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RESEARCH PAPER

Comparing the performance of two camera trap-based methods to survey small mustelids

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ABSTRACT

Small mustelids are an understudied group partly due to the challenges in detecting and monitoring their populations. Despite the classification as Least Concern for several small mustelid species, some studies indicate a population decline in parts of their range. Therefore, efficient and group-specific methods are essential to support monitoring efforts. Camera traps are widely used, particularly to monitor cryptic and nocturnal species such as most carnivores. However, they tend to miss small-sized and fast-moving species due to the sensitivity of the passive infrared sensor. The *Mostela* is a device which consists of a camera trap and a tracking tunnel inside a wooden box, designed specifically to detect small mustelids. Here, we propose testing the performance of this device and comparing it to a tree-mounted camera trap, using the least weasel (*M. nivalis*) as a case study. We used multi-scale occupancy models to estimate differences in the detection probability between devices. Although both methods detected the least weasel, the detection probability was higher with the *Mostela* (0.8, BCI: 0.52–0.97 vs 0.2, BCI: 0.03–0.48). Furthermore, we obtained a higher trapping rate when using a shorter distance between sampling stations (~350 m). Although the *Mostela* performed better at detecting the weasel, the number of independent events was low ($N = 11$). Therefore, we present recommendations in terms of deployment and future research since the development and testing of new methods are essential for the conservation efforts of small mustelids.

Introduction

Small carnivore species are often understudied despite a higher proportion of them being classified as threatened by the International Union for Conservation of Nature (IUCN) than larger carnivore species (Marneweck et al., 2021). In fact, Marneweck et al. (2022) suggested that small carnivores are a more suitable group as sentinel species for global change due to the intrinsic biological and ecological traits of these species. The Mustelidae family, the largest in the order Carnivora, includes species that vary widely in size, behavior and life-history traits, enabling these species to occupy all types of climates and habitats (Wright et al., 2022). However, this also translates into a wide range of conservation status assessments, with some mustelid species well-studied in terms of the threats they face (e.g., Eurasian otter *Lutra lutra* (Yoxon & Yoxon, 2019), black-footed ferret *Mustela nigripes* (Biggins et al., 2011)), while for others, particularly the smaller mustelids, much remains unknown (Bischof et al., 2014; Bright, 2000). Most mustelids are globally assessed as Least Concern by the IUCN, but this is partly related to the species' wide geographic range that often spans entire continents (Wright et al., 2022). However, local and national density estimates and occupancy trends might be very different (Sainsbury et al., 2019), and the insufficient evidence of decline (Hellstedt et al., 2006; McDonald & Harris, 1999) could mean these species are in danger of extinction, without us realizing (Wright et al., 2022).

The challenges in monitoring small mustelids (Croose & Carter, 2019; King et al., 2007) are partly responsible for the lack of knowledge regarding population trends and threats to these species but also for the difficulty in evaluating control efforts in non-native areas (e.g., New Zealand – e.g., King (2017)) where small mustelids are invasive and considered pests. Overall, these species tend to be very cryptic and have secretive habits that make direct observations difficult (King et al., 2007). Although live-trapping is successful in detecting small mustelids,

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either neophobia, trap avoidance and/or resistance to recapture can influence the individual's usual behavior causing biases in the results (King et al., 2007). Also, as a labor-intensive, costly, and invasive method, live-trapping is not adequate for large-scale and/or long-term monitoring. Alternatively, by taking advantage of the species' small size and ability to enter small burrows (Mougeot et al., 2020), researchers have extensively and successfully used tracking tunnels to monitor small mustelids (Graham, 2002; King & Edgar, 1977). Nonetheless, the same limitations related to labor and cost persist; moreover, identifying tracks can be challenging and error prone (García & Mateos, 2009; Westra, 2019), and the lack of individual identification makes it difficult to estimate population density.

Camera traps are now widely used to monitor wildlife, particularly cryptic, nocturnal species such as most carnivores (McCallum, 2013). These devices have a passive-infrared sensor that triggers when it detects a difference in surface temperature (e.g., due to an animal passing through the field of view) and records the event (Welbourne et al., 2016). In this case, it is possible to confirm the species detected with little error. However, camera traps tend to miss small-sized and fast-moving species due to the sensitivity of the passive-infrared sensor (Glen et al., 2013). Therefore, it is necessary to ally the systematic monitoring methodologies already available with new approaches (Bencatel et al., 2018) to target specific species or groups. The Small Mustelid Foundation (https://stichtingkleinemarters.nl/en/what-we-do/) developed the *Mostela* trapping device (Mos & Hofmeester, 2020), a non-invasive method to detect and monitor weasels and stoats. This device combines a regular camera trap with a footprint tracking tunnel inside a wooden box. The camera trap increases the identification possibilities while assuring a high detection rate comparable to studies using only tracking tunnels (Mos & Hofmeester, 2020). Mos and Hofmeester (2020) provide more details on this method.

