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RESEARCH

Comparing the efficacy of two camera trapping techniques for assessing the occupancy, detection and activity patterns of small Mustelids in Britain

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Abstract
Increasing concern over the unfavourable population trends and data gaps for many mustelids highlight the need to improve existing monitoring methods, to enable more accurate population assessments. Here, we investigated the efficacy of two camera trapping techniques for the detection of small mustelids, specifically least weasels *Mustela nivalis*, and stoats *M. erminea* in England. We deployed two concurrent camera trap techniques - a Mostela (a camera trap enclosed within a box) and an external camera trap at 20 sampling sites during summer 2021. We measured the number of daily detections over time and calculated the probability of detection and occupancy for each species. Our results highlighted the efficacy of the Mostela at detecting weasels whilst significantly reducing the amount of video footage to review. Stoats, however, were rarely detected with either technique, although the external camera appeared to be more reliable than the Mostela. European polecats *Mustela putorius* were regularly detected inside the Mostela and were detected at a similar rate as the external cameras after an initial period of avoidance. The data collected from the Mostela also highlighted the nocturnal activity of polecats and diurnal activity of weasels. Here, the Mostela provided an effective method to detect and estimate the occupancy of weasels and this may be just as efficient for polecats if deployed for long enough.

Keywords Monitoring · Carnivore conservation · Mustelidae · Trail camera

Introduction

Globally, there is increasing concern over the conservation status of small carnivores, including those formerly thought to be widespread and abundant, with calls for more research needed to inform conservation efforts (Marneweck et al. 2021; Wright et al. 2021; Jachowski et al. 2024). A common goal in wildlife ecology is determining parameters such as species occupancy, population abundance and density, and population status. However, this is challenging with small carnivores, as they leave limited field signs, are infrequently seen and can be neophobic or show avoidance behaviour towards monitoring devices such as traps. Therefore, small carnivores present additional research challenges and knowledge gaps exist for many species (Marneweck et al. 2021).

Least weasels *Mustela nivalis* and stoats *M. erminea* are two such examples of this. Both species are small-sized mustelids which have a wide circumboreal distribution covering Europe, northern Asia and northern North America (McDonald et al. 2019; Reid et al. 2016), yet in much of their range, their population status and trends are either unknown or of concern. In European countries where Red Lists are available, these species are either classed as Data Deficient (e.g. in Britain; Mathews et al. 2018), endangered or vulnerable (e.g. in the Netherlands; van Norren et al. 2020), while in North America, harvesting data has revealed a decline of all three weasel species (*M. nivalis*, *M. frenata* and *M. erminea)* since the mid-20th century (Jachowski

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et al. 2021). In Britain, a recent study has shown a strong decrease in weasel occupancy since the 1970s (Coomber et al. 2021). Another under-studied mustelid, the European polecat *M. putorius*, is thought to be declining across much of its European range (Croose et al. 2018). In certain areas where populations are very low if not already extinct, the species can be particularly hard to detect, and increased monitoring and data are needed to improve population estimates (Croose et al. 2018).

The unfavourable population trends and data gaps for these small and medium-sized mustelids highlight the need to improve and expand existing methods for monitoring, to enable more accurate population assessments to be made (Jachowski et al. 2024). Methods using enclosed camera traps have been developed and increasingly used in recent years to survey and improve detectability of smaller-bodied species, such as small mustelids (Jachowski et al. 2024). One example of this is the 'Mostela' - a modified camera trapping device combining a camera trap with a plastic tunnel inside a box (Mos and Hofmeester 2020). The Mostela has proven to be effective at detecting the presence of weasels in several studies in Europe and in the USA, although occupancy and detectability estimates vary across studies (Croose and Carter 2019; Mos and Hofmeester 2020; Holloway et al. 2022; Barros et al. 2024; Konradsen et al. 2024; Granata et al. 2024; Hofmeester et al. 2024). Stoats appear to be more challenging to detect with this technique (Croose and Carter 2019; Mos and Hofmeester 2020; Holloway et al. 2022; Barros et al. 2024), which may be due to a reluctance to enter confined spaces and tunnels (King and McMillan 1982; Dilks and Lawrence 2000; Brown 2001). Modifications to the tracking tunnels (e.g. increasing diameter of entrance tunnels) inside the Mostela may therefore improve detectability of stoats. Mostelas have not previously been used to detect polecats, but have detected the similar-sized American mink *Neogale vison* and slightly larger carnivores such as the pine marten *Martes martes* (Croose and Carter 2019; Croose et al. 2021; Allué et al. 2022; Barros et al. 2024).

