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ORIGINAL PAPER

Assessing the detectability of the Irish stoat *Mustela erminea hibernica* using two camera trap-based survey methods

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Abstract
Monitoring small mustelids like weasels *Mustela nivalis* and stoats *M. erminea* is challenging as they are rarely seen, leave scant field signs and display avoidance behaviour towards traps and monitoring devices. The Irish stoat *M. erminea hibernica* is a subspecies endemic to Ireland and the Isle of Man, and despite being widespread in Ireland, no information exists on its population status due to the difficulty of detection. We compared the efficacy of two camera trap methods to detect Irish stoats in counties Mayo and Galway, Republic of Ireland. Firstly, the 'Mostela' (a modified camera trapping device comprising a camera trap and a tracking tunnel inside a wooden box) and secondly, an external camera trap deployed outside the box. We used a single-season occupancy model to estimate the probability of detection and occupancy of Irish stoat using these two methods at 12 sites. Both methods detected stoats, at 17% of sites inside the Mostela and 33% of sites on the external camera, although this non-agreement was not statistically significant. Detection probabilities were low, with wide and largely overlapping confidence intervals for both methods. Occupancy probabilities were relatively low, and the occupancy probability for the external camera was very close to the naïve occupancy estimate. We evaluate the potential applicability of both methods for future work to assess the population and conservation status of this little-studied species.

Keywords Irish stoat · Mustelid · Camera trapping · Monitoring · Detection · Occupancy

Introduction

Gathering data on the presence or absence of a species and estimating the proportion of sites occupied is a common goal in wildlife research (MacKenzie et al. 2003; MacKenzie 2005). Monitoring wary carnivores, such as small mustelids like weasels *Mustela nivalis* and stoats *M. erminea,* is particularly challenging. They often demonstrate neophobia towards new or unfamiliar devices such as traps, show great behavioural flexibility, and an ability to learn from individual experience (King et al. 2007). Furthermore, field signs of weasels and stoats, such as droppings and tracks, are rarely found (McDonald & Harris 1998; King & Powell 2010) and the animals themselves are infrequently seen.

The Irish stoat *M. erminea hibernica* is a small mustelid and a distinct subspecies endemic to the islands of Ireland and the Isle of Man (Sleeman 1987). In Ireland, it is widely distributed, and > 90% of the global population is estimated to occur in the country (Marnell et al. 2009; Sleeman 2016). It is a protected species under the Wildlife Act, 1976 and the Wildlife (Amendment) Act, 2000. Despite this, it is one of several Irish mammal species which are under-studied and for which significant research gaps exist (Lysaght & Marnell 2016). There is no information on overall population trends or population estimates for the species (Marnell et al. 2009). This is often the case with species that are not perceived to be at risk in any way, those that do not impact human or economic interests, or those that are difficult to survey (Lysaght & Marnell 2016).

Whilst trapping of stoats is carried out in countries such as New Zealand (King 1980; Lawrence & O'Donnell; 1999; Elliott et al. 2010), this is not feasible in countries like Ireland where stoats are legally protected. Live trapping is also

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not a suitable method for long-term and large-scale monitoring, and as such, non-invasive monitoring methods are deemed more appropriate (Mos & Hofmeester 2020). In Ireland, the only successful method used to monitor stoats to date has been baited hair tubes (McAney 2010). Elsewhere, non-invasive monitoring methods used for stoats comprise tracking tunnels (Brown 2001; Clapperton et al. 1999), snow tracking (Korpela et al. 2014), and camera trap-based devices (Croose & Carter 2019; Mos & Hofmeester 2020); however, the success of some of these methods has been mixed. In particular, camera traps may not always detect small and fast-moving species like small mustelids, as they are less likely to trigger the passive infrared (PIR) sensor used by most cameras and may cross the camera's field of view quickly before a photo or video is taken (Glen et al. 2013).

