



# How to detect dormice: a comparison of footprint tunnels and camera traps as monitoring methods

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## Abstract

Dormice (Gliridae) are hard to detect, as they are small, nocturnal, often arboreal when active and in or on the ground when hibernating. In Germany, the garden dormouse (*Eliomys quercinus*) and the edible dormouse (*Glis glis*) are afforded special protection by the German Federal Nature Conservation Act, while the hazel dormouse (*Muscardinus avellanarius*) is listed in Annex IV of the EU Habitats Directive and therefore strictly protected under the German Federal Nature Conservation Act. However, information on their exact geographic distribution is still incomplete. Reliable and efficient monitoring methods are therefore needed. The aim of this study was to compare the detection probability of footprint tunnels (FTs) and camera traps (CTs), taking potential effects of season into account. To achieve this, 25 FTs and two CTs were installed across 41 distinct transects and monitored from May until October between 2019 and 2022. CTs and FTs were installed to detect garden dormice, which might have influenced the performance of detection for the other two species. All three species could be detected with both methods. In the edible dormouse detection probabilities of both methods did not differ significantly and ranged around 50% and 70% for CTs and FTs, respectively. For garden dormice CTs had an almost 12 times higher detection probability than FTs, reaching detection probabilities above 90% in July and August. Hazel dormice showed an almost 34 times higher detection probability with FTs compared to CTs, with a detection probability of 95% observed in September. However, the effect of the month was not significant for either of the two methods in the three species. To survey all three dormouse species at a given site, we recommend using a combination of both monitoring methods between July and September. For the detection of garden dormice, we recommend to use CTs during July and August and for hazel dormice FTs in September. Both methods seem to work in edible dormice but showed only moderate detection probabilities.

**Keywords** Small mammals · Gliridae · Specific detection efficiency · Method evaluation

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## Introduction

Like many small mammals, dormice (Gliridae, rodents) lead a cryptic lifestyle and are difficult to detect. They are often arboreal when active and in or on the ground when hibernating. The hazel dormouse (*Muscardinus avellanarius*), the garden dormouse (*Eliomys quercinus*) and the edible dormouse (*Glis glis*) are listed in Appendix III of the Bern Convention. The hazel dormouse is also listed in Annex IV of the EU Habitats Directive 92/43/EEC, which mandates regular monitoring of its geographic distribution and conservation status. Accordingly, in Germany the hazel dormouse is strictly protected, the garden dormouse and the edible dormouse are specially protected under the Federal Nature Conservation Act.

Historically, the garden dormouse originally ranged from Portugal to the Urals, but in the last 20 to 30 years, it has disappeared from more than 50% of its former range, mainly in Central and Eastern Europe, and is now regarded as extinct in many eastern regions (Bivoleanu et al. 2022; Büchner et al. 2023; Bertolino et al. 2024; Cichocki et al. 2024). It is therefore considered to be the fastest declining mammal in Europe and is currently listed as Vulnerable on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Bertolino et al. 2024).

To understand why a certain species is threatened and to determine appropriate conservation measures, information on its geographical distribution and habitat requirements is essential. However, for the three dormouse species mentioned, knowledge about their geographical distribution remain incomplete, and a reliable, efficient monitoring method is therefore needed.

For the hazel dormouse several monitoring methods are recommended. Searching for gnawed hazel nuts and nests, checking nest boxes and nest tubes represent the standard monitoring methods used to detect hazel dormice in Europe (Bright et al. 1996, 2006; Juškaitis 1997; Chanin and Woods 2003; Büchner et al. 2009; Chanin and Gubert 2011). Nest tubes are today a preferred method because they are much cheaper and easier to install than nest boxes (Chanin and Woods 2003; Bright et al. 2006; Melcore et al. 2020). For this, either an area is equipped with about 20 nest tubes per hectare in a grid pattern, or they are set every 20 m along linear habitats such as hedgerows. Monitoring occurs monthly from May to October, and both direct observation of a dormouse and the presence of its characteristic nest within a tube are considered reliable records (Chanin and Woods 2003).

Footprint tunnels (FTs) are non-invasive survey tools used to detect the presence of small mammals by recording their footprints. They consist of a board mounted with a thick paper within a tube and two ink pads located at both

ends of the tube. Animals that walk over these ink pads leave their species-specific footprints on the paper, revealing the local wildlife. FTs have been proposed to detect and monitor dormice (Haag and Tester 2016; Mills et al. 2016). Previous studies have systematically compared the detection probabilities of nest boxes, nest tubes and FTs for all three species in an alpine habitat (Melcore et al. 2020), and for the hazel dormouse in England (Bullion et al. 2021). These studies suggested that FTs have a higher detection probability compared to nest tubes or boxes in all three species. Garden dormice were detected exclusively via FTs, but not by the other two methods (Melcore et al. 2020).

Nest boxes and nest tubes rely on dormice selecting them as nesting sites, with detection based on direct observation or identification of species-specific nests. In contrast, FTs record species-specific footprints left in the tunnel by individuals passing through it. Therefore, a single pass through a FT can confirm a species' presence, which may explain the higher detection probability of this method. In addition to their high detection probability, FTs are comparatively inexpensive, allowing large areas to be surveyed, which makes them suitable for monitoring species that occur at low population densities. However, the deployment of the FTs is time consuming, the ink pads need to be topped up regularly, and training is required to identify footprints of the different species, especially when prints are numerous or overlapping. Thus, for this method to be used in citizen science projects, it must be closely supported and supervised by experts. In the future automated footprint recognition by AI, could further enhance their feasibility not only for citizen science monitoring (Büchner et al. 2023; Sheard et al. 2024).