The aim of this study was (1) to investigate the use of the Mostela compared with standard camera trapping techniques for the detection of small mustelids; (2) assess the efficacy of two different diameter entrance tunnels (8 cm and 10 cm) to detect different small mustelid species; and (3) assess species' activity patterns.

Methods

Study area

Data collection was carried out on an estate in Herefordshire, western England (centred on 52°01'52.7"N, 2°22'55.4"W). The estate is mixed land use characterised by parkland, agricultural land (both arable and pasture), improved grassland, hedgerows and small woodlands, and is managed for recreation, gamebird shooting and agriculture. The climate in the study area is temperate and wet, with average temperatures ranging from 2–8 °C in January, and 12–22 °C in July (Met Office 2022). Weasels, stoats and European polecats (hereafter referred to as polecats) are known to be present at the site (Crawley et al. 2020).

Data collection

A total of 20 sampling sites were established. Ten 1-kilometre squares were selected, based on habitat characteristics and permitted land access. Within each kilometre grid square, two sampling sites were established to ensure spatial independence for the target species with the smallest home ranges (1–10 hectares for females weasels and 2–25 hectares for males; MacPherson 2024). At each sampling site, two concurrent camera methods were used. Firstly, a Mostela comprising a wooden box (measuring 620 mm x 300 mm x 175 mm) with a camera trap (Browning Strike Force Pro) and a plastic entrance tunnel sited inside. For a full description of the design, see Mos and Hofmeester (2020). Two entrance tube sizes were used in the Mostelas, measuring the same length (35 cm) but different diameters (either 8–10 cm – randomly allocated), in order to test the effect of diameter size on visitation by small mustelids (Mos and Hofmeester 2020). No bait or lure was used inside the Mostela, instead relying on the natural curiosity of small mustelids to investigate tunnels and holes. A section of pond liner was laid on top of each box to provide protection from the weather, and camouflaged with vegetation.

The second camera method comprised a stand-alone external camera trap (Browning Strike Force Pro) set up outside of the Mostela, to record footage of animals passing by and either entering, or not entering the Mostela. This camera was fixed either on a 'bank stick' (an adjustable metal rod, with a fixture to attach a camera to the top and a spike to secure the rod into the ground) or attached to a fence post and directed towards the entrance of the Mostela at a distance of approximately 1 m. The cameras were set to record for 10 s with a 1 s delay, and the trigger speed was 0.3 s.

Both the Mostela and camera were set inside a hedgerow, along a woodland edge or along a stone wall, as small mustelids are known to use linear features to move around the landscape (Mougeot et al. 2000; MacPherson 2024). The study took place for 19 weeks from May to September 2021. The cameras were visited once every one or two weeks to check and change SD cards and batteries, where required.

The videos were reviewed and the species detected classified, using two methods. The majority of the videos were manually classified by the authors (EC and SG). As reviewing a large quantity of videos was very time-consuming, a remaining subset of videos were uploaded to MammalWeb (https://www.mammalweb.org/en/), a citizen science platform for collating and validating camera trapping data, and classified by volunteers (Hsing et al. 2022). As video and image classification accuracy can vary across species (Hsing et al. 2022) and weasels and stoats can be particularly challenging to distinguish in videos, any videos classified as weasel or stoat by volunteers on MammalWeb were accuracy checked and verified by EC.

