphibians (Pearce et al., 2005). Avoiding bycatch is important not only for ethical considerations related to the killing of beneficial and/or patrimonial species, but also for regulatory compliance, as some non-target species may be legally protected. Moreover, the incidental capture of non-target organisms may compromise the quality and representativeness of insect samples. Decomposing bodies of vertebrates accelerate the decomposition of insect samples and may attract additional insect species (Pearce et al., 2005), while collecting a large volume of non-target organisms may also reduce trap efficiency for targeted species (Spears et al., 2021). This would in turn bias the sample and increase the time necessary to sort the samples (Pearce et al., 2005). To avoid these issues, while maintaining the effectiveness of the trap, trap designs often need to be adapted (e.g. Pearce et al., 2005; Spears et al., 2021).

The canopy of forests provides a diverse range of specific trophic resources, microhabitat and microclimatic conditions for insects (Sallé et al., 2021). As a result, it harbors diverse and unique, yet largely understudied, arthropod communities (Floren and Schmidl, 2008; Bouget et al., 2011; Ulyshen, 2011; Urban-Mead et al., 2021). In this regard, temperate forest canopies may serve as reservoirs for rare and conservation-important species (Plewa et al., 2017; Le Souchu et al., 2024a). The canopy may also provide critical resources to fulfill the life cycle of forest insect species associated with other forest strata and may consequently provide an optimal location for trapping certain species (Ulyshen, 2011; Sallé et al., 2021). Setting traps in the canopy may consequently improve the detection and monitoring of both patrimonial insect species and major forests pests (Plewa et al., 2017; Rassati et al., 2019; Sallé et al., 2020).

Many species of bats also rely on the forest canopy for roosting and foraging (Müller et al., 2013; Law et al., 2016; Erasmy et al., 2021). This is particularly true for the canopy of old-growth oak forests which harbor a large amount and diversity of microhabitats, including loose bark, cracks and cavities that are used by bats for roosting and nesting (Regnery et al., 2013). Forest insects are an important food source, and bats may play a role in the control of forest pests (Beilke and O'Keefe, 2023; Augusto et al., 2024). Bat populations in Europe are

thought to have experienced significant declines in the last century, and some species have undergone significant range contractions (Browning et al., 2020). In France, eight of the 36 bat species are classified as threatened, and eight are considered near threatened (Arthur and Lemaire, 2021). In Europe, 25 percent of the 40 bat species are threatened (Temple and Terry, 2009), and all bat species consequently benefit from legal protection across Europe (Council Directive 92/43/EEC, 1992). Nevertheless, several studies have reported incidental captures of bats in traps intended for insect sampling (McLeod et al., 2021; Holzinger et al., 2023; Ancillotto et al., 2024).

This study reports the incidental capture of bats by three types of insect trapping devices deployed in the canopy of oak stands in France, designed primarily for sampling canopy-dwelling insect fauna. Given the growing interest in canopy trapping for ecological research, invasive insect surveillance, and monitoring programs, we propose a simple modification to these devices to minimize bat bycatch while maintaining trapping efficacy for the targeted insect groups. We first document the species composition and abundance of bats captured, then evaluate the effectiveness of the modified trap design in reducing these unintended captures. Lastly, we assess the impact of change in trapping design on the abundance, species richness, and mean body size of the targeted insect taxa.

Material and methods

The study was conducted in six oak-dominated forests located in France (Table 1). The two dominant tree species in these forests were *Quercus robur* L. and *Quercus petraea* (Matt) Liebl. In each forest we selected 3 to 9 stands. The main objective of the study was to characterise the community of insects dwelling in oak canopies. For this, three kinds of traps were used: black and green multi-funnel traps (BMF and GMF respectively, Chemtica Internacional, San Jose, Costa Rica), with 12 fluon-coated funnels (figure 1), and flight interception traps with transparent panels (FI, Ecole d'ingénieurs de Purpan) (figure 1). Traps were suspended among the lower branches in the canopy (i.e. approximately 10 - 15 m above the ground). The collectors were filled with a solution of 50% (v/v) monopropylene glycol and water plus a drop of detergent. Setting GMF traps in the canopy layer is considered as one of the most efficient sampling approaches to collect *Agrilus* species (Rassati et al., 2019; Sallé et al., 2020), and can be used either to monitor native species or detect exotic ones (Santoiemma et al., 2024; Le Souchu et al., 2024b), but also to monitor and detect a wide array of canopy-dwelling insects (Sallé et al., 2020 ; Vincent et al., 2020 ; Le Souchu et al., 2024a). BMF traps were baited with volatiles (a blend of longhorn pheromones, ethanol and alpha-pinene, see Roques et al., 2023). These traps have been developed for early detection of exotic longhorn beetles (Roques et al., 2023). FI traps are routinely used to sample saproxylic beetles (Bouget et al., 2009). The traps were installed during three consecutive years, from 2019 to 2021, approximately from April to September,

and were emptied every month. The number of stands, and traps per stand, varied among forests and years (table 1).