Here, we propose to test the performance of the *Mostela* using the least weasel (*M. nivalis*) as a case study. The least weasel is a small carnivore and the smallest mustelid in Europe. This species has a vast distribution worldwide and can be found from North America to Europe, being introduced in some islands (McDonald et al., 2019; Rodrigues et al., 2017). The weasel is considered a specialist predator (Andersson & Erlinge, 1977) with a relevant ecological role as a regulator of rodent populations (Hanski et al., 2001). The survival and reproduction of the least weasel appear to closely depend on rodent availability, especially for females during spring (King & Powell, 2010), as populations exhibit cyclic fluctuations related to rodent's peak of abundance (Mougeot et al., 2019). The size of the weasel's home range also seems to vary with prey density, as wide home ranges are related to low prey abundance (Brandt & Lambin, 2007; Macdonald et al., 2004) and the species habitat preferences are influenced by the availability of adequate shelter and food resources. As a small carnivore, avoidance of larger predators, both terrestrial and aerial, requires dense vegetation cover (Brandt & Lambin, 2005; Zub et al., 2008). Also, weasels tend to use the habitat's linear features both as hunting grounds and for moving through the landscape (Macdonald et al., 2004). Despite the species' vast distribution, some authors argue that populations are declining, especially in Europe (Sainsbury et al., 2019; Torre et al., 2018). Its small size and preference for dense vegetation (Schneider et al., 2012) make direct sightings and encountering field signs difficult, which combined with the cyclicity of population density results in a largely understudied species.

To properly monitor small mustelid populations such as the least weasel, new group/species-specific methods must be employed and tested in different landscapes and population contexts to inform research and monitoring efforts. So far, and to our knowledge, the *Mostela* was successfully tested in the Netherlands (Mos & Hofmeester, 2020; Westra, 2019), in Ireland (Croose et al., 2022) and in England (Croose & Carter, 2019). Here, we aim to test the performance of the *Mostela* to detect the least weasel in a Mediterranean agroforestry landscape and compare its efficiency, in terms of detection probability, to tree-mounted camera traps (hereafter tree-camera). Furthermore, we compare the performance of the *Mostela* using two sampling designs to make recommendations in terms of the deployment of these boxes. We expect the *Mostela* to have a higher detection probability of the least weasel when compared to tree-cameras, given the design of the *Mostela* is specific to detect small mustelids and it performed well in other study areas (Croose & Carter, 2019; Mos & Hofmeester, 2020). Also, we expect the distance between sampling stations to influence performance in terms of trapping rate. Validating this method for studying small mustelids could open research opportunities to address longstanding knowledge gaps across the species distribution range.

Materials and methods

Study area

We conducted fieldwork at two study areas in Portugal (Fig. 1), both research and monitoring sites of a Long-Term Socio-Ecological Research Platform (LTSER Montado). Companhia das Lezírias (CL; 38°50′32.6"N, 8°49′56.5"W) is the largest agroforestry farmstead in Portugal (~180 km^2), located 50 km north-east of Lisbon. Cork oak *montado*, a savannah-like landscape, occupies approximately 66 km^2 of the estate and is interspersed by pine stands, scrublands, olive groves, rice fields and irrigation plots. The area is crossed by over 35 km of intermittent watercourses, with a highly variable density of riparian vegetation. Of these, 11 km display dense and fully developed arboreal and shrubby strata composed of riparian species (e.g., *Salix alba, Fraxinus angustifolia*). The *montado* occurs in pure or mixed patches and with variable composition and density of understorey, depending on grazing pressures and/or shrub clearance activities. Cattle are raised in a rotating system between grazing plots in most of the forested area. The climate is typically Mediterranean, with a mean annual temperature of 16.6 °C and annual rainfall averages of 700 mm.

Herdade da Ribeira Abaixo (HRA; 38°06′23.4"N, 8°34′20.8"W), located 120 km south of Lisbon, has a size of 2.21 km^2 and is mainly composed of cork oak *montado* (90 %), with small patches of olive groves, vegetable gardens and riparian vegetation. The understorey vegetation is highly developed and dominated by two *Cistaceae* species (*Cistus ladanifer* and *Cistus salvifolius*) and topped lavender (*Lavandula stoechas*). The area is crossed by several temporary streams of the Sado's hydrographic basin, with stretches of riparian vegetation (e.g., *Populous nigra, Salix atrocinerea, Rubus ulmifolius*) (Rebelo et al., 2009). The climate is also Mediterranean, with a mean annual temperature of 16.3 °C and mean annual rainfall of 500 mm.