The potential of camera trap-based devices for studying small mustelids has been advanced with the recent development of a device known as the 'Mostela' (Mos & Hofmeester 2020). The 'Mostela' is a modified camera trapping device comprising a camera trap and a tracking tunnel inside a wooden box (see full description in methods), which has been used to successfully detect weasels and, in some cases, stoats, in England (Croose & Carter 2019) and the Netherlands (Mos & Hofmeester 2020; Stichting Kleine Marters 2021). However, whilst the Mostela is effective in detecting weasels, the detection rate for stoats is much lower, and on some occasions Mostelas have failed to detect stoats when they were present. This was the case during a study in England, where stoats were not detected inside the Mostelas at some sites, even though they were seen in close proximity (Croose & Carter 2019) and in the Netherlands, where stoats were not detected at all in one study (Mos & Hofmeester 2020). This low detection rate may be due to stoats being reluctant to enter confined spaces and tunnels (the diameter of the tracking tunnel of the Mostela is 80 mm), as has been found in New Zealand (King & McMillan 1982; Dilks & Lawrence 2000; Brown 2001). Therefore, using Mostelas as a method in isolation may fail to detect stoats when they are present, and using a second method in combination with the Mostela may help to address this.

A key issue in wildlife monitoring is the imperfect detection of a species, whereby a species will not be detected even when it is present at a site (MacKenzie et al. 2003). When a species is not detected at a site, it does not mean that the species is genuinely absent from a location; rather, an observed absence may be attributed to the survey method failing to detect the species even though it is present (MacKenzie 2005). Imperfect detectability will lead to biased estimates of occupancy, which may result in false conclusions about distribution and abundance (MacKenzie 2005). Detection data can be integrated into occupancy models to produce unbiased estimates of the proportion of sites occupied by a species and related parameters, whilst addressing imperfect detection (MacKenzie et al. 2002; 2003).

Due to the uncertainties of stoats entering Mostelas, we tested the Mostela alongside a second camera trap method. The objective of this study was to compare detectability of Irish stoats between two camera trap-based survey methods: (1) the Mostela (described fully in Methods) and (2) an external camera trap deployed alongside the Mostela. We used occupancy modelling to determine detection probabilities (the probability of detecting the species at a site during a survey, given it is present) and occupancy probabilities (the probability a site is occupied by the species) of Irish stoats using these two methods. We evaluate the potential and limitations of both methods and discuss their applicability for future work.

Materials and methods

Study area

The study was conducted in counties Mayo and Galway in the west of the Republic of Ireland (centred on 53° 33′ 32.5044" N, 9° 15′ 50.7204″ W) (Fig. 1). The landscape is characterised by broadleaf woodland, scrub dominated by hazel *Corylus avellana*, hawthorn *Crataegus* and bramble *Rubus fruticosus*, grazed grassland and meadows. The area has a temperate climate, with average temperatures ranging from 15.6 °C in the summer to 5 °C in the winter and annual average precipitation of 906.8 mm (Weatherbase 2019). The study was focused in areas where stoats had been recorded in recent years.

Sampling design

A grid consisting of contiguous 2 km × 2 km squares was selected and within each square, one 'site' was established, spaced as evenly apart from other sites as practical. This spacing pattern was used to maintain spatial independence, and we assumed a maximum home range for stoats of 22 ha, based on Sleeman (1991). A total of 12 sites were established for the study. At each site, we used two concurrent camera trap-based methods to sample stoat occupancy and detectability. Firstly, a 'Mostela', a modified camera trapping device comprising a wooden box (measuring 620 mm × 300 mm × 175 mm) with a plastic tracking tunnel (measuring 350 mm length × 80 mm diameter) running through it. Stoats have been detected using tunnels as small as 50 mm diameter in studies in New Zealand (Brown 2001). A camera trap (Bushnell Trophy Cam HD) was sited inside the box and trained on the tunnel to record video footage of animals that entered. For a full description of the Mostela design, see Mos & Hofmeester (2020). A cotton