In 2019, all traps were installed as supplied by the manufacturers. In 2020 and 2021, to prevent further captures of bats, as they are protected species, all traps were modified accordingly, and no unmodified (control) traps were used in parallel. In 2020, GMF and FI traps were equipped with wooden sticks (5 mm diameter), set as cross, in the last funnel over the collection cup (figure 1). This modification is similar to the one proposed by Holzinger et al. (2023) to prevent bats from being captured by FI traps. BMF traps were not used in 2020. Since this modification proved ineffective (see Results), we implemented and evaluated an alternative modification in 2021. A 13-mm wire mesh was fixed onto a small funnel inserted inside the last funnel of the traps, over the collection cup of all trap types (figure 1), as proposed by McLeod et al. (2021). Preliminary assays conducted at the Museum of Bourges using live common pipistrelles from an animal shelter indicated that larger mesh sizes (2 x 2 cm and 2 x 4 cm) were easily crossed by the bats and, consequently, were too wide. The mesh was connected to the rim of the last funnel to allow bats to exit the trap. We obtained a legal authorization from regional authorities (Direction Régionale de l'Environnement de l'Aménagement et du Logement) for the incidental capture of bats for scientific purposes according to article R411-7 of the French Environmental Code, pending traps were adapted to avoid these captures.

Figure 1: Flight interception trap (FI, top left) and black multi-funnel trap (BMF, top right). Modified funnels with wooden sticks (bottom left) and a 13-mm metallic mesh (bottom right) placed just above the collection cup.

Table 1. Sampling sites and years, and number of traps used. Lat.: latitude, Long.: longitude, GMF: green multi-funnel traps, BMF: black multi-funnel traps, FI: flight interception traps. See text for details. WS-: traps modified with wooden sticks, MM-: traps modified with a metallic mesh.

Location	Lat.	Long.	Years of monitoring	Number of stands	Type of traps used (n)
State forest of Boulogne	47.57	1.53	2021	6	MM-GMF (12) MM-BMF (6) MM-FI (12)
Forest of Chantilly	49.17	2.51	2021	3	MM-GMF (6) MM-BMF (3) MM-FI (6)
State forest of Châteauroux	46.74	1.72	2021	6	MM-GMF (12) MM-BMF (6) MM-FI (12)
State forest of l'Abbaye	46.23	3.37	2019	3	GMF (6) BMF (3) FI (6)
			2021	3	MM-GMF (6) MM-BMF (3) MM-FI (6)
State forest of Orléans	47.87	2.41	2019	9	GMF (18) BMF (9) FI (18)
			2020	6	WS-GMF (12) WS-FI (12)
			2021	6	MM-GMF (12) MM-BMF (6) MM-FI (12)
State forest of Vierzon	47.46	2.19	2019	9	GMF (18) BMF (9) FI (18)
			2020	6	WS-GMF (12) WS-FI (12)
			2021	6	MM-GMF (12) MM-BMF (6) MM-FI (12)

Bats and insects identification

We counted the bats caught in all types of traps during the survey. Bats caught in GMF and FI traps in 2019 and 2020 were kept for identification by the Museum of Natural History of Bourges (France). Bats collected were also sexed. Bats collected in BMF traps were counted but not identified. Saproxylic beetles collected were identified at the species level for most families.

Statistical analyses

All analyses were performed in R, version 4.2.1 (R Core Team 2023). To assess whether mean bat catches per trap varied among years, and after the addition of the wire mesh, we performed pairwise Wilcoxon tests, with a Holm correction for multiple comparisons.