Field tests

We first tested the performance of the *Mostela* using two different sampling designs. The *Mostela* box was built in the dimensions reported by Mos and Hofmeester (2020) (L: 610 x W: 300 x H: 150 mm), and the tube was 80 mm in diameter and ~350 mm in length. Between February and July 2020, 25 sampling stations were deployed at CL using a 2 × 2 km grid; then, between January and February 2021, a smaller area was targeted at CL (~8 km^2), and the devices were deployed at 30 sampling stations in a 350 × 350 m grid. Finally, at HRA we deployed the devices at 26 stations between March and April 2021, using a 350 m grid (Fig. 1) because we obtained better results with this design. Below, each sampling design and sampling period is described in detail.

The pilot field test conducted in 2020 comprised the whole study area of CL (~68 km^2) and ran for nearly six months. The sampling stations were defined using a 2 km grid with a regular design. After local adjustments due to access constraints, the average distance between stations was 1783 m (SD=247, min=1503, max=2085). At each sampling station, we placed a *Mostela* and a tree-camera at a distance of up to 6 m from each other. For both methods, we used Browning Dark Ops HD Pro-X cameras, with a trigger speed of 0.22 s, programmed to operate 24 h per day and take three sequential photographs when

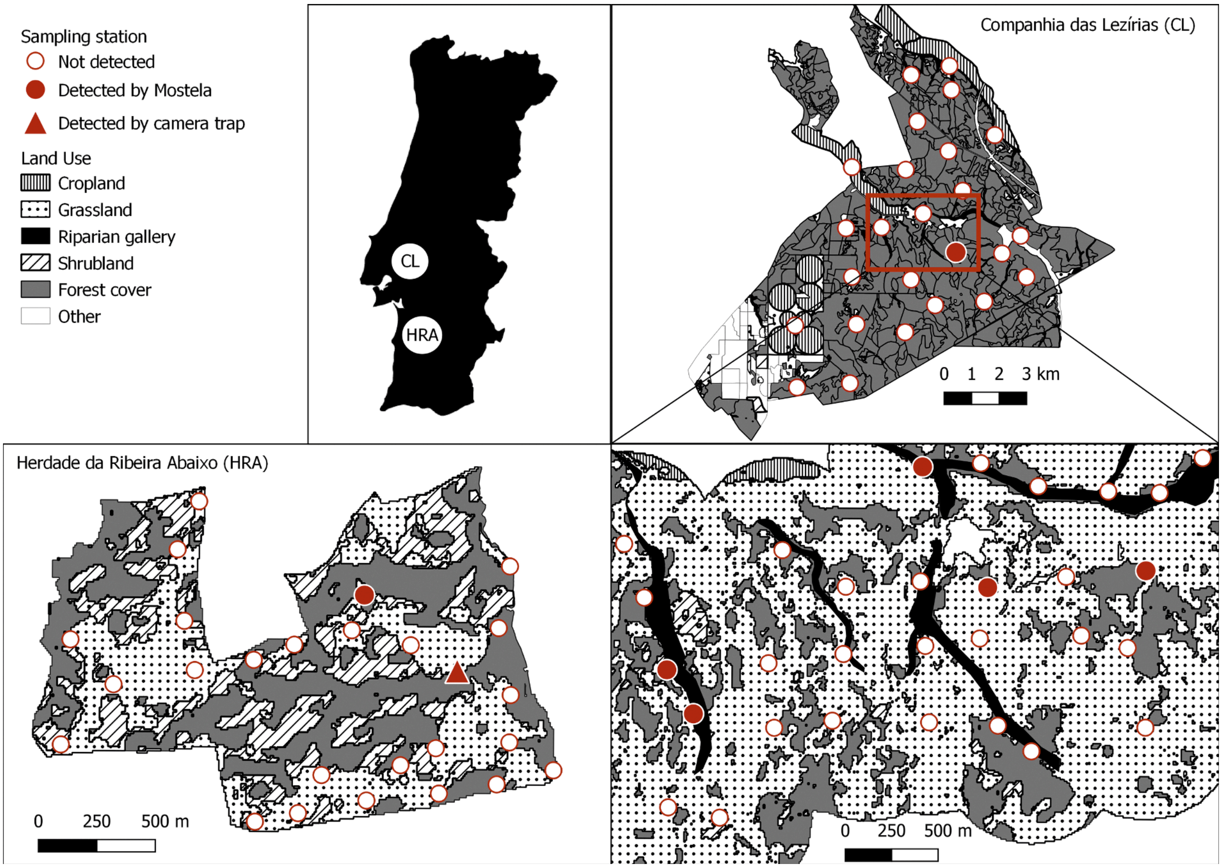

Fig. 1. Map of sampling grid and main land uses for each study area and their location in mainland Portugal (upper left). In the right upper corner, the 2 km sampling grid (2020 field test) and in the rigth lower corner the 350 m sampling grid (2021 field test), both at Companhia das Lezírias (CL). The red rectangle indicates the smaller area at CL where the 2021 field test was conducted. In the left lower corner, the 350 m grid deployed at Herdade da Ribeira Abaixo (HRA) in 2021. Weasel detections are shown with different symbols: open circles indicate the sampling stations where weasel was not detected, red dots indicate where the weasel was detected inside the Mostela box ($n = 7$), and red triangles ($n = 1$) where it was detected by the camera-trap outside (tree-camera).

triggered (1-second interval between bursts).

