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ORIGINAL ARTICLE

Scent lures and baits at camera traps improve time to first detection and detection probability of two typically elusive species of weasel

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Abstract

There is a growing body of evidence that weasel species are in decline globally. More data on their ecology and distribution are needed to plan and justify any conservation management actions. Camera trapping can be an effective survey method for many species; however, the small size and quick movements of weasels present challenges in detection and little consensus exists on practices for attracting them to improve detection. This study tested different combinations of meat baits and scent and audio lures to assess the most effective methods. Camera traps were set up in clusters of three at 42 sites to test the effectiveness of these combinations, accounting for season, in terms of the time to first detection (TFD), detection probability using occupancy models, and the number and clarity of weasel photos. We also repeated TFD and detection probability analyses for setups that were ≥ 20 m apart in case of overlap of effects. The average TFD across all sites was 43 days. Fall typically had the shortest TFD with beaver bait in fall achieving the best results. After accounting for occupancy, predicted detection probability across a 60-day survey was highest in fall with the best combination being salmon lure and beaver bait. The treatment type did not impact the average number of photos captured, but the clarity of photos was significantly positively related to use of bait and lure, type of lure, and specific combinations of bait and lure.

Keywords Attractants · Trail cam · Event curves · Mesopredator · Mustelid · Survey methods

Introduction

Historically, large, charismatic species have been the focus for monitoring ecosystem health and response to change. However, as they have been eradicated by human development, an array of mesopredators have taken their place on top of the food web. However, little is known about their role in trophic cascades and ecosystem diversity (Prugh et al. 2009). Most research has focused either on larger species or these smaller carnivores outside the complex ecosystems they inhabit (Roemer et al. 2009). Evidence suggests many of these smaller species are in danger of extinction (Marneweck et al. 2021). There is a need to monitor populations to determine their effects on various biotic and abiotic factors and identify methods for studying their distribution.

The *Mustelidae*, one such family of mesopredators, is the largest carnivore family and widespread globally (Williams et al. 2018). Many species are understudied and elusive, including the weasels. While the term 'weasel' is largely interchangeable with 'ermine' and 'stoat' in the United States, these are distinct species in other countries. For the purposes of this study, the term weasel will refer to all species in two genera (*Mustela* and *Neogale*). Weasels are known to inhabit young forests, agricultural areas, grasslands, riparian corridors, and old hedgerows or stone walls (King 1983; Sheffield and King 1994; Sheffield & Thomas 1997). As these habitats are lost or become fragmented, there is growing indication globally that weasels are declining (Coomber et al. 2021; Jachowski et al. 2021; Mos & Hofmeester 2020; Torre et al. 2018). Jachowski et al. (2021) showed a 91% decline in regional weasel harvest records since 1960. Conversely, a study in the Southeastern United States determined least weasel was more abundant than previously documented (Linzey & Hamed 2016), so

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population numbers may be higher than declining harvests would suggest.

Camera traps, or trail cams, can be an effective non-invasive survey method for small carnivores, however, there remain challenges with studying them in a natural environment (Bischof et al. 2014b). These species are secretive and can be hard to identify, but camera trapping is increasingly used to determine their ranges and population sizes (Marneweck et al. 2021). Jachowski et al. (2024) show cameras have been the most common weasel monitoring method for the past two decades. Weasels are difficult to study (Bischof et al. 2014b) and have been known to initially keep away from baited traps in their home range (Smith & Weston 2017), so traditional camera trapping methods often need to be adapted to improve detection. Palencia et al. (2022) recommend actions such as increasing sensitivity settings for fast-moving species (such as weasels), adjusting the camera height to match target species, and using lure to increase the probability of getting a clear shot. Despite these challenges, camera trapping is shown to be less expensive and more effective than other methods such as DNA analysis or live trapping (De Bondi et al. 2010; Gompper et al. 2006; Hofmeester et al. 2024; Jachowski et al. 2024; Mos & Hofmeester 2020).

Camera trapping approaches for weasels involve either unenclosed setups, where the camera is placed in the environment and focused on a point, or enclosed setups which are specialized for detection of small, fast-moving species (Jachowski et al. 2024). The *Mostela*, an enclosed camera trap designed for detecting weasels consisting of a wooden box and plastic tunnel, was first used in the Netherlands to detect weasels and has since been used successfully in larger scale applications (Croose & Carter 2019; Croose et al. 2022; Hofmeester et al. 2024; Mos & Hofmeester 2020). The AHDriFT system, which encloses cameras in boxes and directs animals to the boxes through a fence system, has also achieved recent successes in weasel identification (Jachowski et al. 2024). Jachowski et al. (2024) document advantages to enclosed systems such as the possibility of estimating activity patterns and occurrence and a wider range of deployment options in difficult habitats. However, systems like the *Mostela* and the AHDriFT are expensive when compared to traditional trap setups and involve additional equipment. The *Mostela* requires an addition to the camera lens and the AHDriFT requires setting up fencing. Other studies have succeeded by modifying the way traditional unenclosed cameras are deployed to better detect small species while saving time and expense. These modifications include mounting cameras at a lower height, moving them closer to an attractant, setting cameras to take bursts of several photos upon detection, and deploying multiple cameras in close proximity to increase detection (Bischof et al. 2014a; Evans & Mortelliti 2022; Lombardi et al. 2017).

The use of bait (food attractants) and/or lure (scent attractants) has been shown to increase detection of small carnivores (Buyaskas et al. 2020; Holinda et al. 2020; Randler et al. 2020). Additionally, Mortelliti et al. (2024) found a higher cost associated with conducting studies without bait or lure for mustelid species as more sites were needed to achieve measurable results, leading to additional time and resources. However, little consensus exists between studies on the most effective attractants for weasels. Some of the more common bait types were beaver (*Castor canadensis*) or various types of fish, and lure types were skunk-scented lure or fish oil (Evans et al. 2019; Long et al. 2012). Combining bait and lure at a setup has been shown to be particularly effective for detecting mustelids (Buyaskas et al. 2020). Jachowski et al. (2024) document that no individual study in their literature review of the previous 20 years compared effectiveness of different bait and lure types on weasel detection, which indicates a gap in current knowledge.

The three weasel species historically known to occur in Pennsylvania, United States are the least weasel (*Mustela nivalis*), the short-tailed weasel (*Mustela richardsonii*), and the long-tailed weasel (*Neogale frenata*). The long-tailed weasel was previously in the genus *Mustela* (*Mustela frenata*) but was reclassified in 2021 to the new genus *Neogale* (Patterson et al. 2021). *M. richardsonii* was, until recently, believed conspecific with *Mustela erminea*, though a recent study reclassified them as two distinct species of short-tailed weasels with varying distributions (Colella et al. 2021). There is anecdotal evidence that these three species are declining across the state, leading to an interest in better understanding their current distribution. While weasels were once considered common throughout Pennsylvania, they have been notably absent or difficult to detect in more recent studies (Jachowski et al. 2021; Kirkland & Krim 1990; Kirkland & Hart 1999). Least weasel is only historically confirmed in the central and western regions of the state (Richmond & McDowell 1952; Sutton 1929). While outside the study area, this species was included in case its presence was confirmed by the study.

For Pennsylvania, the only data currently available to broadly assess the status of weasel populations come from game take or furtaker surveys (forms filled out by hunters to estimate the number of individuals killed) and pelt data from fur sales. However, these data are infrequent and often not verifiable by state staff. Currently, weasel sightings and records from the Pennsylvania Game Commission (PGC), the entity responsible for managing all state furbearer populations, are rare. This departs from state-specific publications from the early twentieth century that indicated weasel species (long-tailed weasels in particular) were common (Latham 1952; Mohr 1931). Even as recently as 1990 (Kirkland & Krim), weasel populations in Pennsylvania were considered secure, except for least weasel which was given Status Undetermined. This suggests weasel species in the state may be declining, or at the very least, current methods for tracking abundance are inadequate. If weasel species in the state are indeed declining, then recovery options establishing appropriate measures need to be employed to prevent extirpation.