In addition, we have tested whether the change in trap design affected the abundance, species richness and average size of beetles collected. We focussed these analyses on key taxonomical groups of beetles. For this, we selected several families or subfamilies of saproxylic beetles which are either significant forest pests and/or patrimonial species, exhibit various body sizes, and were well sampled by our different trap designs. Consequently we selected four groups: (i) longhorn beetles (Cerambycidae) which have average to large body sizes (13.5 ± 0.5 mm body length, calculated from the database mentioned below), include both pest and patrimonial species, and are specifically targeted by BMF traps, (ii) jewel beetles (Buprestidae) which have average body sizes (9.0 ± 0.5 mm) , include pest species, and are specifically targeted by GMF traps, (iii) flower chafers

(Cetoniinae) which have large body sizes (17.4 ± 1.2 mm), include patrimonial species and are well sampled by FI traps and (iv) bark beetles (Scolytinae), which have small body sizes (2.5 ± 0.1 mm), include pest species, and are also well sampled by FI traps. We assessed whether the mean abundance and species richness per trap varied before (2019) and after (2021) the addition of the wire mesh with Kruskal-Wallis tests. Bark beetles were not identified in BMF traps in 2021 and were consequently discarded from the analyses for this trap type.

Finally, to assess the effect of wire mesh on the average body size of collected beetles, we first assigned an average body size to each of the sampled taxa, within the four above mentioned taxonomic groups, using the database provided by Bouget and coll. (2019). For each group, we then calculated the average body size per trap in 2019 and 2021. For each trap type, we restricted the analyses to the most frequently sampled taxonomic groups (i.e. Buprestidae for GMF traps, Cerambycidae for BMF traps and Cetoniinae and Scolytinae for FI traps). To assess whether the average body sizes varied significantly, we performed Kruskal-Wallis tests. For all tests, the significance level was set at $\alpha = 0.05$.

Results

Bat captures

In 2019, 33 bats were captured: 5 in the 21 BMF traps, 11 in the 42 GMF traps and 17 in the 42 FI traps. In 2020, 17 bats were caught: 8 in the 24 GMF traps, and 9 in the 24 FI traps. One FI trap collected 6 bats during a single survey. In 2021, 5 bats were captured: 1 in the 30 BMF traps, 3 in one of the 60 GMF traps and 1 in FI traps (table S1). While the average number of bats did not differ between 2019 and 2020 in both FI and GMF traps, it significantly decreased in 2021, in all trap types (figure 2).

In 2019 and 2020, FI traps collected six species of bats, mostly Bechstein's bats (37%) and common pipistrelles (30%), while GMF traps collected only two species, mostly common pipistrelles (95%) (table 2). Overall, the captured specimens were predominantly male (83%). Approximately half of the captures occurred in July, with the remainder mostly distributed between May and June.

Table 2: number of individuals (males and/or females) of bat species captured in flight interception traps (FI) and green multi-funnel traps (GMF) installed in oak canopies in 2019 and 2020. nd: not determined

Trap type	*Myotis bechsteinii* (Kuhl)	*Myotis daubentonii* (Kuhl)	*Myotis mystacinus* (Kuhl)	*Nyctalus noctula* (Schreber)	*Nyctalus leisleri* (Kuhl)	*Plecotus auritus* (L.)	*Pipistrellus pipistrellus* (Schreber)
FI	10 (4m, 6f)	2 (m)	1 (nd)	2 (1m, 1 nd)	3 (m)	1 (m)	8 (m)
GMF			1 (m)				18 (m)

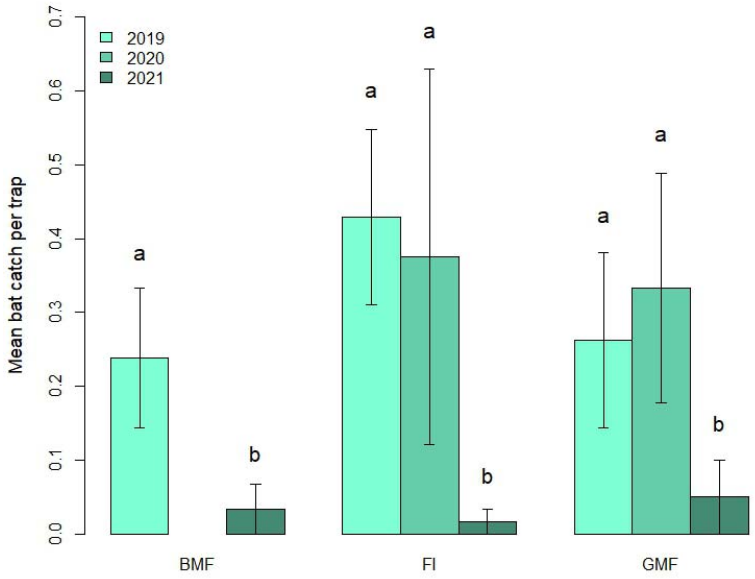

Figure 2: mean number of bats (± standard error) collected in black multi-funnel traps (BMF), green multi-funnel traps (GMF), and flight interception traps (FI) in 2019, in 2019 (with a standard collection cup), 2020 (with a wooden cross above the collection cup) and 2021 (with wire mesh above the collection cup)

Insect surveys

The mean abundance of beetles per trap decreased in 2021 for Cerambycidae in BMF traps and for Scolytinae in FI traps, but did not significantly vary for other taxonomical groups (figure 3). The mean species richness per trap of the four taxonomic groups considered did not significantly vary between 2019 and 2021 (figure 3).