We conducted a second field test in both study areas in 2021. At CL, we targeted a smaller area of cork oak *montado* and riparian vegetation, and the test ran for one month. We selected this area based on previous sightings and signs of presence of the least weasel (S. Alcobia, personal communication; see Appendix A: Fig. 1). Here, we deployed 30 sampling stations using a 350 m grid, with an average distance between stations of 319 m (SD= 52, min= 228, max= 440) after local adjustments. Once again, at each sampling station, a *Mostela* and a tree-camera were placed up to 6 m from each other. Inside the *Mostela*, there was a Browning Dark Ops HD Pro-X camera taking three photographs per trigger with a 5-second delay. Outside, the camera traps were Cuddelink Long Range IR Model J-1521, with a trigger speed of 0.25 s, set to take one photo when triggered (5-second interval between bursts). Lastly, at HRA we followed the same design and used the same camera models described for the second field test at CL. However, due to access limitations, we set up 26 sampling stations, with an average distance between stations of 214 m (SD= 41, min =160, max= 342).

During all surveys, we visited the sampling stations every 15 days to monitor the battery status and replace memory cards. The tree-cameras were mounted at 20 to 30 cm above the ground (Kelly, 2008), and we did not target paths/trails or other landscape structures but selected these when available. The *Mostelas* were placed under shrubs or dense vegetation selecting the best microhabitat features for the least weasel. No type of bait or lure was used either inside or outside the *Mostelas* or near the tree-cameras.

Environmental variables

At each sampling station, two observers visually characterized the surrounding vegetation in a 50 m radius buffer. For each stratum (herbs, shrubs, and trees), the buffer was ranked in terms of low, medium, and high density of vegetation cover. Each rank was attributed according to the visual estimation, as follows: “Low” for 5 to 25 % cover, “Medium” for 25 to 75 % cover and “High” for 75 to 100 % cover. Furthermore, we identified the dominant land cover type within the sampling station buffer. Lastly, the small mammal (referring only to small rodents and insectivores) trapping rate was calculated as the number of independent events per 100 trap-nights, using only the detection events captured inside the *Mostela* at each station. We assumed events were independent when small mammals were detected at least 30 min apart. We did not identify small mammals at the species level, and thus all events were pooled together to calculate the trapping rate.

Statistical analysis

To compare the weasel trapping rate to previous studies (Mos & Hofmeester, 2020), we considered that two events had to occur at least 60 min apart to be independent. We used multi-scale occupancy models (Nichols et al., 2008) to make inferences about method-specific detection probabilities and assess the performance of the *Mostela* and the tree-camera. These models explore the dependence between detections within a sampling occasion to make inferences about scale-specific occupancy. We only used the detection data from the 350 m grid field tests (both study areas) to model weasel occupancy and detection, as these yielded the highest number of independent events (see Results section).

For multi-scale occupancy models, the detection history (coded with 1 for detected and 0 for non-detected) was built for each sampling device (D) deployed at each sampling station (S) for K occasions. For example, for a design with $D = 2$ devices and $K = 3$ sampling occasions, one possible detection history is $H_i = 01\ 11\ 00$, where the species was detected by device two on the first occasion, by both devices on the second occasion, and by neither device on the third occasion. In this study, we collapsed detection events into seven occasions of five days each. Although the sample unit was larger than the station, the closure assumption should hold over the K occasions, which means that the sample unit is either occupied for all occasions or not occupied, and occupancy status does not change for the whole study period (Nichols et al., 2008). Nonetheless, as in single-season occupancy models, this assumption can be relaxed if the changes within a season are random, and then occupancy should be interpreted as use instead (Kendall, 1999; MacKenzie et al., 2004). Given the proximity of the two devices in a sampling station, we slightly adapted the original parameters to consider the following hierarchical structure of the data:

i. ψ is the probability that the sample unit is occupied
ii. θ is the probability that the species is present near the devices at a sampling station at the time of the survey, given that the sample unit is occupied
iii. and p_d is the probability of detection by device d, given that the sample unit is occupied, and the species is present in the surrounding of the sampling station at the time of the survey