Statistical analysis

Weasel, stoat and polecat detections were collapsed into daily detections and the detection histories created using the package 'camtrapR' (Niedballa et al. 2016). For each species, we used a Bayesian statistical analysis approach to estimate the detection probabilities and occupancy estimates for each method (Mostela and external camera) along with a combined estimate which would provide an occupancy estimate closer to the true occupancy of each species. We estimated the probability of detecting each species when present throughout the study area using the R (v. 4.3.2; R Core Team 2021) package ubms (Kellner et al. 2021) and STAN software (Carpenter et al. 2017) implemented in R Studio (v. 2023.12.1; R Studio Team 2015) with 5,000 iterations, 5 chains and the default burn-in setting of half the number of iterations. The following covariates were used to test their effect on occupancy and detection: camera method (Mostela or external camera), tunnel diameter (8–10 cm), adjacent land use, hedge width, buffer strip width, distance to road, distance to woodland, placement of Mostela at the site (in line with the hedge or other linear feature or across it), presence of lagomorphs, and the detection of stoats and polecats for weasel detections.

We used the package 'activity' (Rowcliffe et al. 2014; Rowcliffe 2016) to calculate activity patterns following a nonparametric kernel density approach (Ridout and Linkie 2009). Camera detection times were converted into radians and were used to build circular kernel Probability Density Functions (PDF), which approximate the underlying activity patterns. The coefficient of overlap (Δ) was first calculated, then a randomisation test with 1000 bootstrap iterations was run, followed by a Wald test to estimate the probability that the observed overlap arose by chance (Lashley et al. 2018).

Results

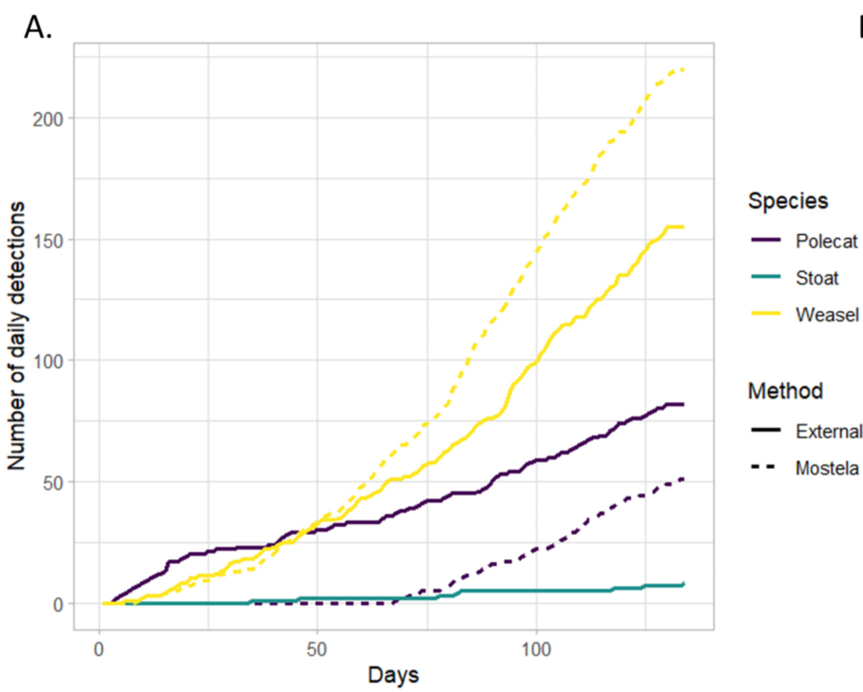
Species detections

The cameras recorded a total of 72,910 videos; 10,466 from the Mostelas and 62,445 from the external cameras. A total of 12 mammalian species were detected inside the Mostelas; mice *Apodemus sp.* (not classified to species level), bank vole *Myodes glareolus*, field vole *Microtus agrestis*, common shrew *Sorex Araneus*, pygmy shrew *Sorex minutus*, Eurasian water shrew *Neomys fodiens*, brown rat *Rattus norvegicus*, grey squirrel *Sciurus carolinensis*, European mole *Talpa europaea*, European rabbit *Oryctolagus cuniculus*, polecat and weasel. Occasional birds, common toad *Bufo bufo* and a grass snake *Natrix natrix* were also detected. A wider suite of mammals was detected on the external camera, comprising those detected inside the Mostelas, plus European badger *Meles meles*, domestic cat *Felis catus*, domestic dog *Canis familiaris*, domestic or feral ferret *Mustela putorius furo*, red fox *Vulpes vulpes*, stoat, brown hare *Lepus europaeus*, European hedgehog *Erinaceus europaeus*, muntjac *Muntiacus reevesi*, roe deer *Capreolus capreolus*, sheep *Ovis aries* and horseshoe bat *Rhinolophidae sp.*