The detection of small mammals by using camera traps (CT) raises several challenges. Due to their fast movements and small body size, they may not trigger the sensors of the CT or depending on the reaction time of the specific camera, the picture is taken after the animal has passed. Often, small mammals do not have distinct features, which makes them difficult to identify by pictures. Optimally, for the identification of small mammals they need to be photographed in close range and have to be in focus, not obscured by vegetation. To optimize detection probabilities of small mammals, high-resolution CTs can be attached to tunnels, boxes, or put into containers like buckets, with bait located in front of the lens, where the animal is in focus (Soininen et al. 2015; Gracanin et al. 2019; Littlewood et al. 2021; Porter and Dueser 2024). Despite all these challenges and with the help of these improvements, the utilization of camera trapping has proven effective for non-invasive small mammal surveys (e.g. Kelly 2008; De Bondi et al. 2010; Glen et al. 2013; Rendall et al. 2014). Additionally, the three dormouse species studied here have distinctive features that make them identifiable, even from partial images (e.g. of the tail

or head), without the need for expert analysis. Studies monitoring small and arboreal mammals showed they can potentially be detected by using CTs (Di Cerbo and Biancardi 2013; Mills et al. 2016; Mori et al. 2020; Randler and Kalb 2021; Büchner et al. 2023; Queckenstedt et al. 2024). CTs are easy to install and can also yield records and information on other wildlife species, making them well suited for citizen science projects. However, their relatively high cost limits the number of sites that can be monitored simultaneously, which may be problematic for species occurring in low population densities, such as the hazel dormouse.

The aim of this study was to compare the detection probabilities of FTs and CTs for edible dormice, garden dormice and hazel dormice in forest habitats, considering seasonal effects on the detection probability. To this end, we monitored transects in Germany between 2019 and 2022, where FTs and CTs were deployed simultaneously in areas with confirmed presence of either species. However, the study was conducted as part of a national biodiversity project “In Search of the Garden Dormouse” (Büchner et al. 2023). Therefore, CTs and FTs were set with a focus to detect garden dormice.

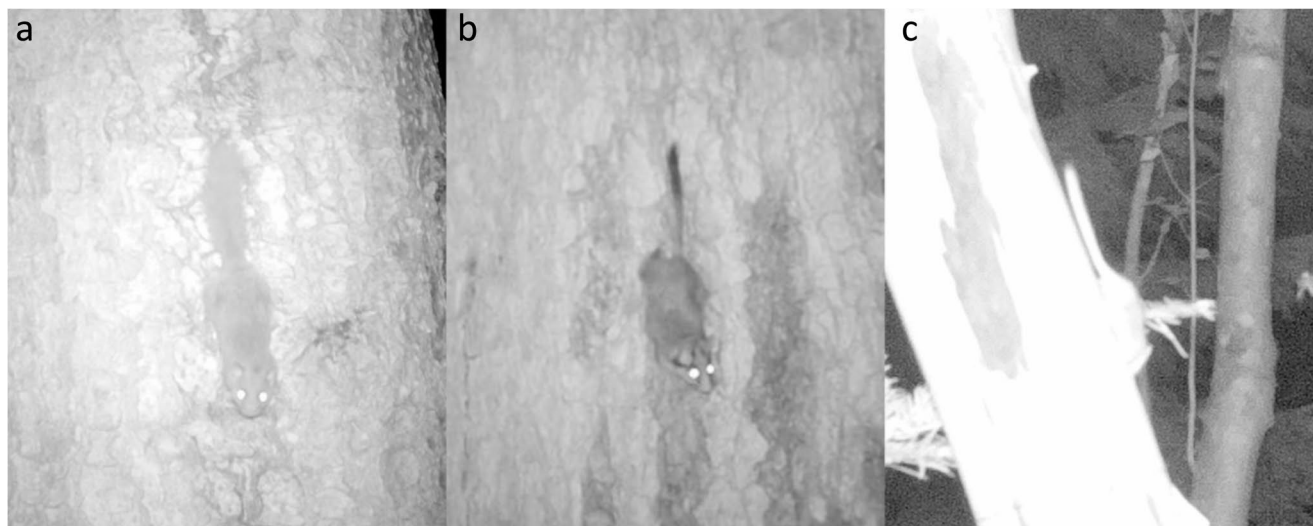
## Materials and methods

### Study species

#### Edible dormouse

The arboreal edible dormouse (*Glis glis*) is with 100 to 230 g the largest of the three dormouse species studied here and can be easily distinguished from the other two species