In this study, we deployed different combinations of baits and scent and audio lures in various habitat types to compare effect on unenclosed camera trap detection of weasels, with the aim of informing a wider regional study of the distribution of these species, but also to inform methods of studying weasel species globally. While success has been documented with enclosed camera setups, we decided to trial methods for improving detections with unenclosed setups to see if we can achieve similar success with less time and expense. Specifically, we measured the impact of baits and lures relative to control setups and hypothesized their use would improve 1) the time to first camera trap detection, 2) the probability of detection while accounting for occupancy, and 3) the quality (clarity and number) of photographs when detected.

Materials and methods

Site selection and camera arrangement

The study took place in eastern Pennsylvania, USA (Fig. 1). Sites with suitable weasel habitat and relatively easy access were chosen in areas of public protected land or where permission could be obtained from private landowners in four counties.

At each site, three cameras were set up using different configurations to test successful detection methods. Cameras were set up 1–3 m away from the focal point (the point where an (un)baited setup would be placed) to increase detection of smaller species. The variation in this distance occurred due to topography and availability of features (e.g., stone wall, log/brush pile, or other rock formation) on which to attach a camera but was random with respect to treatment (see below). The three cameras were clustered to ensure habitat type was consistent between traps. Cameras within clusters were placed 5–65 m (mean 20 m) apart, depending on available features, to reduce overlap of bait/lure scents.

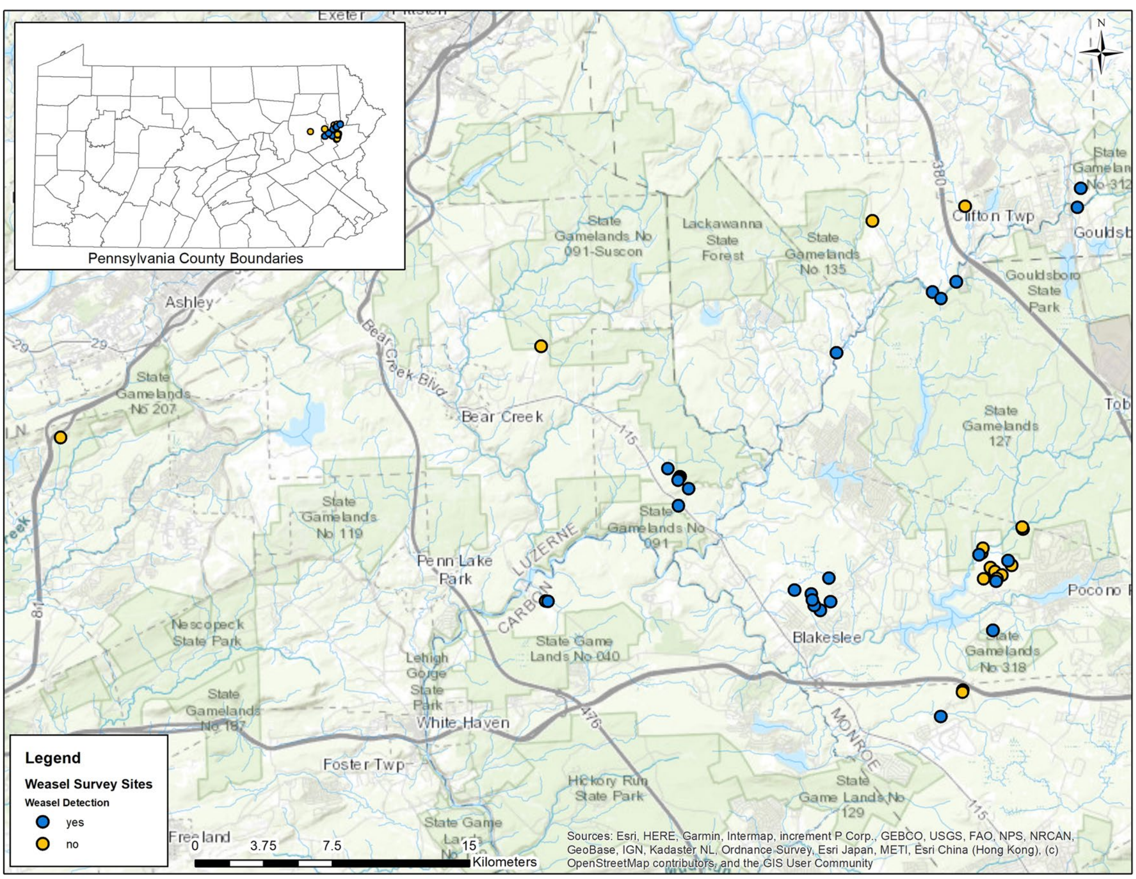

Fig. 1 Location of study sites across four counties in Pennsylvania. Individual sites are depicted by blue dots where weasels were detected and orange dots where they were not. Placement of camera clusters at each site is not shown due to the scale of the map

Sites were visited every 2–4 weeks (variation due to weather or scheduling conflicts) to replace SD cards and refresh bait and lure if present.

Three trap methods were used. In the first (Fig. 2a), cameras were attached to trees or metal fence posts pointed at a feature and 30 cm PVC pipe was added either on or under the feature (adapted from Lombardi et al. 2017). The second trap method (Fig. 2b) further adapted Lombardi et al. (2017), by affixing a 25 cm scale bar to the PVC pipes to aid measurement of weasels. The third method (Fig. 2c) adapted approaches from a study in Maine, USA, by Evans & Mortelliti (2022). A metal wire mesh cage, with 6 × 6 mm openings to minimize rodent and other mammal predation, approximating the suet cages used by Evans & Mortelliti (2022) was affixed to the feature. For non-control setups, bait and lure were placed in the pipe or mesh cage.

Camera setup and duration in the field

The study deployed infrared motion-triggered cameras that were available for the project (Lift II, Exodus, Ohio, USA; Trophy Cam HD, Bushnell, Kansas, USA) at 42 sites from November 2022 through February 2024. Since there are four distinct seasons in Pennsylvania (fall, winter, spring, and summer), each site was assigned a season comprising the entirety or majority of its deployment (Fig. 3). Bait and lure were used at 28 sites while 14 sites were designated as control sites without bait and lure. Supplementary Material 1 lists each site's name, location, and treatment type. To replicate prior successful studies, cameras were set to the highest sensitivity settings and to take three burst shots (Kolowski & Forrester 2017; Laux et al. 2022; Lombardi et al. 2017) with a one-second delay on the Lift II but not the Bushnell which lacked this feature.

Two previous camera trap studies analyzed time to first detection for weasel species and were used to inform duration of camera trap deployment. When studying least weasel (*M. nivalis*) and stoats in England, Croose & Carter (2019) found time to first detection ranged from 16 to 54 days. Smith & Weston (2017), studying stoats (*M. erminea*) in New Zealand, found median time to first detection ranged from nine to 43.5 days. Based on these studies, our deployments per site lasted at least 60 days. Initially, once a weasel was detected at one camera setup, that site remained active for at least three more weeks (even if this extended beyond the 60-day period) to determine whether weasels would return to the same camera trap or visit additional traps at the site. Three exceptions to this three-week period occurred when a camera trap was removed from a site and it was later discovered weasels were detected in the final week. To maximize sample size, from August 2023 deployment time was modified to last only until a weasel was detected at a site since we found the incidence of repeat detections very low. Croose & Carter (2019) theorized detection rates could be negatively influenced by low population densities, poor camera placement, or seasonality. Given these considerations

Fig. 2 Examples of the three trap method setups. On the left (**a**) is the first method consisting of a PVC pipe, and the camera is shown installed on a metal fence post. An example of one of the hanging attractants (bird feather) used early in the study is shown. The second method in the middle (**b**) shows a scale bar affixed to the PVC pipe, and the camera is shown installed on a tree. On the right (**c**) is the third method in which a wire mesh cage is affixed with a metal screw. Red arrows are used to indicate some features described above