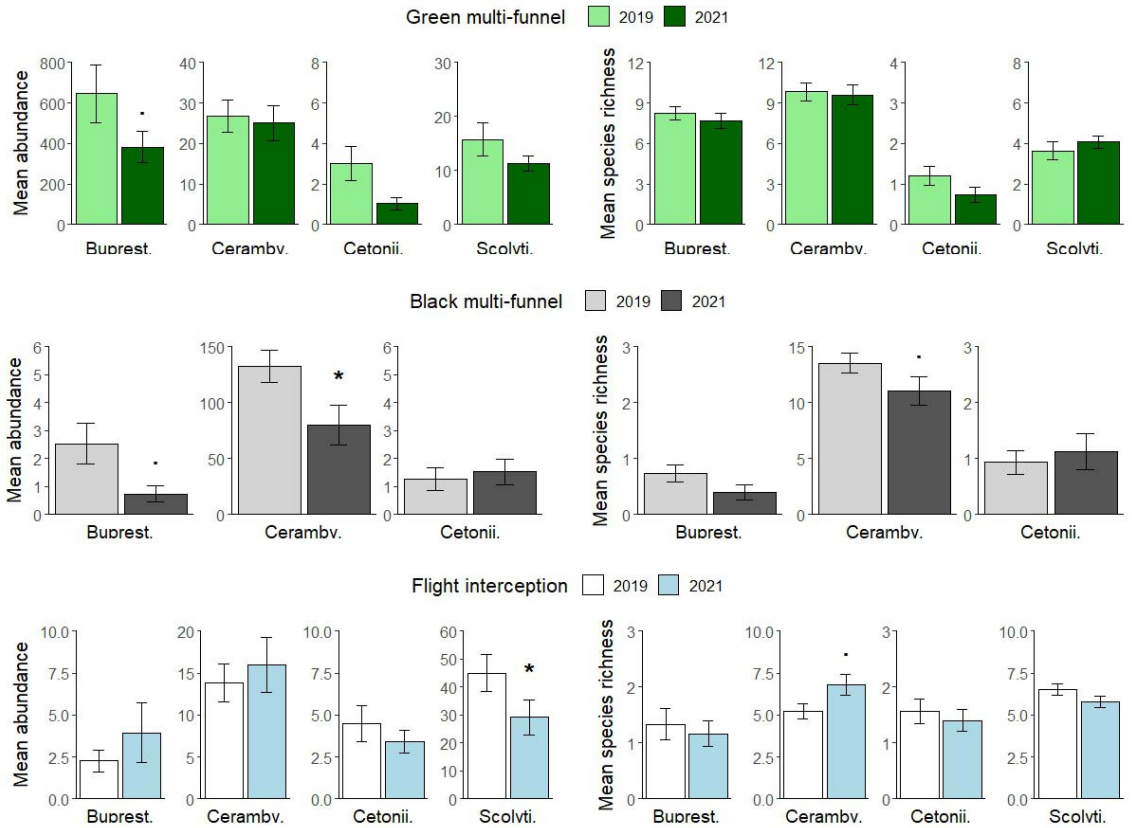

Figure 3: mean abundance (± standard error) (left) and mean species richness (± standard error) (right) per trap of Buprestidae, Cerambycidae, Cetoniinae and Scolytinae collected in green multi-funnel traps, black multi-funnel traps, and flight interception traps in 2019, i.e. with a standard collection cup, and in 2021, with a wire mesh above the collection cup. Symbols: · indicates a p.value < 0.1, * indicates a p.value < 0.05. Note that abundance scales are different among families and trap types.

The average body size per trap slightly increased in 2021 for the Cerambycidae in BMF traps (figure 4). It did not significantly vary for the other taxonomic groups considered, although it tended to decrease for the Cetoniinae (figure 4).