by their grey fur and bushy tail (Fig. 1a). In Central Europe, it preferentially occurs in deciduous mixed forests dominated by the European beech (*Fagus sylvatica*), where it can reach population densities of up to 30 Ind/ha (Schlund 2005c). Edible dormice have an extremely long hibernation period of at least 8 months (Fietz et al. 2020). In Germany adult edible dormice hibernate from mid-September until the end of May, whereas juveniles can be active until the end of October. Due to their long hibernation period, the surveying window in edible dormice is shorter than in the other two dormouse species of this study. Reproduction is synchronized with the masting pattern of beeches and oaks (*Quercus spp.*), and edible dormice skip reproduction in years of mast failure and may extend their hibernation period by up to 11 months (Ruf et al. 2006; Hoelzl et al. 2015). Males emerge from hibernation about two weeks before the females, and mating takes place shortly after females become active (Fietz et al. 2020). In Germany, females give birth to one litter per year with about 5 (up to 11) juveniles that are weaned after 30 days (Vietinghoff-Riesch 1960). Edible dormice are foraging mainly in tree crowns and bushes. In adults the print of the front paw is up to 15 mm long and 10 mm wide and the drop-shaped pads are arranged in a circle looking like a suction pad. Also, the pads of the hind paw are arranged in a circle (Suppl. Fig. 1). But not only the shape of the single footprints, also their pattern on the paper of the FTs is characteristic. Because of their large body size, compared to the other dormouse species, the prints are mostly located at the edges of the long side of the paper, like two lanes on a road, and the suction pads with the drop-shaped pads are in most cases easily recognizable (Suppl. Fig. 2).



**Fig. 1** Pictures taken with a wildlife camera of **a** the edible dormouse (*Glis glis*), which can be identified by its bushy tail, **b** garden dormouse (*Eliomys quercinus*), identified by its characteristic face mask and short haired black tail with a white terminal tassel (sources: Rieke

Vorderbrügge) and **c** hazel dormouse (*Muscardinus avellanarius*), identified by the short haired tail without a tassel (source: Stefanie Erhardt)

## Garden dormouse

Garden dormice have a body mass between 60 and 110 g. Characteristic traits which distinguish the garden dormouse from the other two species studied here are a black face mask, relatively large ears and a short haired black tail with a white terminal tassel (Fig. 1b). One main habitat in Central Europe are coniferous mixed forests (Bertolino 2017), where they forage mainly on the ground and use nesting sites in ground holes and rock crevices (Bertolino et al. 2003; Vaterlaus-Schlegel 1998). The species also occurs in urban areas in some regions. Occurrence and length of the hibernation period depend on the geographical location and the habitat. In forests in Central Europe, hibernation lasts from October until April, whereas in the Mediterranean region garden dormice remain active throughout winter (Moreno 1988; Vaterlaus-Schlegel 1998; Bertolino et al. 2001; Erhardt et al. 2025). Reproduction starts directly after hibernation. Females give birth after 23 days, with litters averaging 4–6 young, which are weaned after 34–36 days (Vaterlaus-Schlegel 1998; Schlund 2005a). Depending on the habitat, garden dormice occur in population densities between 2.7 and 5.5 individuals/ha (Schlund 2005a). Footprints of garden dormice are quite characteristic and can hardly be confused with footprints of hazel dormice, which are much smaller and those of an adult edible dormouse which are larger (Suppl. Fig. 1). In adults, the print of the front paw is maximally 10 mm long and 9 mm wide. The front pads of the front paw are close together and the prints often look like being connected with each other. The print of the hind paw is 18 mm long. However, the print of the heel pad is in most cases missing (Suppl. Fig. 1). In the garden dormouse, the footprints are often spread all over the paper of the FT, as they seem to enter the FT several times and turn around inside the tunnel. In most cases, the print of the front paw can be detected (Suppl. Fig. 2).

## Hazel dormouse

The hazel dormouse (*Muscardinus avellanarius*) has a body mass of 20 to 40 g. It is the smallest of the three dormouse species studied and in contrast to the other two species it has a short haired tail without a tassel (Fig. 1c) and compared to *Apodemus* species shorter ears. It inhabits mixed deciduous forests with rich understory fractions (Schlund 2005b; Juskaitis and Büchner 2010). In Central and Northern Europe, the hazel dormouse hibernates from October/November until April, hibernation is considerably shorter in Mediterranean habitats (Juskaitis and Büchner 2010). During the active season, they are mainly arboreal. Population densities are comparatively low and reach values of 0.5–3 individuals/ha, in optimal habitats they can reach 4–10 individuals/ha (Juskaitis and Büchner 2010). In adults the front paws are smaller than

10 mm and the inner hind pad of the front paw is missing. The pads of the front and the hind paw have a triangular shape and the pads of the toes are often separated, looking like two prints per toe. The pads of the hind paw are arranged in a  $\frac{3}{4}$  circle (Suppl. Figs. 1 and 2). In the hazel dormouse, the prints look very delicate and sometimes there are only very few prints (2–3) on the paper. If there are multiple prints, they often form patches when the dormouse enters the FT several times and turns around inside of the tunnel. The triangular-shaped pads are usually visible at first glance (Suppl. Fig. 2).

## Study sites

Altogether, 41 transects were monitored across Germany between June and October in the years 2019 to 2022. Of these, 39 were located in forest habitats, one on a mixed meadow-forest area, and one in a quarry (Suppl. Table 1).

## Transects and monitoring methods

The study was conducted as part of a national biodiversity project “In Search of the Garden Dormouse” (Büchner et al. 2023). Therefore, CTs and FTs were set with a focus to detect garden dormice.