Therefore, the θ parameter represents a temporal availability process rather than a spatial one, as originally proposed (Nichols et al., 2008), since the individuals' movement patterns can make the species either temporarily available at a sampling station, and thus both devices have a probability ($p_d \neq 0$) of detecting it; or the species is unavailable near the sampling station and so neither device is able to detect it ($p_d = 0$). Following Mordecai et al. (2011), we applied a hierarchical Bayes approach to multi-scale occupancy modelling. Let Z_i denote a binary random variable to indicate the presence or absence of the species at the ith sample unit. We assume:

$$Z_i \sim Bernoulli(\psi_i)$$

Where ψ_i denotes the probability that the species is present at the ith sample unit. Then, let u_{ij} denote the binary random variable indicating presence or absence of the species near the devices, which is conditional on the respective site occupancy state. Thus, we assume:

$$u_{ij}|Z_i \sim Bernoulli\left(\theta_{ij} z_i\right)$$

where j indexes the K occasions within a survey. Hence, θ represents species availability for detection for a given occasion (j) at a sampling station (S_i). Lastly, for the observation model, y_{ijk} denotes a binary random variable indicating if the species was detected or not detected by the kth device in the jth occasion of the ith sampling station. The model is conditional on θ as follows:

$$y_{ijk}|u_{ij} \sim Bernoulli\ \left(p_{ijk} u_{ij}\right)$$

To test the performance of each device in detecting the weasel, we fit one model with device-specific detection probability ($p_M \neq p_C$) and another with constant detection probability. Given the objective of this analysis and the sparsity of the weasel detection data (11 detection events overall) we held the occupancy and detection parameters constant over space and time and did not use any environmental covariates.

We analyzed the models using Markov chain Monte Carlo (MCMC) simulation in JAGS (Plummer, 2003) called from R (version 4.1.3; R Core Team, 2022) using the package R2jags (version 0.7.1; Su & Yajima, 2021). We generated three chains of 1,001,000 iterations each, discarded 1,000 as burn-in and kept every 100th iteration. Regarding the priors for the occupancy (ψ and θ) and detection (p) parameters, we followed best practice recommendations and chose the uninformative priors Beta(1,1) (Northrup & Gerber, 2018). We assessed convergence by visually inspecting the trace plots and used the $\widehat{R}$ statistic (Gelman & Rubin, 1992), assuming no evidence of lack of convergence when $\widehat{R} <$ 1.1. To measure model performance and compare prediction accuracy between models, we used WAIC (Watanabe, 2010), which is considered a more fully Bayesian approach (Gelman et al., 2014). WAIC, contrary to AIC and DIC, averages over the posterior distribution rather than conditioning on a point estimate and is valid for hierarchical models (Hooten et al., 2015). Below, we report posterior means and 95 % Bayesian credible intervals (BCIs) which correspond to the 2.5 and 97.5 percentiles.

Results

We detected the least weasel in both study areas (CL and HRA), although the results differed between study areas, sampling designs and methods. Furthermore, besides the least weasel, other species of mammalian carnivores, small mammals, and birds were detected inside the *Mostelas* (see Appendix A: Table 1 for a summary for each sampling design, study area and sampling method).

In 2020, during the pilot test (2 km grid) at CL, 304 independent events (i.e., at least 60 min apart) were recorded inside the *Mostelas* during 3492 effective trap-nights, while the tree-cameras recorded 1221 independent events during 3104 effective trap-nights (Table 1). During this pilot test, the weasel was detected at only one station (4 %; Fig. 1) inside the *Mostela* after 130 days of deployment in a *montado* area with low shrub cover. Thus, the weasel trapping rate was low, with 0.03 individuals detected per 100 trap-nights (Table 1).

In 2021, for the 350 m grid field test at CL, 1190 independent events were recorded in the *Mostelas* during 1052 effective trap nights, and the tree-cameras recorded 727 species events during 1029 effective trap nights (Table 1). At HRA, 163 independent events were recorded by the *Mostelas*, and 186 independent events were recorded by the tree-cameras, for 858 effective trap-nights (Table 1). At CL, the weasel was detected at 16.7 % of stations (Fig. 1) only inside the *Mostelas*, accounting, in total, for ten independent events. At HRA, the weasel was detected at 7.7 % of stations (Fig. 1), with a single independent event recorded inside the *Mostela* at one station and only recorded by the tree-camera at a different station (Table 1). Therefore, for the 350 m grid field test, the trapping rate was ~8 times higher at CL than at HRA (Table 1). Also, at CL the species was detected only one day after deployment, while at HRA the weasel was detected after 26 days by the *Mostela* and after 12 days by the tree-camera (Table 1). Overall, most stations where the weasel was detected had a dense understory, with

Table 1
Details of weasel detections by the Mostelas and tree-cameras, for both study areas and sampling design grids. Each column summarizes a field test as the combination of year x study area x method. The pilot test in 2020 was conducted at Companhia das Lezírias (CL) between February and July; the field tests in 2021 were conducted between January and February at CL and between March and April at Herdade da Ribeira Abaixo (HRA).

Field test	2020 x CL x Mostela	2021 x CL x Mostela	2021 x HRA x Mostela	2021 x HRA x CT
Sampling grid	2 km	350 m	350 m	350 m
N° trap nights	3492	1052	858	858
N° independent events	1	10	1	1
N° stations detected in	1	5	1	1
Trap rate	0.03	0.95	0.12	0.12
Days to first detection	130	1	26	12

five of the seven stations set in a dense shrub cover plot (see Appendix A: Fig. 2). However, we acknowledge that more than half of all the sampling stations (~59 %) were set in dense shrub cover. Additionally, four of the seven stations where the weasel was detected were located near the riparian gallery.