Weasels were detected at 85% ($n=17$) of sampling sites; at the same 17 sites on the external camera and 75% ($n=15$) of sites inside the Mostela, (i.e. there were two sites where weasels were present and detected by the external camera, but not by the Mostela (Fig. 1). The total number of daily detections for weasels was similar for both camera methods until day 50, then the number of daily detections increased at a faster rate, with the Mostela reaching a total of 220 while the external camera had 155 daily detections at the end of the study (Fig. 1). Stoats were detected at 25% ($n=5$) of sites on the external camera only, with no detections at all inside the Mostela. On one occasion, a video from an external camera showed a stoat entering the Mostela, but the camera inside the Mostela failed to trigger. Polecats were detected at 65% ($n=13$) of sites; and inside the Mostela at 35% ($n=7$) of sites. While the external cameras detected polecats from the beginning of the study, daily detections only increased from day 70 onwards inside the Mostela (Fig. 1).

Detection and occupancy probabilities

When assessing the effect of camera method type for weasel detection, the detection probability was higher with Mostelas (0.11; 95% Uncertainty Intervals-UI 0.096–0.12) than with external cameras (0.068; 95% UI 0.058–0.079). Occupancy estimates using external cameras (0.819; 95% UI 0.641–0.946) and Mostela (0.727; 95% UI 0.522–0.889) were similar for weasels. For polecats, external cameras (0.047; 95% UI 0.038–0.058) and Mostelas (0.055; 95% UI 0.041–0.071) resulted in similar detection probabilities. The occupancy estimates however were lower with the Mostela (0.363; 95% UI 0.182–0.569) than with the external camera (0.638; 95% UI 0.430–0.821). For stoats, estimates



B.

Site	Weasel Mostela	Weasel External	Polecat Mostela	Polecat External	Stoat Mostela	Stoat External
1	●	●	●	●	○	○
2	●	●	○	○	○	○
3	●	●	○	○	○	○
4	●	●	○	●	○	○
5	●	●	●	●	○	○
6	●	●	○	●	○	○
7	●	●	●	●	○	○
8	●	●	●	●	○	○
9	●	●	○	●	○	○
10	●	●	●	●	○	○
11	○	○	○	●	○	○
12	●	●	○	○	○	○
13	○	○	○	○	○	○
14	●	●	○	●	○	●
15	●	●	●	●	○	○
16	○	○	●	●	○	○
17	○	○	○	○	○	●
18	●	●	○	○	○	●
19	○	○	○	○	○	○
20	●	●	○	●	○	●

Fig. 1 Summary of (**A**) the total daily detections over the study period for weasels, stoats and polecats using Mostelas and external cameras (**B**) detections at each sampling point for each method (black dots = detections), in Herefordshire, England