Transects consisted of 25 FTs (400×60×60 mm). A suspension of charcoal powder in sunflower oil was used as ink. On each transect, FTs were placed 25 m apart and fixed underneath branches of shrubs or trees at 0.7 to 1.5 m above ground (for details see Haag and Tester 2016; Mills et al. 2016). In addition, wildlife cameras (DTC550, MINOX GmbH, Germany) were installed at the beginning and end of each transect in 25 m from the last FT at the same height (for details see Mills et al. 2016). We used a cotton cloth (100×100 mm) soaked with pumpkin seed or walnut oil as a bait, which was fixed at 1–4 m from the camera. Cameras were programmed to take three pictures in a row followed by a refractory period of 60 s. Ink pads of FTs were replenished after 2 weeks of exposure and paper replaced if needed because of humidity or gnaw marks. CTs and FTs of the transects were checked for photos and footprints after 3–4 weeks of exposure. In transects that were monitored for several months, FTs were replaced in 2 m distance at the beginning of each month. Dormice are known to use scent marks on frequently used trails. By replacing FTs, we wanted to avoid an increase of the detection frequency due to the use of scent trails.

## Statistical analyses

Only transects where the presence of the respective species was confirmed at least once were included, so that detection probabilities could be compared between CTs and FTs conditional on the species being present. For 9 transects the

presence of the garden dormouse was verified and each transect was checked 5 times. The edible dormouse was known to be present at 21 transects (17 transects were checked once, two transects were checked 5 times, two transects twice). The hazel dormouse was present on 19 transects (13 transects were checked once, 4 transects were checked 5 times, one transect 4 times, one transect twice).

Data for CTs and FTs was aggregated for each month on a transect level. Thus, the number of FTs with footprints or the number of records taken with both cameras were not considered in our analyses. Detection probabilities of the two methods were analysed with binomial GLMMs with a logit link function separately for all three species, taking possible effects of month (3 to 5 levels) and method (2 levels: CT and FT) into account. The detection probabilities of the two methods for each species were also compared separately among months using a GLMM. For all models transect ID was included as random factor. Models were checked for under- and overdispersion using “DHARMA” (Hartig 2024).

Mixed-effects models were implemented using “lme4” (Bates et al. 2015). The Tukey test was used for post-hoc comparisons between months.

Model predictions were obtained from the GLMM as estimated marginal means (EMMs) with 95% confidence intervals (CI) using “emmeans” (Lenth 2021). Estimates were back-transformed to the probability scale (type = “response”) and visualized using “ggplot2” (Wickham 2011). Statistical significance was defined as  $p < 0.05$ . Significance levels are indicated as follows: \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ , ns:  $p \geq 0.1$ .

Statistical analyses were performed in R (R Development Core Team 2020) with the graphical User Interface R Studio (Posit team 2025).

## Results

### Edible dormouse

The edible dormouse could be recorded with both monitoring methods between July and September. As only two transects were surveyed in June and October and any dormice could be detected, these two months were omitted from the final analysis.

Detection probabilities ranged between 50.0% (CI: 19.0–81.1%) and 52.5% (CI: 22.2–81.0%) for CTs and between 68.5% (CI: 32.9–90.6%) and 70.6% (CI: 36.2–91.0%) for FTs (Suppl. Table 2). Detection probabilities did not significantly differ among the two monitoring methods (GLMM:  $p > 0.2$ ; Table 1; Fig. 2) and among months (Tukey post-hoc test:  $p > 0.7$ , Fig. 4).

**Table 1** Results of the generalized linear model (record ~ month + method + (1|ID<sub>transect</sub>), family = “binomial”), explaining the effect of month and method (CT and FT) on the detection probability in edible dormice ( $n_{\text{observations}} = 54$ ,  $n_{\text{transects}} = 21$ ;  $n_{\text{observations}}$ : number of methods x number of sampling occasions x number of transects). Reference level is the month<sub>July</sub>, method<sub>FT</sub>

	Estimate	Std. Error	z	p	Sign.
Intercept	0.876	0.735	1.19	0.23	ns
Month <sub>August</sub>	-0.097	0.887	-0.11	0.91	ns
Month <sub>September</sub>	-0.013	0.830	-0.02	0.99	ns
Method <sub>CT</sub>	-0.777	0.639	-1.21	0.22	ns

### Garden dormouse

Garden dormice could be recorded with both methods between June and September. In October, they could not be detected with either method. We therefore restricted the comparative analyses to the months June until September.

Overall, the detection probability with CTs was nearly 12 times higher than with FTs (GLMM,  $p < 0.001$ ; Table 2; Fig. 3). Detection probability with CTs was highest in July and August with a predicted detection probability of 92.7% (CI: 73.5–98.3%) and 90.1% (CI: 67.8–97.5%), respectively (Suppl. Table 3).

Detection probability with FTs was also highest in July and August with 51.7% (CI: 24.6–77.9%) and 43.2% (CI: 19.0–71.2%; Suppl. Table 3), respectively. For both methods detection probabilities did not differ significantly among months (Tukey post-hoc test:  $p > 0.4$ ).