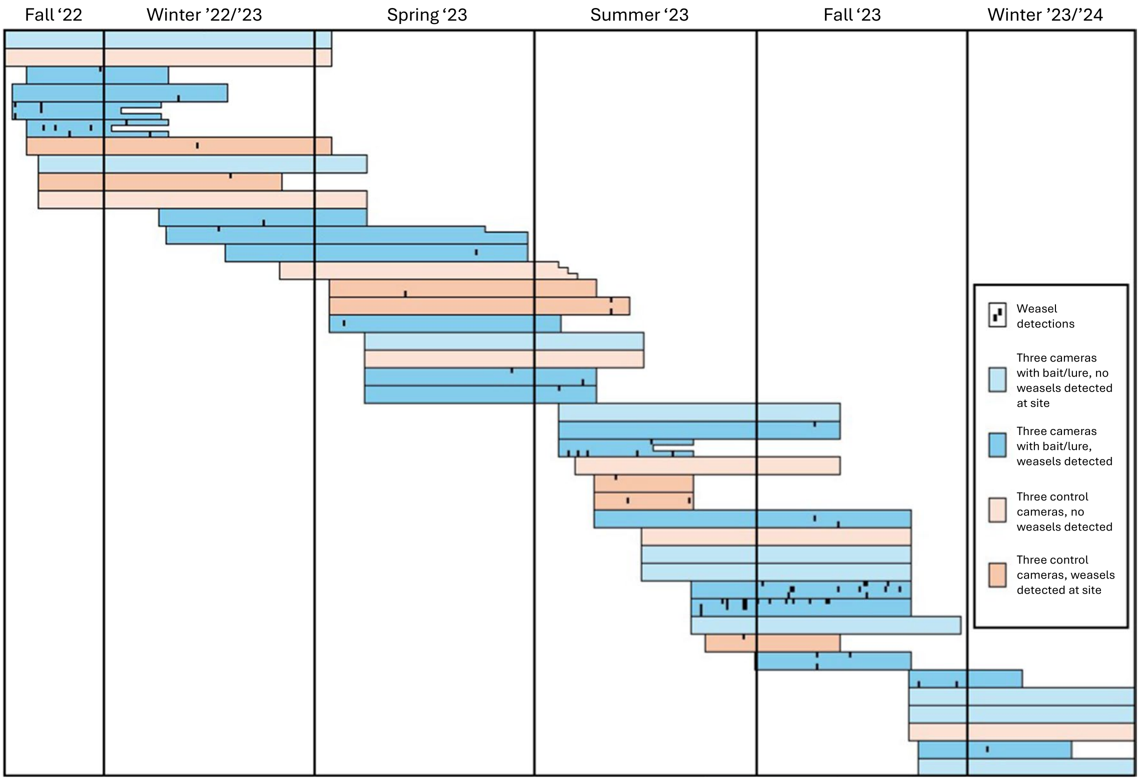

Fig. 3 Calendar of camera trap deployment and weasel detections across the study. Each bar is a site ($n = 42$) representing a set of three associated camera setups (total cameras $n = 126$), color-coded by type of site (with bait and lure combinations or without) and if weasels were detected at the site or not. For analyses purposes, sites were assigned to the season in which the majority of operation days fell

and the lack of Pennsylvania-specific time to detection information, each site without weasel detections remained active for double the amount of time (120 days), apart from four sites active at the end of the study (February 2024). The range in exposure times at different sites did not affect analysis since time to first detection allowed for censoring of data when camera traps were removed before 120 days, and detection was measured as daily detection probability, allowing for varying exposure time (see below for details). At any one time, 10–12 sites utilizing 30–36 cameras were active. This number of sites maximized the cameras available for the study while allowing them to be checked all in one day.

Bait and lure

Each setup received one bait and one lure, which were used in different combinations, to test their effectiveness as attractants. Bait was either North American beaver (*Castor canadensis*) meat (Evans et al. 2019; Long et al. 2012) (hereafter just 'beaver') or Reuwsaat's Extreme Performance "Deep Creek" All Predator paste bait (hereafter just 'paste'), which was suggested for trial by PGC. Beaver meat was placed only in the mesh cages due to concerns with tampering from American black bears (*Ursus americanus*) and raccoons (*Procyon lotor*), except in the case of three sites where it was tried with a scale pipe setup. Paste bait was used only with the two PVC pipe setups due to its viscous nature which was not compatible with the wire mesh.

Lure was either Caven's Long Distance Call Lure "Gusto" (Minnesota Trapline Products, Inc.) (Lombardi et al. 2017), Minnesota Brand Superior Salmon Oil (Minnesota Trapline Products, Inc.) (adapted from Long et al. 2012), or Reuwsaat's Extreme Performance Weasel Supreme Lure (suggested for trial by PGC) which are hereafter just "Gusto", "salmon," and "supreme." Lure was applied to raw sheep's wool, which holds scent for extended periods while increasing attraction with its own scent. A Kill Squeak Trap Call (MasterTrappers.com), an audio lure suggested for trial by PGC, was also utilized at some sites. Control sites had no bait or lure, but some control sites had Kill Squeaks (see Supplementary Material 1).

Initially, visual lures beyond the PVC pipes and mesh cages were used at some of the sites. These lures consisted of either any available bird species feathers (Fig. 2a), or a contraption of mylar flagging attached to a CD with fishing line. They were then attached to a tree branch above the trap setup. This was a method suggested for trial by PGC. However, visual lures were removed by three months into the fifteen-month study due to increased complexity of setup and data analysis, and to avoid tampering from attracting people to the traps.

Data analysis

The original study design had been exploratory since so little information existed about how to attract weasels to camera traps. As such, the distinct types of baits and lures were used in combination to maximize the number of each that could be tested with limited time and resources. We felt this may also maximize our detections as Buyaskas et al. (2020) found combining baits and lures to be effective for detecting mustelids. Evans et al. (2019) documented similar effectiveness for mustelids and saw a three-fold increase in detections of one of our target species (*M. richardsonii*) with the combination of bait and lure as opposed to control or lure only sites. We could not analyze a crossed bait and lure design which included a control as sites were all either (i) a control or (ii) had three of six combinations of the baits and lures. However, we were able to statistically compare 1) any bait and lure combination versus control, 2) each of the two types of bait (with any lure type) versus control, 3) each of the three types of lure (with any bait type) versus control, and 4) each of the six unique combinations of bait and lure versus control. Finally, we could also 5) compare setups with versus without Kill Squeaks. Each variable included in the analysis, and its associated levels, is shown below in Table 1.

Table 1 Definitions and levels for each of the six categorical variables used to test the hypotheses. 'No' or 'none' represent control sites

Variable name	Variable description	Levels
baitlure	Presence or absence of any bait and lure combination	Yes No
baittype	Type of bait used at camera setup	Beaver Paste None
luretype	Type of lure used at camera setup	Gusto Salmon Supreme None
baitluretype	Type of unique bait and lure combination at camera setup	Beaver and gusto Beaver and salmon Beaver and supreme Paste and gusto Paste and salmon Paste and supreme None
KS	Presence or absence of Kill Squeak	Yes No

To test Hypothesis 1, time to first detection (TFD) was assessed in R (R Core Team 2023) using the package 'survminer' (Kosinski et al. 2020) by adapting time-to-event analyses typically used for survival curves following the Kaplan–Meier non-parametric method. Non-independence of camera trap setups within sites was accounted for using site identity as the 'cluster' argument. Data used to develop event curves were right-censored when no detection occurred at a camera trap. The 'ggsurvplot' function in this package allowed detection curves to be fitted for each treatment type to determine the required survey effort. The 'survreg' function allowed a log rank test for the effect of each explanatory variable in Table 1. Using the variables in Table 1, we specified 12 candidate models representing a priori hypotheses about the importance of baits and lures on TFD, including a null model (Table 2). Each of the variables were included with and without a term for season, and season was included as a model on its own. Season (fall, winter,

Table 2 Candidate set of a priori hypotheses and model tested for each, designed to test the effectiveness of different baits and lures as compared to control. Table 1 contains a definition for each explanatory variable. A random effect of site identity was included in each model

Model	Explanatory variable(s)	Hypothesis
1	Null model	None of the variables explain TFD for weasels at camera traps
2	baitlure	The use of any bait and lure influences TFD
3	baittype	The type of bait used influences TFD
4	luretype	The type of lure used influences TFD
5	KS	The use of a Kill Squeak influences TFD
6	baitluretype	The specific combination of bait and lure influences TFD
7	season	The season a site is active influences TFD
8	season + baitlure	The use of any bait and lure in combination with the effect of season influences TFD
9	season + baittype	The type of bait in combination with the effect of season influences TFD
10	season + luretype	The type of lure used in combination with the effect of season influences TFD
11	season + KS	The use of a Kill Squeak in combination with the effect of season influences TFD
12	season + baitluretype	The specific combination of bait and lure in combination with the effect of season influences TFD

spring, or summer) was assigned to each site based on the season in which the majority of that setup was operational. We performed TFD model selection using the small sample Akaike's Information Criterion AIC_c and took inference from any models with $\Delta_{AICc} < 2$. This modelling process was then repeated for a subset of sites with setups ≥ 20 m apart, to mitigate for any potential olfactory overlap of effects.