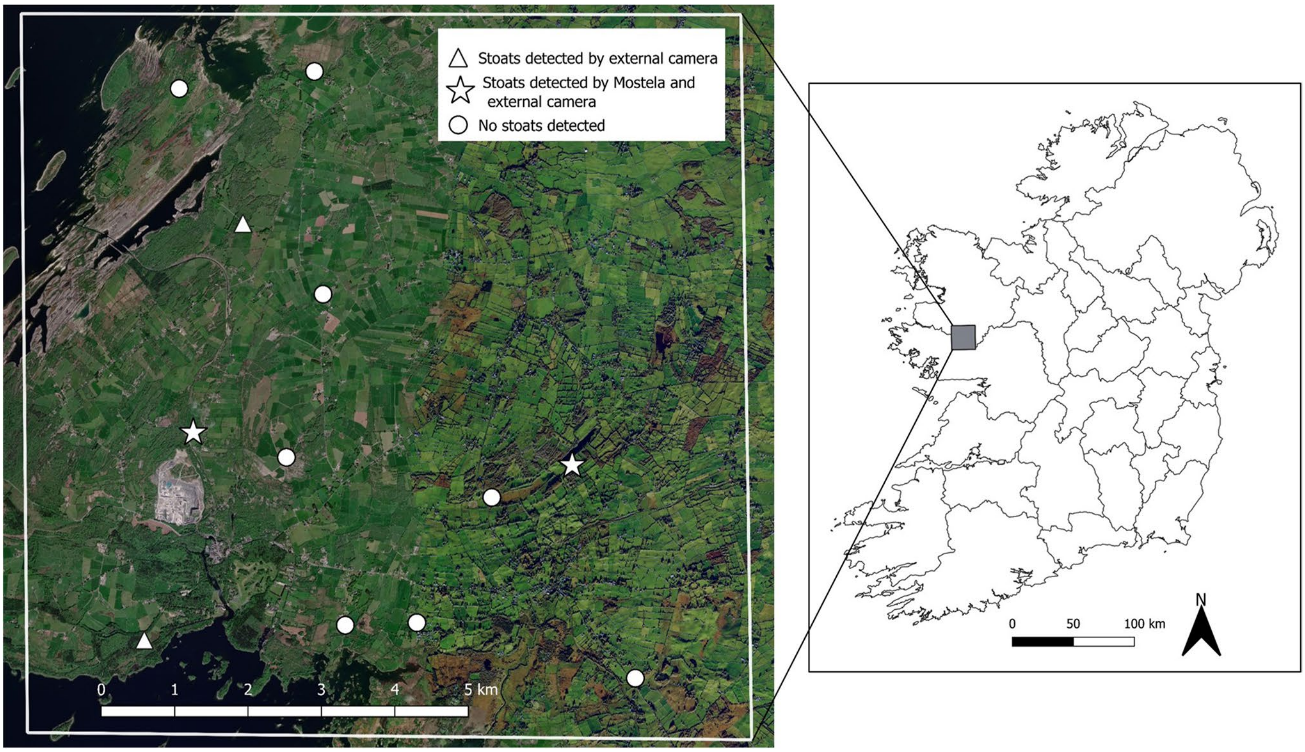

Fig. 1 Location of the survey sites and stoat detections by the two different camera trap-based methods (left) and location of the study area within Ireland (right)

wool pad was soaked with rabbit scent (Liquid Rabbit Scent, National Scent Company, http://www.nationalscentcompany.com) and placed inside a small plastic canister perforated with holes and attached inside the Mostela, just above the tunnel. Studies in New Zealand have found that the use of scent lures increases observations of stoats (Clapperton et al. 1999; Garvey et al. 2016), although stoats have been detected in Mostelas in England and the Netherlands without the use of lure (Croose & Carter 2019; Stichting Kleine Marters 2021). A section of pond liner was laid on top of each Mostela to provide protection from rain and camouflaged with vegetation and small branches.

Secondly, we deployed an external, stand-alone camera trap (Browning Strike Force Pro) outside of the Mostela, to record footage of animals passing by but not entering the Mostela, as well as those that did enter the Mostela. The external camera trap was fixed either on a 'bank stick' (a metal rod of adjustable height, with a fixture to attach a camera to the top and a spike to secure the rod into the ground) or tied to a fence post or tree and directed towards the entrance of the Mostela at a distance of less than 1.5 m. Rabbit scent was only used inside the Mostela and was not applied alongside the external camera trap.

The Mostelas and external cameras were located along stone walls, hedgerows and other vegetated linear features, which stoats are known to use (McAney 2010) (Fig. 2a, b). Mostelas and external cameras were in place for 13 weeks from April to July 2019. Sites were visited once per week, and the SD card and batteries in the camera traps were replaced as necessary. Lure was reapplied after 6 weeks. All footage was reviewed and the species recorded identified.

Statistical analysis

Detection and occupancy probabilities for Irish stoat were estimated using a single-season occupancy model (MacKenzie et al. 2002), implemented in the program PRESENCE, version 13.6 (Hines 2006). For each site where the two camera trap-based methods were deployed, we constructed a detection history coded binomially (1 = stoat detection, 0 = non-detection). We compared the detection and occupancy probabilities between the Mostela, the external camera trap and both methods combined. For determining the detection and occupancy probabilities for both methods combined, we pooled the detection history from both methods to generate a combined detection history. A survey occasion was defined as 1 day, providing daily detection histories and making a total of 90 survey occasions.