### Hazel dormouse

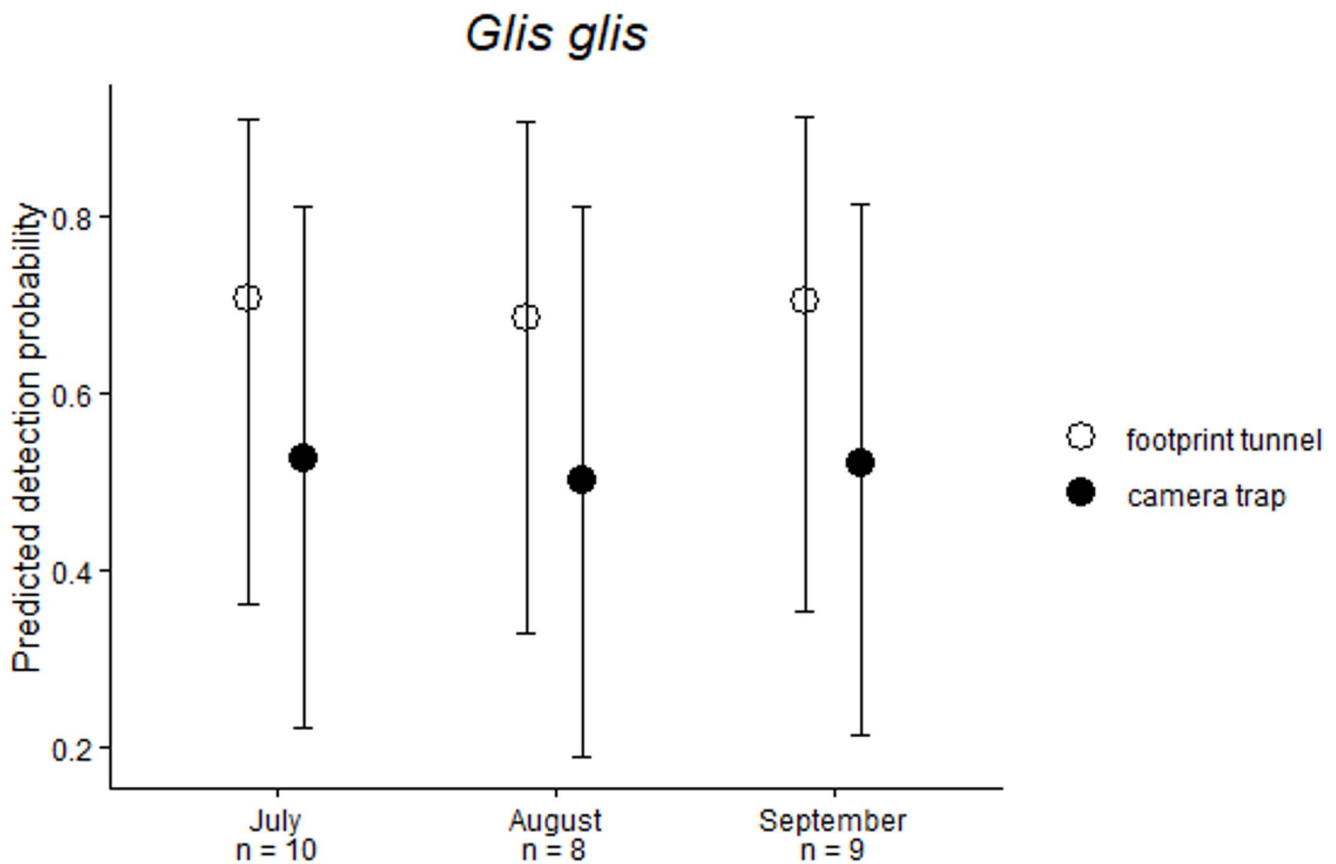
The hazel dormouse could be detected with both methods. However, with FTs hazel dormice could be detected within a longer time frame than with CTs and FTs had also a 34 times higher predicted detection probability than CTs (GLMM,  $p < 0.001$ ; Table 3; Fig. 4).

With FTs hazel dormice could be detected between June and October, with detection probabilities ranging between 19.4% (CI: 1.7–76.7%) in June and 94.8% (CI: 64.2–99.5%) in September (Fig. 4).

With CTs hazel dormice could only be detected between August and October with predicted detection probabilities ranging between 5.5% (CI: 0.8–30.9%) in August and 34.9% (CI: 10.7–70.6%) in September (Suppl. Table 4).

## Discussion

The present study was conducted as part of the national biodiversity project “In Search of the Garden Dormouse”. CTs and FTs were set with a focus to primarily detect garden



**Fig. 2** Predicted detection probabilities with 95% CIs for edible dormice (*Glis glis*) per month with camera traps (black circles) and footprint tunnels (white circles), number of transects checked are given

**Table 2** Results of the generalized linear model (record ~ month + method + (1|ID<sub>transect</sub>), family = “binomial”), explaining the effect of month and method (CT and FT) on the detection probability in garden dormice ( $n_{\text{observations}}=72$ ,  $n_{\text{transects}}=9$ ;  $n_{\text{observations}}$ : number of methods x number of sampling occasions x number of transects). Reference level is the month<sub>June</sub>, method<sub>FT</sub>

	Estimate	Std. Error	z	p	Sign.
Intercept	-2.208	0.745	-2.96	<0.01	**
Month <sub>July</sub>	2.276	0.892	2.55	0.01	*
Month <sub>August</sub>	1.936	0.869	2.23	0.02	*
Month <sub>September</sub>	0.648	0.813	0.80	0.43	ns
Method <sub>CT</sub>	2.248	0.644	3.85	<0.001	***