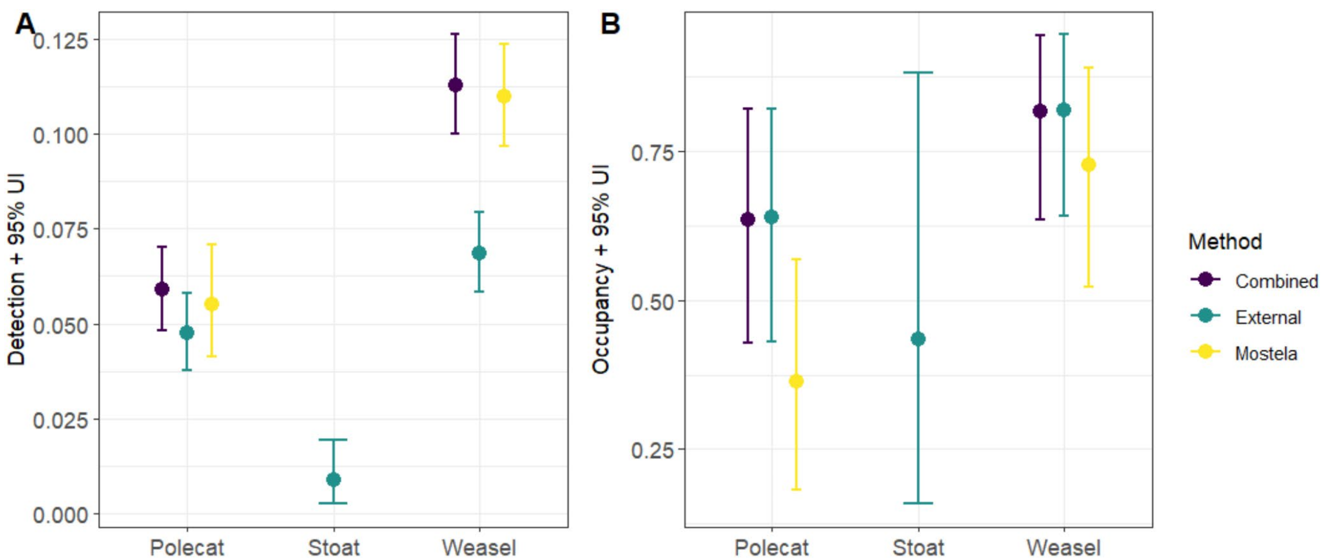


Fig. 2 (**A**) Probability of detection and (**B**) Probability of occupancy estimates with uncertainty intervals (UI) for weasels, stoats and polecats using Mostelas, external cameras and the combined dataset which provides an estimate closer to true occupancy, in Herefordshire, England

were only calculated for the external camera as they were not detected inside Mostelas. The probability of detection was the lowest of all three species (0.0089; 95% UI 0.0027–0.019) and the uncertainty intervals for the occupancy estimates were particularly wide (0.435; 95% UI 0.159–0.882). None of the covariates measured had any impact on the detection or occupancy of any species.

Species activity patterns

Weasel activity patterns were mostly diurnal with a peak of activity at dawn, and activity did not differ between the camera methods ($\Delta = 0.89$, $p = 0.80$). Polecats were predominantly nocturnal and had a higher peak in activity close to 23:00, with activity changing between camera methods

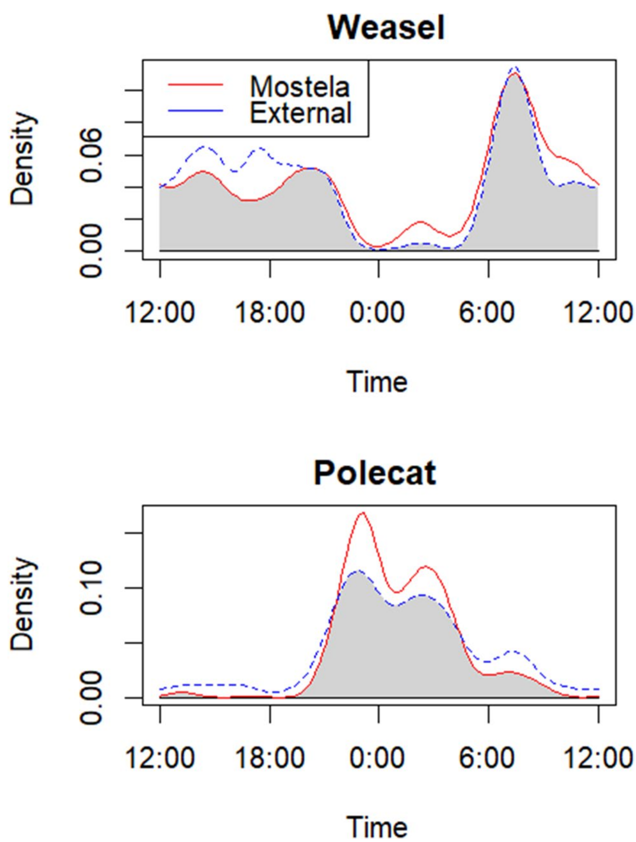


Fig. 3 Weasel and European polecat activity patterns determined from Mostelas and external cameras, in Herefordshire, England. Activity patterns for stoats were not calculated due to too few detections

($\Delta = 0.83$, $p = 0.02$) (Fig. 3). Activity patterns for stoats were not calculated due to there being too few detections.