Given the field tests were conducted in different years and study areas, we estimated the small mammal trapping rate, as prey availability leads to weasel population fluctuations. At CL, the small mammal trapping rate was ~19 times larger in 2021 (estimate ± SE: 124.19 ± 115.73 events/100 trap nights) compared to 2020 (6.58 ± 11.90 events/100 trap nights). Furthermore, in 2021, the small mammal trapping rate was ~8 times lower at HRA (15.82 ± 32.66 events/100 trap nights) compared to CL (see Appendix A: Fig. 3). Lastly, visitation of the *Mostelas* by other carnivores could deter the weasel from entering the box. Common genets, Egyptian mongooses and stone martens entered the *Mostelas* (see Appendix A: Table 1), being detected in 56 % of the sampling stations in 2020 and in ~36 % of the stations in the 2021 field tests. In the pilot test of 2020, a mongoose was detected inside the *Mostela* eight days after the weasel was detected. In 2021, mesocarnivores were detected in half of the stations where the weasel was detected inside the *Mostela*. At two stations, visitation by mesocarnivores occurred three and six days before the weasel detection, while for the third station, visitation occurred after the weasel was detected.

Using only the data from 2021 for the 350 m grid field tests (both study areas), we fitted two multi-scale occupancy models. The model assuming different detection probabilities between devices had a lower WAIC value compared to the null model, which is indicative of a better model fit (WAIC = 97.6 vs 106.3, see Appendix A: Table 2). Detection probability differed between devices and was four times higher for the *Mostela* compared to the tree-camera (*pM*: 0.8, BCI: 0.52–0.97 vs *pC:* 0.2, BCI: 0.03–0.48; Fig. 2A). The posterior mean for the difference in detection probability between devices was 0.6 and only 0.1 % of the estimates indicated a higher detection by the tree-camera relative to the *Mostela* (Fig. 2B). Regarding the occupancy parameters, the occupancy estimate at the scale of the sample unit was 0.46 but with a wide BCI (0.13–0.94), while the theta estimate, regarding the species temporal availability near the devices, was low with a narrow BCI (0.06, 0.02–0.17) (Fig. 2A).

Discussion

Our main goal was to test the performance of the *Mostela* box to detect small mustelids, in particular the least weasel, and compare it to a well-established carnivore sampling method to inform future research and monitoring efforts of these understudied small carnivores. From our field tests, the average detection probability estimate was four times higher by the *Mostela* compared to the tree-mounted camera trap when using the 350 m grid. Despite this difference between the two methods, we acknowledge that the credible intervals were wide, as the number of weasel detections was low. However, on average, the difference in detection probability between methods was 0.6, and for 99.9 % of the posterior samples, the detection was higher by the *Mostela* box. Additionally, using two different camera models for the tree set-up and the *Mostela,* with slightly different settings (i.e., *Mostela*: 3 photos per trigger vs tree-camera: 1 photo per trigger), could partly explain the differences in detection probability between methods. Previous studies have demonstrated the effect of the camera model on detection probability (Hughson et al., 2010; Wellington et al., 2014), especially of smaller-sized species (Palencia et al., 2022). However, by placing the camera trap inside a box, several other factors differ relative to the conditions outside, as the field of view and detection range are reduced, and boxes can be placed in microhabitat features preferred by small mustelids without concern of increasing false triggers due to vegetation. Therefore, although we acknowledge that differences in camera models could confound our conclusions regarding the performance of both methods, we expect the differences in camera set-up to outweigh the differences in detection between camera models.

The low trapping rate with very few detections also meant that the posterior distribution for the occupancy estimate was similar to the prior distribution, with extremely wide credible intervals. Moreover, the estimate of temporal availability around the sampling station (θ) was very low, which could be either a consequence of the species' low density or the microhabitat features selected were not ideal. Weasels are known to avoid open habitats using linear features such as vegetation edges, stone walls or riparian shrubland to move in the landscape (Magrini et al.,