Fig. 2 **a**, **b** Examples of the two camera trap-based methods set up in the field to detect Irish stoats. In both photos, the Mostela is camouflaged to the right of the photo, with the entrance to the tracking tunnel visible, and the external camera is circled towards the left of the photo

Results

Detections

Over a total of 90 survey days, 9615 videos were recorded from both inside the Mostelas and the external cameras. A total of 13 mammal species were detected by at least one method: Irish stoat, pine marten *Martes martes*, wood mouse *Apodemus sylvaticus*, bank vole *Myodes glareolus*, brown rat *Rattus norvegicus*, pygmy shrew *Sorex minutes*, greater white-toothed shrew *Crocidura russula*, red squirrel *Sciurus vulgaris,* badger *Meles meles*, red fox *Vulpes vulpes*, Irish hare *Lepus timidus hibernicus,* fallow deer *Dama dama* and hedgehog *Erinaceus europaeus*.

Stoats were detected at 33% of sites ($n = 4$): 2 sites (17%) inside the Mostela (comprising a total of 17 unique detections) and at 4 sites (33%) on the external camera (comprising 23 unique detections), with 8 detections simultaneously recorded by both cameras (Table 1). Therefore, at 2 sites (17%), stoats were detected on the external camera moving past the Mostela, but not entering it. This non-agreement was not statistically significant (McNemar's $\chi^2 = 1.5$, df $= 1$, $p = 0.22$).

The first stoat detection occurred at the same site, both in the Mostela and on the external camera after 25 days (week 4 of the survey). At one site, a stoat was detected by both methods in 8 weeks out of the 13 weeks that the cameras were deployed. At all of the other sites where stoats were detected, they were detected during 2 or 3 weeks out of 13.

Detections of stoats were highest by both methods during weeks 10–12 of the survey (late June to mid-July), peaking in week 10 (end of June to beginning of July) (Fig. 3). Stoats were not detected by either method during weeks 1–3 of the survey (late April to early May) or weeks 7–8 (mid-June). All stoat detections, with the exception of one, occurred during daylight hours.

Occupancy and detection probabilities

Applying this simple model with constant occupancy and detection probabilities, we found that occupancy and detection probabilities varied according to the methods. Detection probabilities (p) were low, and varied from 0.05 (95% CI 0.03–0.08) for the external camera, to 0.09 (95% 0.05–0.14) for the Mostela (Table 2). The differences in the detection probabilities for all three methods were within 0.04, with wide and largely overlapping confidence intervals (Table 2),

Table 1 Detection of Irish stoats by two camera trap-based methods—Mostela and external camera—in counties Mayo and Galway, Republic of Ireland

Method	Total number of videos recorded	Number of Irish stoat detections*	Proportion of sites where Irish stoats detected	No. of days until first detection
Inside Mostela	1520	17	17% ($n = 2$)	25
External camera	8095	23	33% ($n = 4$)	25
Both methods combined	9615	32	33% ($n = 4$)	25

*Number of unique detections. If multiple consecutive videos were recorded of an animal at the same time and within 2 minutes between the Mostela and external camera, this is classed as one detection.