Absence of weasels on a camera trap could be due either to lack of detection or the fact that weasels do not occupy that site. Following Mos & Hofmeester (2020) and Croose et al. (2022), we used an occupancy model to test Hypothesis 2 by investigating differences in detection probability between treatments while accounting for potential variation in occupancy between sites. Daily encounter histories were constructed based on the calendar in Fig. 3. For detection probability, we used 12 base models for detection containing the same variable combinations as those used for TFD analyses (Table 2) as fixed effects. All models also had a 'site' random effect for both occupancy and detection to account for the grouping of setups within sites. For occupancy, like Mos and Hofmeester (2020), we included a term to account for variation in site use through the annual cycle. In our case this was season rather than month since each setup could be assigned more readily to a season and, due to restricted sample sizes, we could not increase the number of model parameters too much. Season was assigned based on the season in which the majority of that setup was operational, as with TFD analyses. Our primary hypotheses related to the impact of baits and lures on detection probability, but we wanted to account for potential variation in occupancy, so we did not include bait or lure terms in the occupancy component of the model, only season (fixed effect) and site (random effect).

Models were run in the R package 'spOccupancy' (Doser et al. 2022) which fits occupancy models within a Bayesian framework using Pólya-Gamma data augmentation. We used the single-species occupancy model function 'PGOcc' which assigns Gaussian priors to the occurrence and detection regression coefficients. Following Doser & Finley (n.d.), we fitted the models using default initial values for the MCMC sampler, and for the priors we used the default values (hypermeans = 0, hypervariances = 2.72). We used trace plots and the Gelman–Rubin diagnostic to assess MCMC convergence and via trial-and-error found that the default 5,000 MCMC samples was insufficient, so this was increased to 10,000 samples, when all parameter R-hat values were ≤ 1.2 (the threshold indicated in Brooks & Gelman 1998). We used the default burn-in of 3,000 and a thinning rate of 2, with 3 MCMC chains.

We performed occupancy model selection using the WAIC and took inference from the model with the lowest WAIC and any models with $\Delta_{WAIC} < 2$ (the confidence set). We also assessed model fit of the selected models using the Freeman-Tukey statistic and Bayesian P-value, although these had to be applied to equivalent models with fewer MCMC samples (the default 5,000) due to memory allocation limits. As with TFD, occupancy modelling was then repeated for a subset of setups ≥ 20 m apart, to mitigate for any potential olfactory overlap of effects.

For confidence set models, we converted estimated daily detection probability (DDP) values to probabilities of detecting a weasel in 60 days (P_{60}) using Eq. 1. The period of 60 days was chosen because this is a reasonable timeframe for which to collect data, is inclusive of all first detections at sites from Croose & Carter (2019) and all median detections at sites from Smith & Weston (2017), and is a more intuitive value for practitioners to consider than daily detection probabilities. We also converted our highest and lowest daily detection probabilities to probabilities of detecting a weasel in 14 days (P_{14}) for ease of comparison to Mos & Hofmeester (2020) using Eq. 2.

$$P_{60} = 1 - (1 - DDP)^{60} \quad (1)$$

$$P_{14} = 1 - (1 - DDP)^{14} \quad (2)$$

Testing Hypothesis 3, two measures of photo quality were analyzed against the variables in Table 1. The first measure of quality was the average number of photos for each weasel detection based on treatment type assuming that a higher number of photos would allow for easier identification of weasel species. The second measure was a subjective assessment of clarity of the photo(s) with respect to weasels. This was measured on a scale (excellent, good, fair, poor) and averaged across all weasel encounters at a camera trap, defined as a set of photos taken within a one-hour period. The definition of each level of scale is shown in Table 3 and examples of photos for each are shown in Fig. S1 (Supplementary Material 2). Analyses for both quality measures and each explanatory variable were completed using a Mann–Whitney U Test, Kruskal–Wallis Test, or General Linear Model depending on response variable (count or score), number of levels (two or more), or apparent normality of residuals.

Results

Across all sites, 75 weasels were detected of which 55 were long-tailed weasels, 16 were short-tailed weasels, and four were weasels unable to be identified to the species level. No least weasels were identified during this study. Examples of detections for each species are shown in Fig. 4. Weasels were detected at 25 of the 42 sites at 38 camera trap setups. They were detected at 36% of camera traps with bait and lure and 19% of camera traps without.

Table 3 The four levels of photo clarity for each treatment type. An example for each level is shown in Fig. S1 (Supplementary Material 2)

Photo score	Description
Excellent (4)	A clear shot of a weasel where the species can be identified, and orientation is such that measurements can be taken of the head, body, and tail
Good (3)	A mostly clear shot where species can be identified, and orientation is such that measurements can be taken of either the head and body or the tail
Fair (2)	A shot where orientation is such that measurements cannot be taken, and the subject is blurred in motion or partially obscured
Poor (1)	A shot that is blurry and/or obscured where the subject is passing through the site quickly; species is difficult or impossible to determine

Fig. 4 Examples of weasel detections at four setups in the study. Photo (**a**) shows a long-tailed weasel at night interacting with bait and lure in a mesh cage. Photo (**b**) shows a short-tailed weasel in daytime investigating bait and lure in the PVC pipe and/or the Kill Squeak next to it. Photo (**c**) shows a long-tailed weasel in daytime near the scale bar at a control setup. Photo (**d**) shows a short-tailed weasel at night near a PVC pipe housing bait and lure

Time to first detection

The mean time to first detection (TFD) across all sites was 43 days, though it ranged from one to 119 days. Values from two setups had to be assumed as a midpoint between researcher visits when two cameras stopped recording date and time. Setups with bait and lure had a shorter mean TFD (39 days) than setups without (58 days).

There were three models in the confidence set ($\Delta_{AICc} \leq 2$) for the full dataset and two for dataset containing only setups ≥ 20 m apart (Table 4). For TFD, season was contained in all confidence models both for the full set of sites and the restricted set. For all setups (Table 4a) there was some support for a model with just season ($w_i = 0.2$) but also equal or more support for models containing season and baitlure ($w_i = 0.20$) or season and baitype ($w_i = 0.43$). For the setups ≥ 20 m apart, the confidence set contained season and baitlure ($w_i = 0.50$) and season and baittype ($w_i = 0.29$) and not the season-only model, suggesting slightly stronger evidence for an effect on TFD. Plots showing estimated TFD are shown in Fig. 5, though due to space only for two representative best models from Table 4. The remaining three plots showing results for the restricted dataset and season alone are included in Fig. S2 (Supplementary Material 3). Setups with any baitlure combination consistently performed higher than those without during fall, though remain varied during the other seasons (Fig. 5a). For baittype models, beaver bait generally performed best with some exceptions based on season or length of deployment (Fig. 5b). When considering season alone (plot in Supplementary Material 3), fall was the season with the shortest TFD, i.e. weasels

Table 4 Comparison results for candidate set of TFD models in Table 2 for a) all setups (n = 126) and b) only setups ≥ 20 m from another (n = 73). df = degrees of freedom, − ln(L) = negative log-likelihood of model, AICc = small sample Akaike's information criterion, Δ_{AICc} = difference between the AICc for given and best model, w_i = Akaike's weights. Explanatory variables are defined in Table 1. Models shown in bold form the confidence set ($\Delta_{AIC} < 2$)