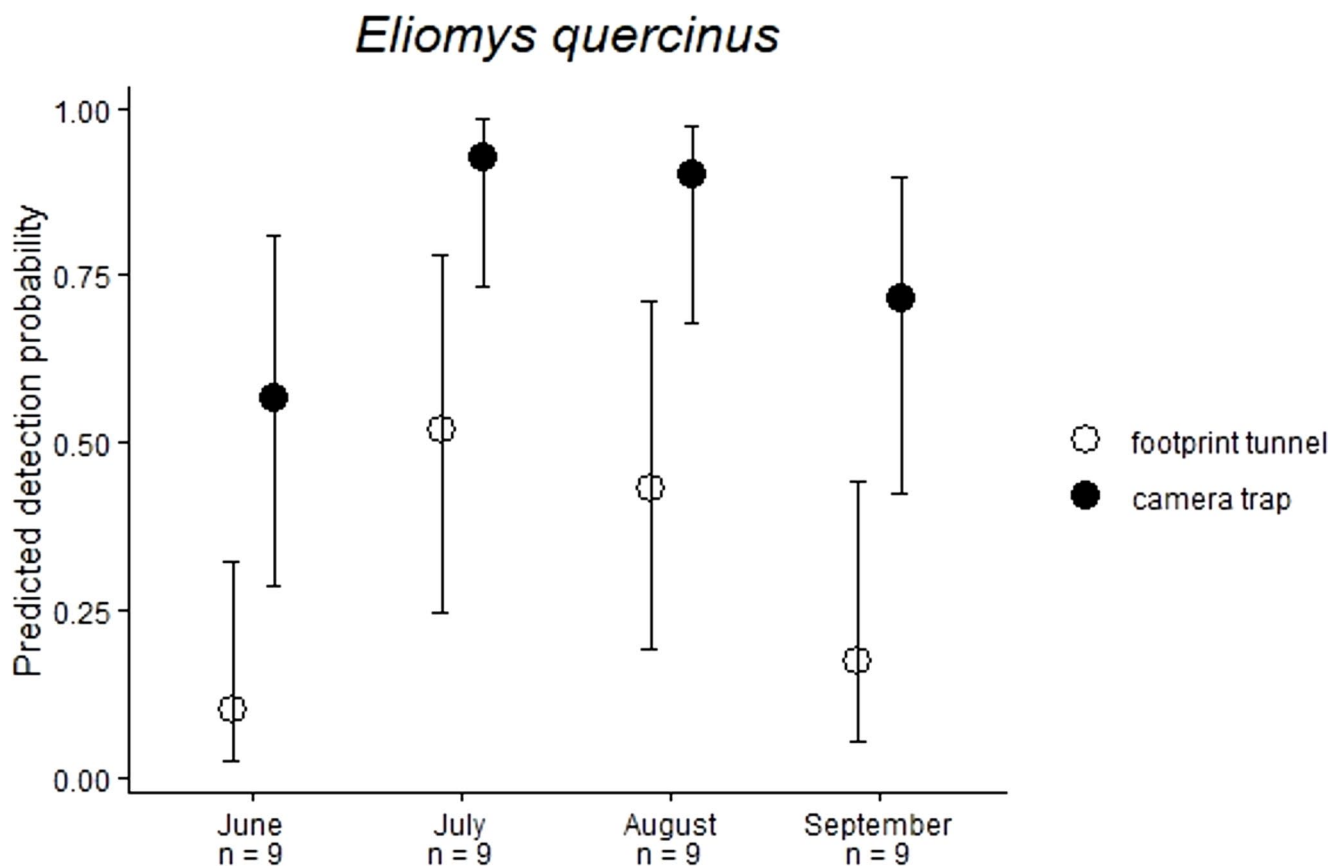
dormice. In this study we, for the first time, systematically compared the detection probabilities of FTs and CTs for garden dormice, edible dormice and hazel dormice, taking seasonal variations into account. Because of their small size, nocturnality, and predominantly arboreal activity, dormice lead a cryptic lifestyle and can be difficult to detect. Consequently, suitable and efficient monitoring methods are required. Previous studies have shown that FTs have a higher detection probability than nest tubes or nest boxes for all three dormouse species investigated in this study (Melcore et al. 2020; Bullion et al. 2021). However, all three

dormouse species can potentially also be detected with CTs (Di Cerbo and Biancardi 2013; Mori et al. 2020; Randler and Kalb 2021; Büchner et al. 2023; Queckenstedt et al. 2024).

### Edible dormouse

Edible dormice could not be detected in June and October with either of the two methods. This short time frame can be explained by their long hibernation period. In Germany, edible dormice emerge during June and adults start hibernation in September, whereas juveniles can be active until the end of October (Fietz et al. 2020). Thus, in edible dormice the survey window is shorter than in the other two dormouse species.