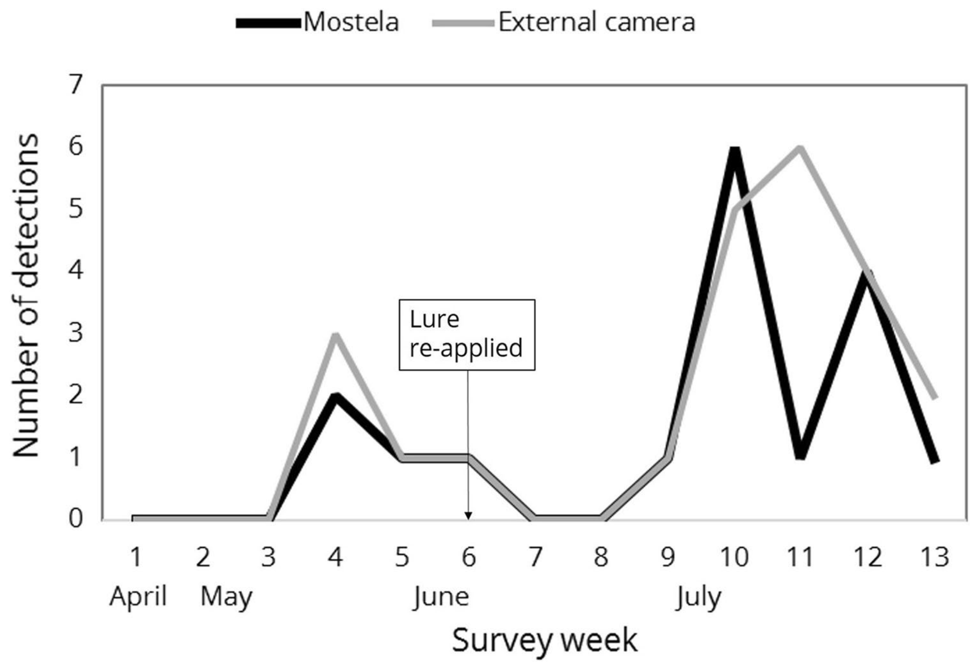

Fig. 3 Detections of stoats over a 13-week survey period by different camera trap-based methods in counties Mayo and Galway, Republic of Ireland

Table 2 Occupancy and detection probabilities for Irish stoat using different camera trap-based methods in counties Mayo and Galway, Republic of Ireland

Method	Naïve occupancy	Detection probability estimate (p) (95% C.I.) (s.e.)	Occupancy probability estimate (Ψ) (95% C.I.) (s.e.)
Mostela only	0.17	0.09 (0.05–0.14) (0.0214)	0.17 (0.04–0.48) (0.1076)
External camera only	0.33	0.05 (0.03–0.08) (0.0119)	0.34 (0.13–0.63) (0.1372)
Both methods combined	0.33	0.06 (0.04–0.09) (0.0130)	0.34 (0.13–0.63) (0.1365)

suggesting that they are not significantly different. However, this is based on a relatively small sample size, and a larger study would likely result in higher precision, enabling a difference in detectability between methods to be detected if one exists.

Occupancy probabilities (ψ) were relatively low; 0.34 (95% CI 0.13–0.63) for the external camera and 0.17 (95% CI 0.04–0.48) for the Mostela (Table 2). The occupancy probability for the external camera (0.34) was very close to the naïve occupancy estimate (0.33). The naïve estimate also falls within the confidence intervals for the Mostela occupancy probability.

Discussion

This is the first study to test the efficacy of camera trap-based methods (the 'Mostela' and a stand-alone camera trap) for detecting the Irish stoat. Both methods were successful in detecting stoats to varying degrees. In this study, stoats were detected in more locations by the external cameras than the Mostelas. However, at the sites where stoats were detected by the Mostela, they entered the Mostela on more occasions and were therefore recorded by this method more often than they were recorded by the external cameras. This resulted in the Mostelas having higher detection probabilities and lower occupancy probabilities.

It is encouraging that Irish stoats were detected inside the Mostelas, when stoats have not been detected in Mostelas in some studies elsewhere (Mos & Hofmeester 2020). In this study, we used liquid rabbit lure as bait inside all of the Mostelas. We acknowledge that by applying lure inside the Mostela but not outside with the external cameras, this could have made the Mostela more attractive to stoats than the external camera alone, which may account for the higher detection rate by the Mostelas than the external cameras. Whilst we cannot objectively evaluate any impact the lure might have had on visitation by stoats, in some of the videos recorded, the stoat can be seen approaching and smelling the canister containing the lure, suggesting an interest in the scent. The use of scent lure or food bait has been shown to increase detection rates of stoats in New Zealand (Clapperton et al. 1999; Garvey et al. 2017), yet other studies using Mostelas have not used bait or lure and have still achieved detections of weasels (Mos & Hofmeester 2020; Croose & Carter 2019) and stoats (Croose & Carter 2019).

The detectability of a species by a given method is partly influenced by inter-individual variation in behavioural traits, which shapes an animal's motivations and responses (Merrick & Koprowski 2017; Garvey et al. 2020). Bold, active, exploratory or aggressive individuals might be more likely to explore novel objects, such as Mostelas or tunnels, and therefore more likely to be detected by this method (Carter et al. 2012), whilst individuals that are less active, neophobic or too wary to approach may fail to be detected by methods which require exploration (Merrick & Koprowski 2017). During this study, there were two sites at which stoats were detected on the external camera passing the Mostela, but not entering it. Studies in New Zealand have demonstrated that some individual stoats are particularly neophobic and are reluctant to enter tunnels or traps (King & McMillan 1982; Brown 2001). It is possible that increasing the diameter of the tracking tunnel into the Mostela might increase visitation by stoats. In Mos & Hofmeester's (2020) study, they found that the detection probability for weasels was approximately two times higher for Mostelas with a 10-cm tracking tunnel compared with 8 cm (the size used in this study), although stoats have used much smaller tunnels (5 cm diameter) in studies in New Zealand (Brown 2001), and Irish stoats are generally smaller than British stoats (Sleeman 1987). It is not known how the proximity of the Mostela to the external camera influenced the detection of stoats by the external camera. To test this, both camera trap-based devices would need to be sited far enough apart to ensure that they could not influence each other.