Model	Explanatory variable	df	− ln(L)	AICc	Δ_{AICc}	w_i
9	**season + baittype**	**7**	**-239.2**	**493.4**	**0.00**	**0.426**
8	**season + baitlure**	**6**	**-241.1**	**494.9**	**1.50**	**0.202**
7	**season**	**5**	**-242.2**	**494.9**	**1.51**	**0.200**
11	season + KS	6	-241.7	496.1	2.76	0.107
10	season + luretype	8	-240.5	498.3	4.94	0.036
12	season + baitluretype	11	-238.1	500.4	7.03	0.013
3	baittype	4	-246.5	501.4	7.98	0.008
2	baitlure	3	-248.1	502.4	9.00	0.005
1	null model	2	-250.3	504.7	11.30	0.001
5	KS	3	-249.8	505.8	12.43	0.001
4	luretype	5	-247.7	505.8	12.46	0.001
6	baitluretype	8	-245.4	507.9	14.54	0.000
Model	Explanatory variable	df	− ln(L)	AICc	ΔAICc	w_i
9	**season + baittype**	**7**	**-169.3**	**354.3**	**0.00**	**0.498**
8	**season + baitlure**	**6**	**-171.1**	**355.4**	**1.12**	**0.285**
10	season + luretype	8	-169.8	357.9	3.65	0.080
7	season	5	-173.6	358.0	3.74	0.077
12	season + baitluretype	11	-166.9	360.1	5.79	0.027
11	season + KS	6	-173.4	360.1	5.86	0.027
2	baitlure	3	-179.4	365.2	10.92	0.002
3	baittype	4	-178.4	365.3	11.02	0.002
1	null model	2	-181.3	366.8	12.53	0.001
4	luretype	5	-178.6	368.1	13.86	0.000
5	KS	3	-181.1	368.5	14.20	0.000
6	baitluretype	8	-176.8	371.9	17.64	0.000

detected more quickly, followed by summer, spring, then winter.

Probability of detection

Three models were in the confidence set of occupancy models ($\Delta_{WAIC} \leq 2$) for the full dataset and two for the dataset with setups < 20 m apart removed (Table 5). In both cases the top model contained luretype as the detection covariate and the second top model included the addition of season. For the full dataset, a third model containing season and baitluretype was also selected. In both cases the w_i of models in the confidence set were substantially higher than those of models outside. We could not calculate Bayesian P-values for the models due to memory allocation, but with reduced MCMC samples (the default 5,000) these were 0.443 (all data, model 4), 0.376 (all data, model 10), 0.382 (all data, model 12), 0.686 (setups < 20 apart removed, model 4) and 0.497 (setups < 20 apart removed, model 10), indicating no lack of fit (which would be indicated by values < 0.1 or > 0.9). Naïve and modelled occupancy values for these models are in Table 6.

Detection probabilities calculated over 60 days (P_{60}) from two representative best supported models from Table 5 are plotted in Fig. 6. The three remaining plots from the models in Table 5 are included in Fig. S3 (Supplementary Material 4). For models without season as a detection term, salmon lure had the highest detection probability, followed by supreme, gusto, and none. Where season was included, detection probability was highest in fall, followed by summer, spring then winter. For the model that assessed each combination of bait and lure, the combination of beaver bait with salmon lure had the highest detection probability. The mean estimated values of detection over 60 days ranged from 0.05 (paste bait and gusto lure in winter) to 0.96 (beaver bait and salmon lure in fall). For comparison for detection over 14 days (P_{14}, Mos and Hofmeester 2020), these are equivalent to 0.01 and 0.53 respectively.

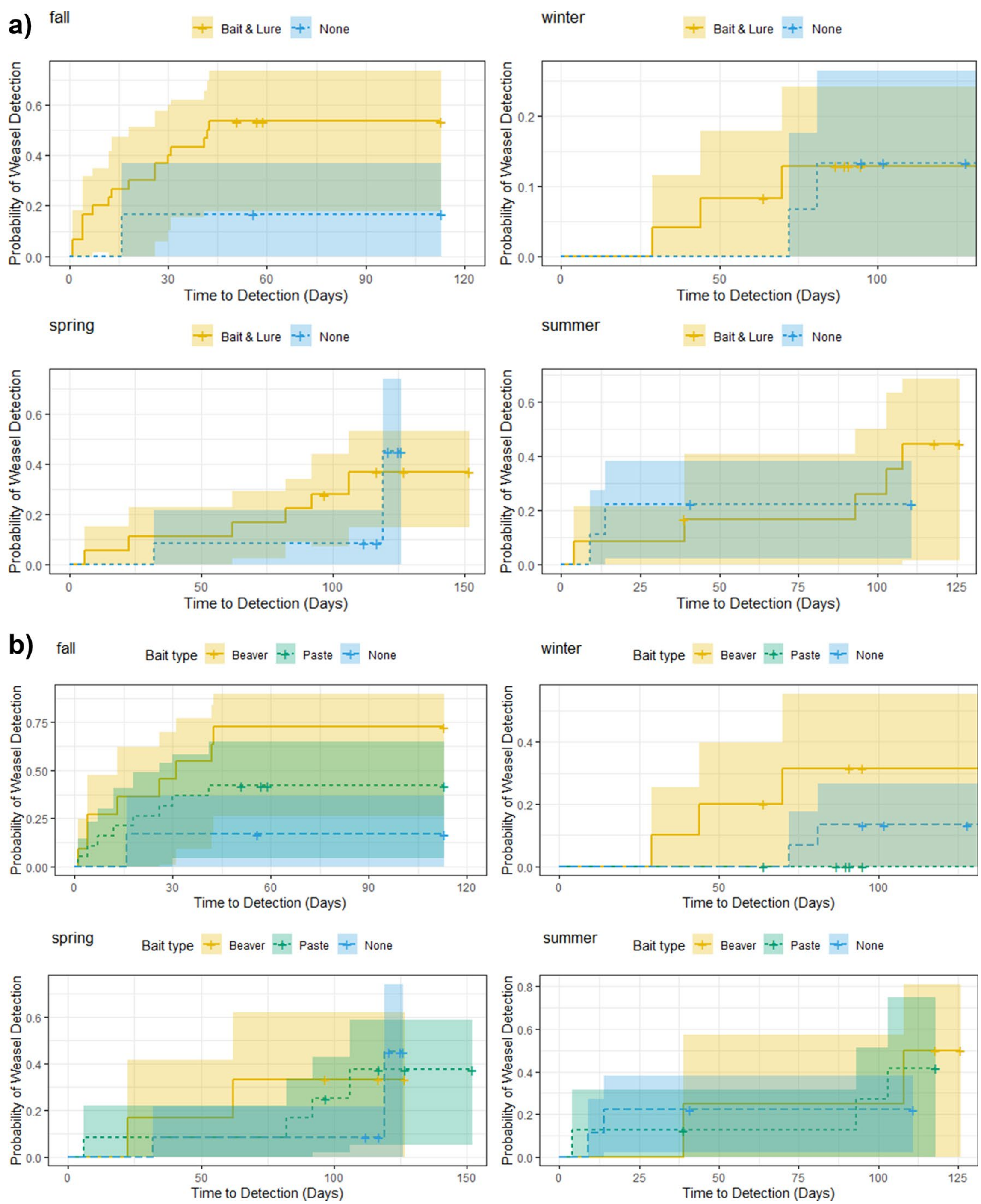

Fig. 5 Event curves (±95% confidence intervals) depicting time to first detection (TFD) estimated for two representative best models (Table 4) (**a**) use of bait and lure vs. control during the four seasons for the full dataset and (**b**) type of bait used during the four seasons for the full dataset. For brevity, we only show plots from these two models, and plots of the remaining three best models are provided in Supplementary Material 3. The '+' symbols indicate where data were censored when the camera trap was removed before a weasel detection occurred

Photo quality

Across all setups in the survey, the median number was 3 photos with a minimum number of 1 photo and a maximum number of 57 photos. The average number of photos taken at each camera trap that detected weasels was not significantly related to the use of bait and lure ($P=0.117$), the type of bait used ($P=0.283$), the type of lure used ($P=0.220$), the

Table 5 Model selection results for occupancy models containing a) all setups ($n=126$) and b) only setups ≥ 20 m from another ($n=73$). elpd = expected log point-wise predictive density, pD = effective number of parameters, WAIC = Widely Applicable Information Criterion (-2*[elpd-pD]), Δ_{WAIC} = difference between WAIC of each model and that of the lowest, w_i = Akaike's weight of the model. All models contain a season occupancy term and a site random effect for both occupancy and detection