Discussion

The use of Mostelas for monitoring small mustelids has been gaining momentum, yet their efficacy for detecting and surveying stoats and polecats remains unclear. In this study, we investigated the use of the Mostela against standard camera traps for the detection of weasels, polecats and stoats at a site in Britain. Our results highlight the high efficacy of the Mostela at regularly detecting weasels throughout the study area and add to the increasing body of evidence from studies elsewhere in the weasel's range (Mos and Hofmeester 2020; Holloway et al. 2022; Barros et al. 2024; Hofmeester et al. 2024; Granata et al. 2024). The key advantage of the Mostela over standard camera traps is the reduction in the number of videos and non-target species recorded, and subsequent footage to review. The use of external or standalone cameras can generate a huge amount of footage of non-target species as well as false triggers from vegetation. This is problematic as large numbers of videos can quickly fill a memory card and drain camera battery, meaning more frequent camera servicing is required and increasing the risk of missed detections due to loss of camera function. Furthermore, excess amounts of footage only exacerbate the existing challenge of processing camera trap footage in a timely manner (Glover-Kapfer et al. 2019). The Mostela can also be placed in suitable microhabitat features preferred by weasels, such as hedgerows and field margins, without risk of increasing the number of false triggers from moving vegetation. This may also make the cameras less susceptible to theft, provided there is sufficient cover to conceal the Mostela. However, the cumbersome nature of the Mostela incurs a practical constraint on the deployment of a large number of units, especially at more remote sites.

The Mostela was equally as effective at detecting polecats over time, although it appears that polecats avoided them for the first two months of the study, before being detected at a similar rate as the external cameras. This could be explained by an initial period of avoidance or a seasonal variation in behaviour, with juveniles becoming independent and more willing to investigate new features towards the end of the study period. This latency would explain the lower occupancy estimates from the Mostela as the species was not detected at as many sites. Leaving Mostelas in the field for a longer period or the use of lures may improve the detection of polecats (Ebel and White 2024), and both approaches are worth exploring due to the lack of established monitoring methods for polecats and their concerning conservation status in Europe (Croose et al. 2018).

Previous studies have demonstrated that stoats may avoid or be reluctant to enter confined spaces, such as traps and tunnels, possibly due to a neophobic response towards novel objects (King and McMillan 1982; Dilks and Lawrence 2000; Brown 2001). Here, stoats were considerably more elusive and were rarely detected with either camera technique. The Mostela proved to be less efficient than external cameras as it completely failed to detect the species, while the external cameras detected stoats at five sites. Previous studies have also highlighted the limitations of the Mostela in detecting stoats (Croose and Carter 2019; Mos and Hofmeester 2020; Croose et al. 2021) and the influence of regular visits by few individuals resulting in high detection probabilities and lower occupancy estimates than the external cameras (Croose et al. 2021). However, more recent research contrasts with these findings and has demonstrated that the Mostela is more effective at detecting stoats at some sites. The Mostela has been used in the Catalan Pyrenees for detecting altitudinal gradients in the distribution of stoats (Allué et al. 2022) and was considered as the preferred option for their long-term monitoring in the Italian Alps (Granata et al. 2024). A study in Denmark found that the Mostela resulted in a higher detection rate of stoats than weasels, although capture rates were low for both species (Konradsen et al. 2024). Stoats were also effectively detected in a recent study in the Netherlands and Mostelas showed a higher probability of detection than external cameras (Otte et al. 2024). The occupancy of stoats presumably varies a lot locally as habitat and regional differences in study areas likely play a role in the population dynamics and contrasting detectability in different studies. At a national scale in Britian, Coomber et al. (2021) suggested an occupancy close to 0.25 for both stoats and weasels, with a more important decline in occupancy in weasels. While the high occupancy for weasels suggests a high population in our study, low numbers of stoats could simply explain the low number of detections of the species.