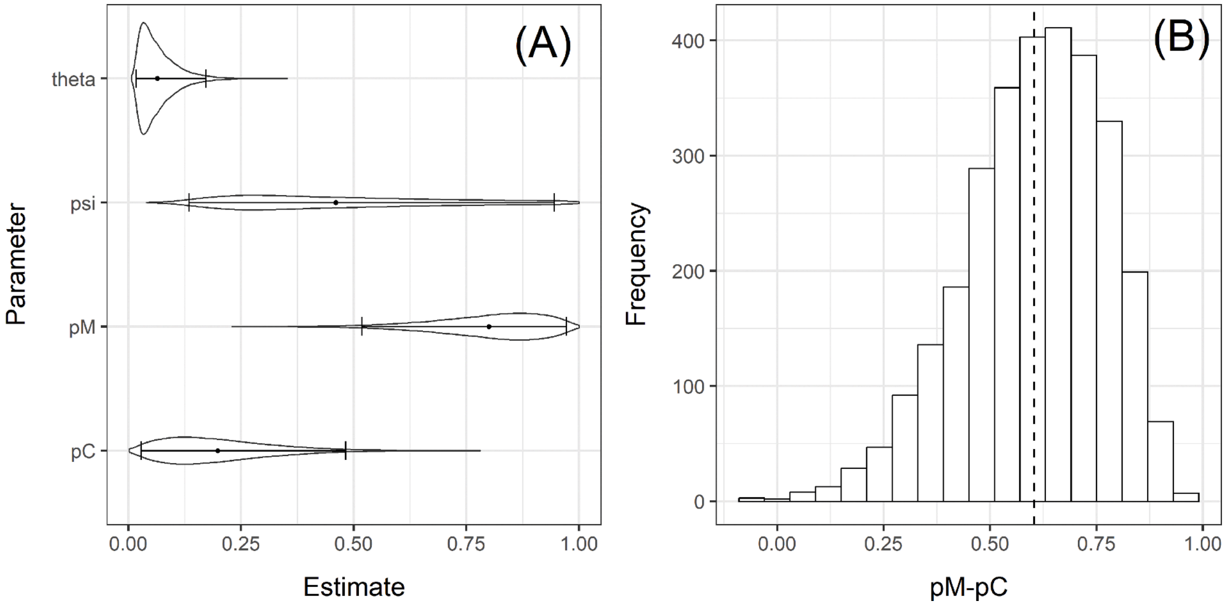

Fig. 2. Plot (A) of the full posterior probability distributions for the occupancy and detection parameters of the best model, which accounted for different detection probabilities between methods (Mostela and camera trap). The parameters refer to sample unit occupancy (psi), sampling station use (theta), detection by the Mostela (pM) and detection by the tree-camera (pC). Bars represent 95 % credible intervals. (B) Frequency distribution of the difference between the posterior distribution for the detection probability of the Mostela box relative to the tree-camera. The vertical dashed line refers to the posterior mean.

2009). At HRA, the low trapping rate could either reflect a low-density weasel population, supported by the low small mammal trapping rate, or the difficulty in placing the sampling stations, particularly the *Mostela* box. The dense and homogeneous shrub cover at HRA made it difficult to target those linear habitat features favored by the weasel (Brandt & Lambin, 2005; Macdonald et al., 2004). At CL, the heterogeneity of a managed landscape allowed identifying those features that the weasel would use as stepping-stones to travel in an open matrix, namely shrubby patches; but the availability of linear features is characteristically low in these agroforestry systems. Thus, although in each study area, we targeted areas favorable for weasel in Mediterranean landscapes (i.e., *montado* with varying densities of shrubs and riparian vegetation), the microhabitat features at each sampling station were not always as appropriate and that might partly explain the lower trapping rate compared to Mos and Hofmeester (2020).

Although camera traps are known to miss these smaller species due to the sensitivity of the PIR sensor and the species rapid movements (Rowcliffe et al., 2011; Tobler et al., 2008), their widespread use to survey mammalian carnivores (Burton et al., 2015) motivated the comparison with this new group-specific method. In fact, adjustments in terms of camera height to up to 30 cm from the ground can increase the detection of smaller species while not compromising the detection of the larger species (Kelly, 2008). Using camera trap data, Bischof et al. (2014) investigated the space use and activity patterns of a community of carnivores, and detected the Altai mountain weasel (*Mustela altaica*), despite camera traps being set up 50 to 60 cm above ground. Also, adding baits or lures (i.e., attractants) to the tree-mounted camera could improve the performance of this method for detecting small mustelids. The use of beaver meat in Evans and Mortelliti (2022) yielded over 700 events of American ermine (*M. richardsonii*) and long-tailed weasel (*M. erminea* and *M. haidarum*) across 197 survey sites from 2017 to 2020. Thus, although not the preferred method to survey these small mustelids, they can be detected by camera traps, and we clarify that our conclusions regarding the higher performance of the *Mostela* box are relative to standard camera traps since the use of attractants could improve detection. Nevertheless, using attractants has its own limitations because this can alter species' behaviour and bias statistical inferences (Balme et al., 2014). Therefore, the development of more targeted methods that do not require the use of attractants would be more advantageous. Although attractants can be used inside the *Mostela* box, the use of lure in Croose and Carter (2019) did not influence the detection of small mustelids, and Mos and Hofmeester (2020) obtained much higher weasel trapping rates without any attractants. Furthermore, we suggest coupling group-specific methods, such as the *Mostela*, with standard camera-trapping to explore other topics of interest, such as community structure, interspecific interactions and predator-prey dynamics.