Model	Detection	elpd	pD	WAIC	Δ_{WAIC}	w_i
4	**luretype**	**-366.78**	**21.96**	**777.48**	**0.00**	**0.36**
10	**season + luretype**	**-364.79**	**24.07**	**777.73**	**0.25**	**0.32**
12	**season + baitluretype**	**-365.26**	**23.70**	**777.93**	**0.45**	**0.29**
6	baitluretype	-366.79	24.38	782.33	4.85	0.03
11	season + KS	-368.26	25.38	787.28	9.80	0.00
7	season	-370.23	25.86	792.18	14.70	0.00
5	KS	-370.35	26.16	793.01	15.53	0.00
8	season + baitlure	-370.38	26.56	793.87	16.39	0.00
9	season + baittype	-370.79	27.41	796.39	18.91	0.00
1	*null*	-372.47	26.81	798.55	21.07	0.00
2	baitlure	-374.03	25.77	799.61	22.13	0.00
3	baittype	-372.09	28.23	800.64	23.16	0.00
Model	Detection	elpd	pD	WAIC	Δ_{WAIC}	w_i
4	**luretype**	**-287.56**	**15.22**	**605.55**	**0.00**	**0.53**
10	**season + luretype**	**-286.96**	**16.54**	**607.00**	**1.45**	**0.26**
12	season + baitluretype	-287.25	17.71	609.92	4.36	0.06
6	baitluretype	-288.36	16.90	610.52	4.97	0.04
8	season + baitlure	-287.78	17.87	611.31	5.75	0.03
1	*null*	-289.23	16.83	612.12	6.57	0.02
7	season	-288.54	17.53	612.15	6.59	0.02
2	baitlure	-289.15	17.15	612.60	7.05	0.02
11	season + KS	-289.04	17.32	612.73	7.17	0.02
5	KS	-288.87	18.15	614.04	8.49	0.01
3	baittype	-289.48	17.96	614.88	9.32	0.01
9	season + baittype	-289.08	18.65	615.45	9.89	0.00

Table 6 Naïve and modelled occupancy estimates for a) all setups and b) only setups ≥ 20 m from another for the models selected (Table 5). Sample size (n) for naïve occupancy per season shown. Empirical mean and standard deviation for modelled occupancy are given

Season	Naïve occupancy	Model 4	Model 10	Model 12
fall	0.47 ($n=36$)	0.91 (±0.10)	0.81 (±0.18)	0.79 (±0.20)
winter	0.13 ($n=39$)	0.75 (±0.18)	0.74 (±0.22)	0.75 (±0.23)
spring	0.30 ($n=30$)	0.45 (±0.23)	0.74 (±0.25)	0.76 (±0.26)
summer	0.30 ($n=21$)	0.76 (±0.18)	0.84 (±0.17)	0.84 (±0.18)

Season	Naïve occupancy	Model 4	Model 10
fall	0.61 ($n=23$)	0.90 (±0.11)	0.91 (±0.11)
winter	0.19 ($n=21$)	0.68 (±0.24)	0.74 (±0.24)
spring	0.39 ($n=18$)	0.70 (±0.26)	0.77 (±0.23)
summer	0.36 ($n=11$)	0.83 (±0.16)	0.86 (±0.14)

specific combinations of bait and lure ($P=0.166$), or the use of a Kill Squeak ($P=0.903$).

The median score for photo clarity was 3.0 (IQR: 2.0 – 4.0), corresponding to a score of 'good' with an interquartile range of 'fair' to 'excellent.' Photo clarity was significantly related to use of any bait and lure (W = 74.5, $P=0.046$), the type of lure used ($X^2=10.55$, df = 3, $P=0.014$), and the specific combinations of bait and lure ($X^2=16.11$, df = 6, $P=0.013$) (with results for each shown in Fig. 7) but not to bait type ($P=0.114$) or use of a Kill Squeak ($P=0.916$).

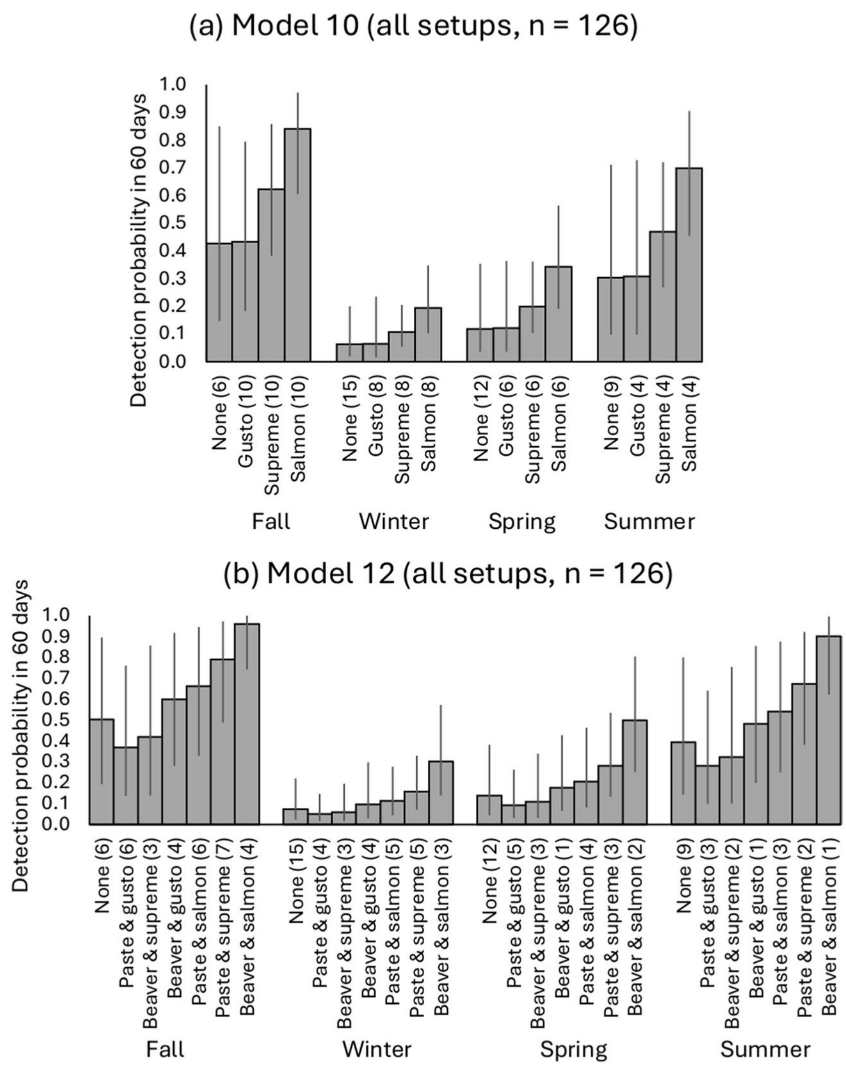

Fig. 6 Estimated (±95% credible intervals) 60-day weasel detection probability from two representative best occupancy models (Table 5). The sample sizes of setups in each category are shown in parentheses. For brevity, we only show plots from these two models, and the other three plots of best models are provided in Supplementary Material 4

Discussion

As predicted, the use of bait and lure can appear to affect detection rates (in keeping with Buyaskas et al. 2020; Holinda et al. 2020; Randler et al. 2020) and time to first detection (TFD) for weasels, though this varied across the four seasons. Certain baits, lures, or their combination substantially improved detection rates, particularly within certain seasons. The type of bait used and season were significantly related to TFD while the type of lure used and the specific bait-lure combinations were significantly related to detection probability and photo clarity. Despite expectations, the average number of photos of weasels was not significantly related to any treatment type. The use of a Kill Squeak appeared to have no significant effect. It is worth mentioning that while results were non-significant for the Kill Squeak, this product was designed to attract larger predators and was not made specifically for weasels. Our mean TFD (43 days) was within the range of both Smith & Weston (2017) who documented a median of nine to 43.5 days and Croose & Carter (2019) who documented a range of 16 to 54 days. Our fall daily detection probability (0.05) for our highest bait and lure combination (beaver and salmon) was also comparable to Croose et al. (2022) who documented 0.05–0.09, and to Evans & Mortelliti (2022) who show an approximate range of 0.05–0.14.