In our study, both methods showed only moderate detection probabilities for edible dormice ranging between 50.0 and 52.5% for CTs and 68.5 and 70.6% for FTs. Detection probabilities with FTs of this study are comparable to values found in the study by Melcore et al. (2020) with 52%. This suggests that the setting of the FT with the aim to detect garden dormice, did not influence the detection rate. As also CTs were directed to places where garden dormice can be expected, the detection rate of the CT for edible dormice



**Fig. 3** Predicted detection probabilities with 95% CIs for garden dormice (*Eliomys quercinus*) per month with camera traps (black circles) and footprint tunnels (white circles), number of transects checked are given

**Table 3** Results of the generalized linear mixed effects model (record ~month+method+(1|ID<sub>transect</sub>), family = “binomial”), explaining the effect of month and method (CT and FT) on the detection probability in hazel dormice ( $n_{\text{observations}}=78$ ,  $n_{\text{transects}}=19$ ;  $n_{\text{observations}}$ : number of methods x number of sampling occasions x number of transects). Reference level is the month<sub>June</sub>, method<sub>FT</sub>

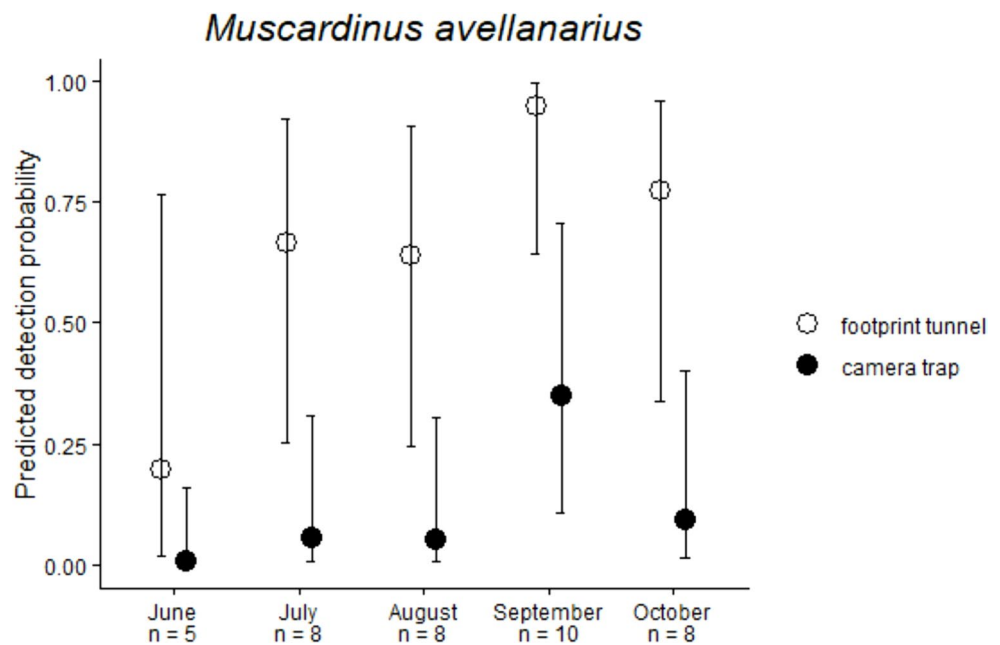
	Estimate	Std. Error	z	p	Sign.
Intercept	-1.422	1.332	-1.07	0.29	ns
Month <sub>July</sub>	2.116	1.561	1.36	0.18	ns
Month <sub>August</sub>	1.999	1.528	1.31	0.19	ns
Month <sub>September</sub>	4.336	1.748	2.48	<0.01	**
month <sub>October</sub>	2.653	1.600	1.66	0.10	ns
Method <sub>CT</sub>	-3.537	1.030	-3.43	<0.001	***

might be underestimated. However, as we used aromatic oil as bait, we assume that this should not play a major role. Both methods work for the species, however, acoustic surveys using the typical squeaks and churring calls of edible dormice (Hoodless and Morris 1993; Rodolfi 1994; Jurczyszyn 1995) may be a better choice for mapping the species on a larger scale. Adamik et al. (2019) could show, that the acoustic survey carried out from July to September represents an efficient mapping tool, which could also be conducted by citizen scientists.

### Garden dormouse

As Melcore et al. (2020) highlighted, garden dormice are generally detected with FTs but not with nest tubes or boxes. The systematic comparison of the detection probabilities of FTs and CTs for garden dormice revealed, that CTs had an almost 12 times higher detection probability than FTs. Detection probabilities reached values above 90% in July and August. Garden dormice have a characteristic tail and a face mask, which make this species easy to identify in pictures even if only part of the body is visible. Thus, in forest habitats for garden dormice the method of choice seems to be the use of CTs set out at the end of summer baited with an aromatic oil for about 4 weeks. In contrast to our findings in forests, garden dormice could not be detected with FTs in urban areas (Nava et al. unpublished data). However, systematic acoustic surveys, using the characteristic calls of the garden dormouse, were shown to work well in urban areas (Nava et al. 2024) but did not work in the forest, where dormice hardly call (Erhardt pers. observation). Thus, the method of choice depends on the habitat, which was not investigated in this study.

**Fig. 4** Predicted detection probabilities with 95% CIs for garden dormice (*Muscardinus avellanarius*) per month with camera traps (black circles) and footprint tunnels (white circles), number of transects checked are given



Footprints of garden dormice are quite characteristic. However, footprints of garden dormice can potentially be confused with footprints of juvenile edible dormice. Edible dormice are born from the end of July until the beginning of August and become independent at the end of August or early September with an age of four weeks. Thus, as long as the FTs are set out in August, the chance to confuse their footprints with those of juvenile edible dormice is negligible, as they are not weaned at this time of the year (Fietz et al. 2009). Furthermore, edible dormice synchronize their reproduction with the seed production of beeches and oaks. Thus, in years of mast failure no edible dormouse juveniles are born (Ruf et al. 2006).