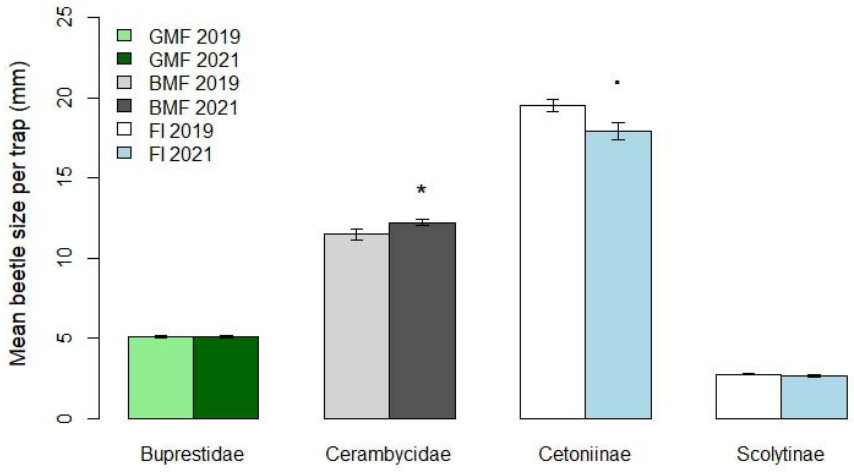

Figure 4: mean body size (± standard error) per trap of species of Buprestidae, Cerambycidae, Scolytinae and Cetoniinae collected in green multi-funnel traps (green bars: Buprestidae), black multi-funnel traps (grey bars: Cerambycidae), and flight interception traps (white and blue bars: Cetoniinae and Scolytinae) in 2019, i.e. with a standard collection cup, and in 2021, with a modified collection cup. Symbols: · indicates a p.value < 0.1, * indicates a p.value < 0.05.

Discussion

All trapping devices set in oak canopies incidentally captured bats. However, while FI traps collected a relatively diverse range of species, MF traps almost exclusively captured males of common pipistrelles. This may seem surprising given that bats use echolocation to detect prey and avoid obstacles (Jones and Holderied, 2007). Nevertheless, several studies have reported that bats can collide with large stationary objects (Orbach and Fenton, 2010; Greif et al., 2017; Tanalgo et al., 2025). Smooth vertical surfaces may function as ecological traps, as bats can perceive tilted smooth vertical plates as open flyways (Greif et al., 2017). This is a plausible explanation for the bycatch observed in FI traps (Holzinger et al., 2023), but it does not account for the captures in MF traps. An alternative explanation is that bats are attracted to insects resting on the traps, or to the sounds produced by insects trapped within the collectors, and fall into the traps while trying to catch them. A third possibility, specific to MF traps, is that pipistrelles mistake these devices for potential roosting sites, resembling loose bark or bark crevices, which they commonly use for summer roosting (Bat Tree Habitat Key, 2018; Holzinger et al., 2023).

The bat species captured with both trap types are commonly found in French oak forests (Tillon et al., 2016; L. Arthur, pers. comm.). Two additional species, namely *Myotis alcathoe* Helversen & Heller and *Barbastella barbastellus* (Schreber), are also known to occur in the region's forests but were not captured during our survey. FI traps deployed in an Austrian oak forest also caught *M. bechsteinii* and *N. noctula* as well as *M. alcathoe*, *Myotis brandtii* (Eversmann) and *Pipistrellus pygmaeus* (Leach) (Holzinger et al., 2023). In our study, most of

the pipistrelle captures occurred during the maternity and juvenile-rearing period (May to July). During this time, colonies are primarily composed of females, which typically settle in anthropogenic sites such as towns and villages (Mathews et al., 2023). Solitary males, on the other hand, tend to forage in distinct areas, including forests (L. Arthur, pers. obs.), which may explain why they were overwhelmingly predominant in our captures as well as in those reported in Austria (Holzinger et al., 2023). We observed several times two or more bats in the same collector, with a maximum of six female Bechstein's bats caught together. This explains the high standard errors for mean bat catch per trap (figure 2). It is possible that trapped individuals emitted distress calls that attracted conspecifics, especially if a roosting site was in the vicinity (Russ et al., 1998).