Because baits and lures were only used in combination with one another at all sites, it is difficult to analyze them as separate entities. This was done in line with the assertion in Buyaskas et al. (2020) and Evans et al. (2019) that bait and lure in combination are particularly effective. Due to the scant and often mixed nature of prior studies on weasels, especially in the northeastern United States, it was difficult to know which baits and lures to invest in, or whether they were worth investing in at all. Our study design allowed for a larger quantity of baits and lures to be tested to fill a significant knowledge gap and inform future studies. This is in line with recommendations from Jachowski et al. (2024) and

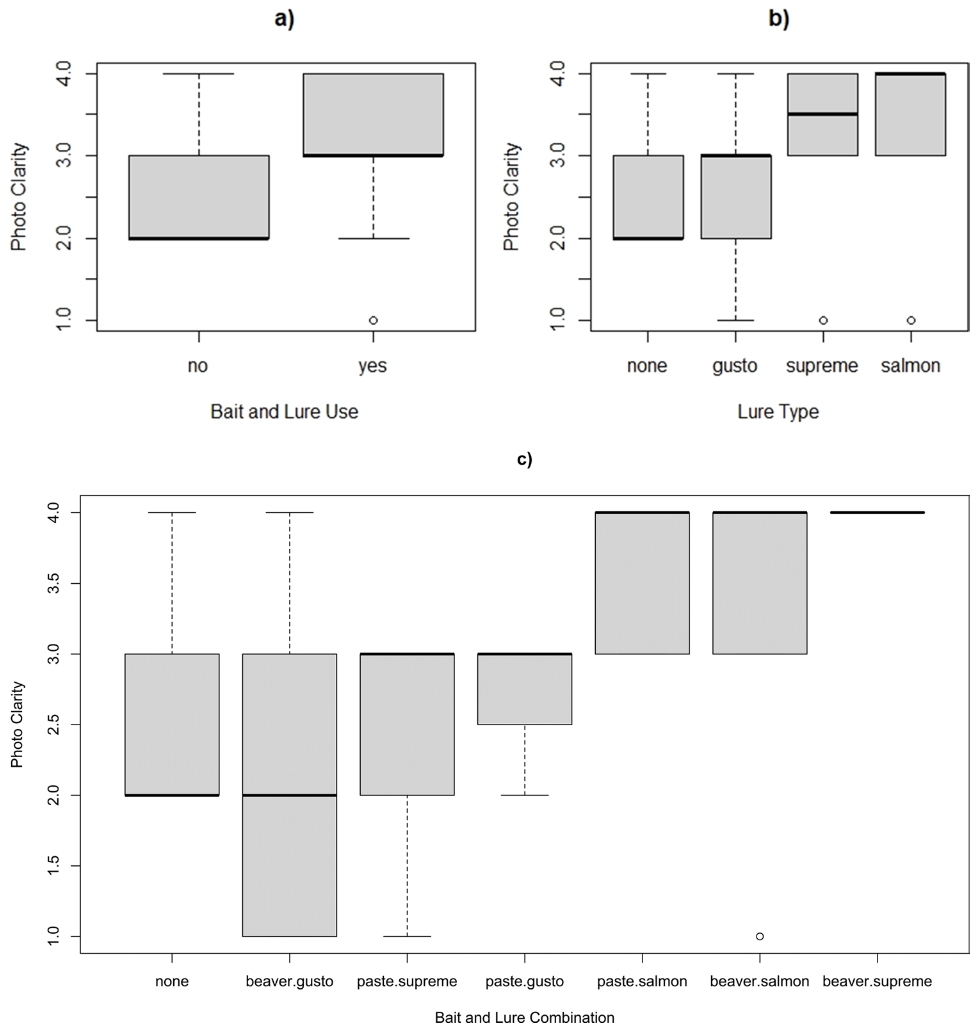

Fig. 7 Differences in photo clarity between (**a**) any bait and lure vs. none (the control), (**b**) three types of lure (across all bait types) vs. none, and (**c**) specific combinations of bait and lure vs. none. As shown in Table 3, 1 = Poor, 2 = Fair, 3 = Good, and 4 = Excellent

is an attempt to aid in developing future best practices for improving detection of weasel species. Given that most seem relatively effective when compared to control, for research purposes it is recommended that bait and lure be separated at future study sites to test their effectiveness as independent variables. Similarly, it was not possible to isolate the effect of the type of bait or lure used from the type of housing in the analysis. The relatively low number of detections precluded analysis of the bait/lure housing as a covariate, although we are able to report that there were challenges with installing the wire cages or scale bars in rocky conditions, and they were often tampered with by nuisance species, rendering them less effective. It seems most practical for future study to choose one housing that will work with any baits or lures, such as modifying the PVC pipe to house various baits/lures, to reduce the number of variables.

Within the first 60 days of a site being deployed, the overall probability of detecting a weasel was generally higher and the first event happened sooner (with the exception of summer) when certain types of bait and lure were present, which means the resources required to purchase and place attractants are likely worth the effort. This aligns with findings from Mortelliti et al. (2024) that there is a higher cost associated with using only control sites due to needing an increased number of sites to achieve sufficient detections. Despite evidence from previous studies that weasels will avoid baits and lures at first (Smith & Weston 2017), there were many instances where we captured weasels investigating baited and lured setups within a week, or even one day, of being deployed. Beaver bait appeared to provide a shorter TFD at the sites, except during summer when results were more mixed. While the inclusion of a season only model for the full dataset may reduce support for a bait effect on TFD, its exclusion from the restricted dataset (which accounts for independence of sites) suggests stronger support for any bait and lure or beaver bait providing shorter TFD. This potentially suggests that baited/lured setups close together may cross-influence each other which should be considered in future studies seeking to test bait/lure effects. Notably, salmon lure seems to perform well as an attractant, with the highest detection probability across each of the seasons. During any season, salmon when considered alone or in combination with beaver bait, typically at least doubled (though sometimes more than quadrupled, as in the case of beaver and salmon in winter in Model 12) the estimated mean detection probability within 60 days.

It should be noted that the probability of detection for the beaver and salmon combination could have been influenced by a setup with a particularly high number of detections ($n=12$), but salmon lure did also perform well when averaged across all baits. It is initially puzzling why salmon, which is not a natural food source for weasels, would be so attractive, but this could be due to the novelty of the scent, or the oil-based lure may have been more persistent in the environment. In contrast, Gusto appeared to produce detection probabilities similar to control sites, suggesting that using any type of lure is not always effective and careful testing is required.

While TFD and detection probability both consider the likelihood of drawing a weasel to a setup, they do not correlate in the results. This may be because they use different measures of probability, with TFD only considering only the first detection, and detection probability first and all subsequent detections. In theory, certain baits, lures, or combinations could draw weasels in more quickly, but not attract repeat/future visits, or vice versa. This could explain why, for example, there is no evidence of salmon oil impacting TFD, yet it having a higher overall detection probability. It was of note that beaver bait seemed to be associated with higher TFD in some seasons and also, when combined with salmon oil, better overall detection probability.

In terms of deployment time, 60 days was selected based on previous studies (Smith & Weston 2017; Croose & Carter 2019), and the duration seems well supported by our findings. In this study, 83% of detections were within 60 days of camera trap deployment, and a 60-day survey duration per site (as opposed to longer) would allow an increased number of sites to be monitored relative to a longer duration. Our estimated detection probabilities over 14 days had a maximum value of 0.53 (beaver bait and salmon oil lure) which is lower in general than those achieved in initial reporting of the *Mostela*, which ranged between 0.27 and 0.99 (Mos & Hofmeester 2020), although this is not a direct comparison as the species and locations were different (that study was in the Netherlands and detected least weasel and *M. erminea*). Season should be considered alongside deployment length for future study since it played such a significant role in detection times and probabilities. Weasels remain active throughout the year in Pennsylvania, continuing to hunt even in snowy winter conditions (King 1983; Sheffield & Thomas 1997). Young are born in spring, and weasel activity and population sizes are higher in summer and fall, which correlates with higher availability of active prey (Sheffield & Thomas 1997). These increased population and activity levels during certain months may explain some of the differences observed between seasons in this study. The results of the occupancy estimates suggest we either encountered large populations of weasels across the study area, or more likely, relatively few, though active, weasels. Juvenile weasels dispersing in the landscape may have also been frequently encountered in summer and fall, which may have accounted for higher detection rates. Because fall and summer respectively saw the highest amount of weasel activity, these may be optimal seasons to target if resources are limited.