### Hazel dormouse

In previous studies it has already been shown, that FTs have a ten times higher detection probability than nest tubes or nest boxes for different habitats such as hedge, forest and bushes (Bullion et al. 2021) or in the Italian Alps (Melcore et al. 2020). In our study, we further showed that FTs have a 34 times higher detection probability than CTs. With the latter hazel dormice could only be detected during part of their activity period and with comparatively low detection probabilities. Footprints of hazel dormice are distinctive. Therefore, with some experience and knowledge, their footprints cannot be confused with those of other dormice or small mammal species. In contrast to the detection with CTs, hazel dormice could be detected with FTs from June until October reaching the highest detection probability in September (95%). Even though the monthly detection

probabilities did not vary significantly, the high probability of detecting hazel dormice in September can be explained by their reproduction cycle which has a second peak during this time and therefore population densities are highest (Juskaitis and Büchner 2010). As already mentioned above, the CTs were directed to places where garden dormice can be expected. This likely reduced the chance to detect hazel dormice which forage in dense vegetation and use small branches for traveling (Juskaitis and Büchner 2010). However, high detection probabilities of 95% during September do not support this apprehension. Furthermore, setting the CTs into dense vegetation where the probability of encountering hazel dormice should be higher, would probably lead to low quality pictures where the dormouse cannot be identified. Multiple false releases of the CT caused by moving branches in the wind may produce thousands of pictures, which is extremely time consuming in the analysis. Because of their small body size, the quality of the picture has to be good for reliable proof. To achieve standardized high-quality pictures of small mammals in general and to avoid false triggering by moving vegetation, the setup of the CT can be modified. Of the three species investigated here, hazel dormice have the lowest population densities varying between 0.5 and 3 individual/ha (Juskaitis and Büchner 2010) and using only two cameras could be not enough for a species with such low population densities. Despite the high detection probability of hazel dormice with FTs, as shown by the present and previous studies (Bullion et al. 2021; Melcore et al. 2020), the method is unfortunately not yet recognized as a standard method and not commonly used in the context for survey and monitoring purposes.

## Camera traps

This technique is non-invasive and does not require investment of a great deal of time on the part of the surveyor. In addition, it provides relatively unambiguous, permanent records for species that are difficult to observe (pers. observation). CTs represent therefore a suitable monitoring method also for citizen science projects. However, equipment failure and user error can pose significant challenges, and initial expense limits the number of spots that can be monitored (Cutler and Swann 1999; Silveira et al. 2003). This is problematic for species occurring in low densities such as the hazel dormouse. In most countries of the European Union, the use of cameras in public areas is restricted and national laws may limit or prohibit the use of wildlife cameras in these areas or lead to the need for permissions and the installation of a warning sign. Another disadvantage is the number of pictures taken by the camera. Depending on where the CT is installed, you may get huge numbers of false detections and pictures caused by moving vegetation, moving shadows or precipitation. The analysis of these pictures is time intensive, however, in the future the invested time could potentially be reduced by the use of AI, trained to recognize certain species (Kissling et al. 2024). To make the use of CTs more efficient, we suggest using aromatic oil as bait, as we did in our study.

## Footprint tunnels

In contrast to CTs, FTs are comparatively cheap and you can therefore potentially equip a large area with them. Although you need to ask the landowner for permission to install them, you do not require official approval due to privacy concerns or for capturing wild animals. However, the mounting of the FTs is time consuming, and you need time and training to analyze and identify the footprints of the different species. Therefore, this method cannot easily be applied in citizen science projects. Furthermore, footprints may be difficult to identify, if they are numerous and overlapping. This is particularly a problem in years of high population densities in mice. In these instances, you could reduce the time exposed of the FTs and increase the frequency of checking the FTs and install them in the vegetation, where the number of mice is lower than on the ground. Another problem may occur when under dry and hot conditions the charcoal-oil mixture loses its capacity as ink pad more quickly. A time-consuming substitution in the field could be the consequence.

Thus, both methods have advantages and disadvantages, and the method of choice depends on the species, season, and other conditions, such as habitat and if the study is conducted by experts or by citizen scientists.

When focusing on the detection of hazel dormice, in our view the use of FTs seems to represent the most efficient and effective method compared to other monitoring methods investigated so far and supports the results of previous studies (Bullion et al. 2021; Melcore et al. 2020). Highest detection probabilities occurred at the end of the summer when population density has increased due to the appearance of weaned juveniles. In contrast, CTs represent the method of choice for garden dormice, having the highest detection probabilities in July and August. There was no difference in the detection probabilities of the two methods for edible dormice with only moderate detection probabilities.

The study shows that the efficiency of the different monitoring methods varies among the three species investigated. We therefore suggest using a combination of both monitoring methods between July and September, if you aim to monitor all three dormouse species at a certain spot.

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**Author contributions** JF designed the study, collected and analysed the data and wrote the manuscript. SB, SBü and JL designed the study and collected data. FL and SE collected data and prepared the figures. TFN, HB, UW, EK, AG, AK, JS, SS, CT-B collected data. All authors reviewed the manuscript.

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**Data availability** The dataset used in the current study is available from the corresponding author on request.

## Declarations

**Consent for publication** All authors have read, commented on and approved the manuscript.

**Competing interests** The authors declare no competing interests.

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