Few previous studies have reported bats being captured in FI or MF traps (McLeod et al., 2021; Holzinger et al., 2023). MF traps were originally developed to collect bark beetles (Lindgren, 1983) and have since been widely used across the globe for sampling forest insects. Similarly, FI traps are commonly employed for forest insect monitoring (Bouget et al., 2009). However, these traps are typically placed at ground level, where they might be less likely to interfere with bat flight paths. Nevertheless, some evidence exists that Western long-eared bats (*Myotis evotis* (H. Allen)) have been unintentionally captured in MF traps set in harvested Douglas fir stands (McLeod et al., 2021). Since the introduction of the emerald ash borer (*Agrilus planipennis*, Fairmaire) in North America, GMF traps have been extensively deployed for the detection and monitoring of this invasive pest (Crook et al., 2014; Santoiemma et al., 2024), and it is recommended to place these traps within the tree canopy (Crook et al., 2014), as in our sampling design. This maximizes detection of *A. planipennis*, as newly emerged adults feed and mate in the foliage (Crook et al., 2014). The common pipistrelle is not present in North America but is widely distributed across the Western Palearctic (Mathews et al., 2023). This could explain why, despite the widespread use of MF traps in that region, there have not been reports of large-scale bat captures. The emerald ash borer has also been introduced into Russia and is currently spreading westward through Europe, posing a serious threat to native ash populations (Orlova-Bienkowskaja, 2014; Orlova-Bienkowskaja et al., 2020). In Europe, deploying GMF traps in ash canopies is recommended for the early detection of this pest, allowing for timely implementation of management measures (European Food Safety Authority et al., 2020; Evans et al., 2020; Santoiemma et al., 2024). However, if not properly adapted, these traps could inadvertently cause significant bat mortality, including among species classified as vulnerable in France (e.g., *N. noctula*) or Europe (e.g., *M. bechsteinii*).

The addition of wooden sticks did not prevent bats from falling into the collectors, suggesting that the trap modification proposed by Holzinger et al. (2023) may not be effective in mitigating bat bycatch. However, installing a 13-mm metallic mesh significantly reduced the number of bat captures. Since we did not operate standard and modified traps

simultaneously, out of concern for further bat mortality, we cannot entirely rule out the possibility that the decrease in bat captures observed in 2021 was due to interannual fluctuations in bat populations. However, this explanation appears unlikely, as it would imply a simultaneous population decline across all bat species. Furthermore, as these modified traps have since been used for insect sampling in forest canopies in both France and the United Kingdom, and bat captures have been rarely observed, this supports the conclusion that adding a mesh is an effective measure to reduce incidental bat captures. The mesh did not completely prevent bat captures, and a few individuals still fell into the collectors in 2021. Close examination of these traps suggests that the gap between the mesh and the upper funnel may have been too narrow, preventing bats from escaping and forcing them to pass through the mesh into the collector. Particular care should be taken in positioning the mesh to avoid such issues. Using a finer mesh may further reduce bat captures, though this could also affect trap efficiency for insects. In addition, it may be preferable to use a square mesh rather than a hexagonal one, as bats' forelimbs might get caught in the latter (A. Chrétien, pers. obs.).

Adding a mesh could have reduced both the quantity and diversity of insects captured, particularly larger specimens that may have escaped before falling into the collector (Pearce et al., 2005). Nonetheless, we did not observe any significant reduction in mean species richness associated with mesh installation. Similarly, no significant decrease in average beetle size was found, even among larger taxa such as Cerambycidae and Cetoniinae. Only a decreasing size trend was observed in Cetoniinae. Nonetheless, we did observe a significant decrease in abundance between 2019 and 2021 in some trap types for Cerambycidae and Scolytinae, with a similar trend for Buprestidae. As with bat captures, because standard and modified traps were not used in parallel, we cannot conclusively attribute these reductions to the mesh, especially given the known interannual variability in forest insect populations (e.g., Garnas et al., 2023; Le Souchu et al., 2024b). It is possible though that reduced abundance was due to mesh clogging by leaves, twigs, or other tree debris, which may have blocked insects from reaching the collector, hence more frequent maintenance and monitoring would likely mitigate this issue. BMF traps are commonly used for the biosurveillance of wood-boring insects at points of entry such as ports and airports (Roques et al., 2023). In this context, maximizing the number of individuals captured is crucial, as exotic species are typically detected in very low numbers. Adding a mesh to MF traps may reduce their capture efficiency and, consequently, the likelihood of detecting quarantine or other targeted exotic species.

In conclusion, adding a 13-mm mesh to the funnel just above the collector proved to be a simple and effective modification that reduced bat bycatch without significantly affecting beetle diversity, although it may reduce beetle abundance. We recommend the systematic

modification of traps deployed within the tree canopy, at least within Europe, and urge trap manufacturers to consider this issue in future trap designs.

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