While the general pattern was that use of bait and lure yielded photos with higher clarity, it should be noted that there were significant exceptions. At one control setup, for example, a weasel spent considerable time exploring the setup, yielding clear photos. Similarly, at some non-control setups, weasels appeared to pass through quickly while showing no interest. The analysis of photo clarity showed similar patterns to detection probability, in that salmon and supreme outperformed Gusto as lures. Despite Gusto consistently performing lowest among the lures, it or other skunk-based scents have performed well in other studies (Lombardi et al. 2017; Evans et al. 2019; Evans & Mortelliti 2022), so it would be useful to test it independently of bait in the future.

Practical considerations

A primary takeaway of this research is that weasels remain difficult to study despite adapted camera trap methods. A relatively long period and high effort was required, and this high investment of time and resources also came with challenges from operating the cameras for extended periods. The bait did not always last for the three-week period between checks. It was often eaten or became desiccated. It is difficult to determine whether the scent from the lure lingered for the entire three-week period, though it was sometimes dried out or the wool was removed by nuisance species. The Kill Squeaks also did not typically last for the entire three weeks. They are advertised to last for 10 days, though they occasionally could still be heard after three weeks, so it is impossible to determine how long they were active at each setup. In the future, sites may need to be checked more frequently, though this would have to be weighed against available time and resources.

The main advantage to using baits and lures, if employed correctly, is that they may attract the study species to a camera setup more quickly, and subsequently may make them spend more time than they would have otherwise. We have documented that use of certain baits and lures can potentially shorten time to first detection, increase probability of detection, and improve photo clarity. However, it was not possible to determine within what range a bait or lure may draw a weasel to a camera, nor whether this may change with time in the field, as discussed above. It is also important to consider how the use of bait and lure may affect the behavior of the target species and to be careful when drawing conclusions based on analysis of these artificial conditions. Given these unknowns, it cannot be assumed that absence of detections in certain areas indicates a lack of healthy weasel populations nor that frequent detections at baited/lured sites indicates a strong presence in the area.

It may be that, as recommended by Jachowski et al. (2024), a multi-faceted approach to studying weasels would be needed in the future. They document success with citizen science efforts and eDNA or other non-invasive genetic sampling in addition to camera trapping by researchers. It remains to be seen whether these methods would be most effective when combined with enclosed or unenclosed camera setups. For our part, the relative ease of setting up the unenclosed camera traps across many environments when weighed against achieving measurable results indicates this method is worth further testing. As noted above, our TFD results were comparable to prior studies whether they used enclosed methods (Croose & Carter 2019) or unenclosed (Smith & Weston 2017). Our daily detection probability estimate for our best combination and season was identical to Croose et al. (2022) for their unenclosed setups (0.05) though lower than their enclosed setups (0.09), though they did not detect significant difference between the two types. We were at the low end of the range for Evans & Mortelliti (2022), though their prolonged study in ideal habitat may have contributed to their higher success rate.

A frequent issue at some setups was shifting vegetation or shadows which caused cameras to trigger almost constantly during the day. This was likely exacerbated by the high PIR sensitivity settings necessary to detect fast moving species. Consequently, the batteries would sometimes run out or the SD cards would fill up prior to the camera traps being checked, but this only accounted for a median of 12.5 days per set up (or 12% of observed days per set up). This may have slightly impacted the average TFD as some potential first detections could have been missed but would not introduce bias with respect to treatment as camera trap function was affected solely by the surrounding environment. The setups were deemed inactive during these periods, and it is possible weasels may have visited during those times without being recorded. These effects were limited as far as possible by placing the camera closer to the subject area. The use of larger SD cards and higher capacity batteries could help resolve this in the future. Additionally, setups with bait and lure frequently had numerous detections of small *Rodentia* species, especially those with beaver bait, increasing time to analyze photos. Better tamper-proofing of baits may turn them into non-reward elements which might decrease interest from small rodents. It is also interesting to consider that drawing these prey species to the setups could have been an additional attractant for weasels, in keeping with findings in Weston et al. (2024).

While the decision to cluster camera traps at each site could have led to identical or near-identical results at all cameras, this was not found to be the case, and weasels were often only detected at one camera per site. This was further controlled for by separately considering a reduced dataset in which only sites ≥ 20 m apart were included, which generally showed similar, or in the case of TFD, slightly stronger findings. Habitat should be a key consideration for any future study. Anecdotally, sites with especially prime habitat for weasels (i.e. open areas with brush or rock piles) tended to have a shorter TFD and higher detection probability likely because the scents can only extend so far, as discussed above, although we did not test this. However, it is essential to also consider these microhabitats in context. If they were too isolated, camera traps in these areas often did not detect weasels even with bait and lure present as attractants. For example, traps placed along a rock wall that appeared to be prime weasel habitat did not yield any detections despite being active for more than 130 days. This rock wall was in the middle of a forested area far away from any water bodies or obvious movement corridors. Weasels were found in areas nearby, so it was likely that this wall was too far away from other resources to be in a typical weasel home range. These highly specialized habitat requirements should be considered alongside site access for any future study.

A final consideration is that it is also difficult to distinguish between the two species present in this region. Popp (2021) provides size ranges for weasels used to identify the two species when measurements could be obtained from photos in this study. However, there is considerable overlap in these ranges which makes certainty in identification difficult. Wide variation across literature and field guides in measurements for each species, based on geography and sex, similarly confound certainty in identification. It may not be possible to achieve certainty from these camera trapping methods, despite the adaptations for weasel species. Kays et al. (2022) document that it is rarely possible to easily distinguish between *M. erminea* and *N. frenata* from camera trap photographs. Specialized approaches such as the *Mostela* (Mos & Hofmeester 2020) or the AHDriFT system (Jachowski et al. 2024) may be necessary for achieving a higher confidence level. Though this would need to be weighed against the investment of resources for these approaches.

Management implications

Given the relative difficulty of detecting weasels and the relative ease of detecting other mesopredators, there is no evidence to suggest that weasels are not in decline in the study area as documented in other areas of the world (Coomber et al. 2021; Jachowski et al. 2021; Mos & Hofmeester 2020; Torre et al. 2018). However, long-tailed weasels do appear to be more common than short-tailed, which is consistent with previous findings (Latham 1952; Mohr 1931). Further study may be warranted to determine presence or absence of both species in certain habitats and to develop occupancy models across the state. While further experimentation is recommended to test the various attractants separately, in the meantime, evidence suggests that in this region the combination of beaver and salmon is likely to be optimal. To narrow down the theory from Croose & Carter (2019) that detection rates could be negatively influenced by camera placement, low population densities, or seasonality, it may be worthwhile to place camera traps more densely during future study. This may increase the chances of capturing weasels if they move through an area but do not investigate each setup. While evidence from this study for this suggestion is only anecdotal, it sometimes appeared that weasel detections may have happened due to camera traps being placed in or near common travel corridors (as suggested by a single photo of a weasel running through the site). Placing more camera traps may increase the chances of detecting them in an area regardless of interest in the baits or lures.

Conclusions

Given that weasels are suspected to be in decline, making them potential species of conservation concern in Pennsylvania, more information is needed about their basic ecology and current distribution. This study was completed to determine effective methods for attracting weasels to camera traps in the hopes of providing guidance for a larger statewide survey. The findings show that relative to control sites, baits and lures can significantly and substantially improve detection of weasels and, where detected, the clarity of photos captured. Salmon oil appears to be particularly effective at increasing detection probability while beaver bait potentially increases speed of first detection. Future studies could test the well-performing baits and lures in isolation, further refining these approaches.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13364-024-00771-0.

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Author contributions Conceptualization: K Ebel, PJC White; Methodology: K Ebel, PJC White; Data collection: K. Ebel; Formal analysis and investigation: K Ebel, PJC White; Writing – original draft preparation: K Ebel; Writing – review and editing: K Ebel, PJC White; Funding acquisition: K Ebel; Resources: K Ebel; Supervision: PJC White.

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Data availability Datasets generated and analyzed during the study, and corresponding R code, are available at: https://github.com/pjcwhite/weasel-camera-trapping.

Declarations

Conflicts of interest The authors declare no competing interests.

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