Regarding sampling design, the trapping rate was higher with the 350 m grid (0.95 vs 0.03 individuals/100 trap days at CL), and the species was detected after only one day of deployment and at more sampling stations. However, we acknowledge that differences in the temporal and spatial resolution of the field tests confound our conclusions on the performance of different sampling designs. For one, the weasel population density could have been lower in 2020 compared to 2021, as population fluctuations are common in small mustelids (Korpimäki et al., 1991; Sundell et al., 2013). These fluctuations are primarily influenced by prey availability (Korpela et al., 2014; Korpimäki et al., 1991), namely rodents. In our study, the small mammal trapping rate was much lower during the 2020 pilot test compared to 2021, although we targeted a smaller area in 2021. Secondly, the field test in 2021 targeted an area at CL that included the only sampling station where weasel was detected in 2020. Therefore, the increase in the number of sites where weasel was detected and an overall higher trapping rate could be due to having a higher camera trap density in an area where weasel presence had been confirmed. Nonetheless, previous monitoring efforts at CL had recorded weasel presence (i.e., signs of presence and direct observations) in other areas included in the 2020 pilot test. Although this could limit our conclusions on the use of a shorter inter-camera spacing, this is still our recommendation. For one, deploying several camera traps per weasel home range should increase the chance of detecting the species when present. Also, for landscapes where identifying the appropriate microhabitat features for small mustelids might be challenging, this could increase the chances of having at least one box located at a preferred microsite. In previous studies, the sampling grid used was slightly smaller than the 350 m spacing in our study (~136 m in Mos and Hofmeester (2020); 50 to 200 m in Croose and Carter (2019)), but weasel trapping rate was similar to that of Croose and Carter (2019) (1.4 weasels per 100 trap nights), although much lower than in Mos and Hofmeester (2020) (19.9 and 8.8 weasels per 100 trap nights in 2017 and 2018, respectively). The lower trapping rate could be related to differences in population density or landscape structure between study areas, as previously discussed. By targeting a smaller area, we were able to obtain more species events, although some of these could be the same individual given weasel's home range can vary between 0.11 and 2.16 km^2, with marked seasonal changes (Magrini et al., 2009) but also depending on the individual's sex (King, 1975) and food availability (Jędrzejewski et al., 1995). To estimate population density, having several cameras per home range is necessary, and the potential to identify individuals in the *Mostela* box (Mos & Hofmeester, 2020) allows the implementation of capture-recapture methods without live-trapping. Unfortunately, in our field tests, we could not make such identifications as most events were of a single photograph and weasel heads peeking in. Only one event was of two individuals simultaneously inside the box.

It could be argued that timing surveys for summer and autumn could yield better results as weasel populations show the highest densities in these seasons, both in the UK and the Netherlands (King & Powell, 2010; Mos & Hofmeester, 2020). However, in a 3-year study conducted in Portugal in a Mediterranean agrosystem, with monthly live-box-trapping sessions (total of 14.472 trapping units) and individual identification, no seasonal pattern for weasel abundance was detected. The highest (19 ind./100 ha) and lowest (2 ind./100 ha) densities were observed in October 1985 and 1987, respectively (Santos-Reis, 1989). Moreover, in a more recent mesocarnivore research project conducted in one of our study areas - CL (Raposo, 2022) -, with *Mostela* sampling conducted in autumn (September/October 2021) and spring (April/May 2022), a single weasel detection was recorded only in May supporting the findings in our study. Nevertheless, we recommend more tests in different phases of the weasel's life cycle (e.g., breeding and non-breeding seasons).

Finally, prey and predators of these small mustelids also visited the *Mostelas*. Therefore, it could be an interesting tool to investigate the population cycles of small rodents and their relation to small mustelids. The relation between predator and prey cycles has been the focus of much research on small mustelids (Korpela et al., 2014; Korpimäki et al., 1991; Sundell et al., 2013), but sometimes with contradicting results (Brandt & Lambin, 2007; Oli, 2003). However, the visitation by other mammalian carnivores, potential predators of small mustelids (Korpimäki & Norrdahl, 1989), could deter visitation of the *Mostelas* through scent cues. Here, we could not investigate this further due to the low number of species events, but the preliminary results suggest a non-avoidance behavior by the weasel.

Developing species and group-specific methods also requires testing and reporting on their performance in different ecosystems. Here, we reported on the performance of the *Mostela* for detecting small mustelids, but as other methods emerge (King et al., 2007; McCleery et al., 2014; Soininen et al., 2015), these should also be compared to other well-established carnivore sampling methods (camera-trapping, live-trapping, tracking tunnels), to inform research and conservation efforts. This information is crucial to ascertain the population status in countries where these species are possibly declining (Hellstedt et al., 2006; Palomo & Gisbert, 2002; Torre et al., 2018) or to develop effective control methods in places where they are considered pests (Blackie et al., 2012).

Data availability

The data on weasel detections used to fit the multi-scale occupancy models is available in an online repository (DOI: 10.5281/zenodo.7561951).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.baae.2024.01.004.

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