Evidence on the efficacy of different entrance tunnel widths for detecting stoats is scarce as most studies tend to use a single diameter width of 8 cm (Barros et al. 2024; Croose et al. 2021; Croose and Carter 2019; Park and Lim 2023). Mos and Hofmeester (2020) found that the probability of detecting weasels in the absence of stoats was between 1.6 and 1.9 times higher with a 10 cm wide entrance tunnel. There is no clear explanation for these differences. Although stoats are known to enter 5 cm wide tunnels (Brown 2001), Mos and Hofmeester (2020) had initially expected higher detections in the 8 cm tunnels if other carnivores were present as they would have potentially been safer for weasels. Both species were present at this study site, yet weasels showed no preference in tunnel size whilst stoats failed to use any of them.

With similar results as the external camera, the Mostela provided an effective method to assess activity patterns of both weasels and polecats, and confirms activity patterns previously recorded for both species through radiotracking (e.g. Jędrzejewski et al. 2000; Marcelli et al. 2003). The activity patterns for weasels mirrored the findings by Mos and Hofmeester (2020) with a main peak of activity at sunrise and a smaller one close to sunset, suggesting a crepuscular pattern. The activity of polecats was more uniform although small peaks at the start and end of the night were observed. Differences in activity patterns observed in polecats between the external camera and the Mostela were most likely due to the regular use of Mostela for socialising inside the box, whereby two polecats together were recorded inside the Mostela for extended periods of time (approximately 30 min) on multiple occasions, and at least one individual polecat appeared to use the box for resting and sleeping. To our knowledge, this is the first study to detect activity patterns of polecats using non-invasive methods.

The spacing of sampling units is an important consideration for occupancy studies. If individual home ranges overlap more than one sampling unit (i.e. Mostela or camera), there is the potential for spatial correlation in the occupancy states of neighbouring sites. Barros et al. (2024) found that average detection probability estimates were higher for the Mostela compared with external cameras. They also found that reducing the spacing between Mostelas from the 2 km grid used in the first year to a 0.35 km grid the following year resulted in a higher detection rate for weasels and a shorter time to first detection. The 1 km square spacing chosen for our study was to accommodate both stoats and weasels, while minimising the risk of spatial correlation. Weasel home ranges are approximately 1–10 hectares for females and 2–25 hectares for males, although have been recorded up to 192 hectares, while stoats home ranges are typically larger but highly variable across different parts of their range, varying from 2 to 124 hectares in females and 8-256 hectares in males (MacPherson 2024). Therefore, the aim should be to space sampling units to adequately cover these areas, whilst avoiding the risk of spatial correlation. Fuller et al. (2022) recommended a spacing of sampling units of 0.67 times the home range of target species so that animals would tend to overlap no more than two ‘detectors’. The 0.35 km grid spacing used by Barros et al. (2024) is sufficiently large for weasels, but a stoat would likely be detected at one or two sampling points using this spacing. Polecats have a home range of 40–400 hectares, so a 1 km square spacing would be appropriate.

To summarise, the Mostela was effective for both weasels and polecats but, due to the different spacing requirements to study each species, future surveys would need to focus on one species or the other. Here, the Mostela was not effective at detecting stoats, although studies in other countries have proven to be successful. We would recommend the use of Mostelas if the study is long enough or these are set up without cameras at least two months in advance. While the construction of Mostelas can be costly, the method did result in a six-fold reduction of videos captured, which then reduces time required to review the footage.

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Author contributions E.C., S.C. and J.M. designed the study, E.C.; S.G. and P.W. undertook the field work and E.C. and P.W. wrote the main manuscript text and are considered as joint first authors. All authors reviewed the manuscript.

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Data availability Supporting data for this study has been deposited on Figshare digital repository - https://doi.org/10.6084/m9.figshare.28522610.v1.

Declarations

Ethical approval This study was approved by the VWT ethics committee.

Competing interests The authors declare no competing interests.

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