Each camera-based method has some drawbacks which are worth considering for future studies. Using external, stand-alone camera traps increased detections of non-target species (videos of stoats accounted for < 1% of all videos recorded by the external cameras during this study) and therefore requires increased resources to analyse the video footage. However, using a citizen-science approach or emerging machine learning models to classify species in camera trap footage can facilitate analysis and reduce the time required to manually classify videos or images (Green et al. 2020; Tabak et al. 2019). The Mostela is much more species-specific and resulted in fewer detections of non-target species than the external camera (1520 videos recorded inside the Mostela versus 8095 recorded by the external camera). However, using a Mostela does increase the cost of the equipment, as the cost to construct the box plus the camera combined makes it more expensive than using a camera trap alone.

It is not known how detection and occupancy probabilities for Irish stoats would vary monthly or seasonally, and we were not able to explore this during this study. Mos & Hofmeester (2020) found large seasonal differences in site use (occupancy) and detectability of weasels using Mostelas in the Netherlands, with the highest site use in June to October and highest detection probability in August and September. Our study was carried out during spring and early summer (April to July), and stoat detections peaked during the end of June and beginning of July. As this study period coincided with the breeding season for stoats, this may have resulted in the assumption of a 'closed' population for the single season occupancy model being violated. This should not have changed the occupancy estimates, as any site would have had to have been originally occupied by a female stoat for breeding to occur; however, the detection probability would likely increase with animal density and as newly independent young are easier to detect.

The Mostelas detected multiple mammal species aside from stoats, which suggests that they could be applied for studies targeting other species. Of particular interest may be the detection of two shrew species; the native pygmy shrew (detected at 33% of sites) and the non-native, invasive greater white-toothed shrew (detected at 42% of sites), which were detected at two of the same sites. The expansion of the greater white-toothed shrew is causing a decline and apparent extirpation of the native pygmy shrew (McDevitt et al. 2014), and the Mostela, or a similar device, could be used to monitor these two species. Pine marten, a species of conservation interest in Ireland, was recorded inside the Mostela at 58% of sites and on the external camera at 92% of sites, although other methods of studying martens are already well-established (O'Mahony et al. 2017). The presence of pine martens did not appear to have a negative effect on stoat visitation, and both species were recorded at the same site within a short time frame (< 30 min).

This study builds on other work which highlights the potential for using modified camera trap methods to monitor small mustelids (e.g. Croose & Carter 2019; Mos & Hofmeester 2020), by demonstrating the applicability for monitoring the Irish stoat—a little-studied species. For future studies, it would be valuable to trial different approaches to the methods to test any effect on occupancy and detection probabilities. Firstly, testing Mostelas with a larger entrance tunnel diameter (10 cm, compared to the 8 cm used in this study), sensu Mos & Hofmeester (2020). Secondly, applying a scent lure with the external camera trap (e.g. at the bottom of a tree or fencepost where the camera is attached), as has been demonstrated to effectively detect stoats in New Zealand (Breedt & King 2021). For these studies, it would be worthwhile using pseudo-random site selection and exploring monthly, seasonal or yearly differences in detectability and occupancy of Irish stoats, as well as collecting data on covariates that may affect stoat occupancy, such as habitat features and rabbit presence. Overall, both the Mostela and stand-alone camera traps offer the potential for a wide-scale survey of the Irish stoat using citizen science. Such a monitoring programme would enable assessment of the population and conservation status of this little-studied species.

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Author contribution EC, SPC, RH, KM and JM contributed to the study conception and design. Material preparation was carried out by EC, RH, BH and KM. Data collection was performed by RH and BH. Data analysis was performed by EC and JM. The first draft of the manuscript was written by EC, and all authors commented on the manuscript and approved the final version.

Data availability The datasets generated during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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