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REVIEW

Non-invasive methods for monitoring weasels: emerging technologies and priorities for future research

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ABSTRACT

1. Weasels (genus *Mustela* and *Neogale*) are of management concern as declining native species in some regions and invasive species in others. Regardless of the need to conserve or remove weasels, there is increasingly a need to use non-invasive monitoring methods to assess population trends.
2. We conducted a literature review and held the first ever International Weasel Monitoring Symposium to synthesise information on historical and current non-invasive monitoring techniques for weasels. We also explored current limitations, opportunities, and areas of development to guide future research and long-term monitoring.
3. Our literature search revealed that in the past 20 years, camera traps were the most commonly used non-invasive monitoring method (62% of studies), followed by track plates or scent stations designed to collect footprints (23%) and walking transects for tracks in snow or soil (8.7%).
4. Experts agreed that the most promising non-invasive monitoring techniques available include use of citizen scientist reporting, detection dogs, detecting tracks, non-invasive genetic surveys, and enclosed or unenclosed camera trap systems. Because each technique has benefits and limitations, using a multi-method approach is likely required.
5. There is a need for strong commitment to dedicated monitoring that is replicated over space and time such that trend data can be ascertained to better inform future management action. The diversity of non-invasive monitoring methods now available makes such monitoring possible with relatively minor commitments of funding and effort.

INTRODUCTION

Weasels (members of the genus *Mustela* and *Neogale*, here primarily focusing on the smaller species long-tailed weasel *Neogale frenata*, stoat *Mustela erminea*, and least weasel *Mustela nivalis*) are small mustelids distributed across much of the northern hemisphere. Weasels play an important role in ecosystem function (King & Powell 2007), although data from North America (Jachowski et al. 2021) and Europe (Wright et al. 2022) suggest weasels are in decline through portions of their historical range. Where weasels have been introduced, they can have detrimental impacts through predation and displacement of native species (Pech & Maitland 2016, Rodrigues et al. 2017). Whether to conserve or remove weasels, there is a need for standardised, long-term monitoring to determine factors important to their presence, distribution, and use of habitat across multiple spatial scales over time (Jachowski et al. 2021).

Broad-scale surveys and long-term monitoring for weasels have largely been limited to regions where there are intensive, sustained efforts to eradicate weasels (Jones et al. 2004), or to the northern extent of the range through annual track surveys or lemming nest occupancy rates (Feige et al. 2012, Schmidt et al. 2012). Trapping harvest data were historically used to monitor weasel (and other furbearer) population trends (Tapper & Reynolds 1996, Aebischer et al. 2011), but harvest data are not always proportional to abundance (McDonald & Harris 2002, Maunder et al. 2006, Fukasawa et al. 2020). In North America, decline of fur markets and regulation of harvest for conservation, further limit availability of these data (Jachowski et al. 2021).

A primary challenge in monitoring weasels is that they are difficult to detect. Traditionally, invasive methods such as live-trapping were used to study weasels (King 1980, Zub et al. 2008), but high cost and effort required for such methods makes them impractical at spatial or temporal scales meaningful to conservation. Non-invasive methods for small carnivore monitoring are typically less labour-intensive and can be more easily replicated across sites and repeated over time. Historically limited to surveys based on animal tracks (Quick 1944), camera traps have become a common non-invasive method for monitoring small carnivores globally over the past several decades and setups have recently been developed specifically for weasels (Mos & Hofmeester 2020). Other techniques useful for detecting weasels non-invasively include the use of detection dogs (Steury 2012), citizen science (Linzey & Hamed 2016), and most recently, non-invasive molecular techniques (Zielinski et al. 2020, Broadhurst et al. 2021). With this rapid emergence of multiple potential non-invasive monitoring methods, there is a need for information on which methods are best suited to future research and monitoring.

Here, we summarise recent trends in non-invasive weasel monitoring techniques and highlight priorities for future development. In 2023, we conducted a literature review and held the first International Weasel Monitoring Symposium to synthesise information on historical and current non-invasive monitoring techniques for weasels. We also explored current limitations, opportunities, and areas of development for each technique to guide future research in broad-scale surveys and long-term monitoring.

MATERIALS AND METHODS

We conducted a Web of Science search on 17 April 2023 for published literature on non-invasive monitoring methods for weasels in the wild over a 20-years period (2003–2023) using the following query: TS=('Mustela' OR 'Neogale') and TS=('monitoring') AND DT=(Article OR Book OR Book Chapter OR Review) AND PY=(2003–2023). We reviewed titles and abstracts of the 673 papers generated and determined that 69 papers were relevant (i.e. documented weasels in a field setting using a non-invasive method) for subsequent scoring. From these studies we extracted the technique used, year of study, country, focal species, bait type (if any), and population metric calculated from each technique.

On 24 February 2023, we hosted a virtual International Weasel Monitoring Symposium with experts from Europe and North America presenting talks in sessions structured around widely used non-invasive weasel monitoring methods: citizen science, detection dogs, tracks, non-invasive genetic surveys, unenclosed camera traps, and enclosed camera traps. Sessions concluded with structured discussions on history of development, advantages and strengths, current limitations, and areas of future development for each technique. Subsequently, subgroups of experts drafted sections of this manuscript following the symposium topics.

RESULTS

Breadth of non-invasive weasel monitoring techniques

In the past 20 years, camera traps (or video recorders) were the most commonly used non-invasive monitoring method (62% of studies, Fig. 1). Other common methods were track plates or scent stations designed to collect footprints (23% of studies) and walking transects for tracks in snow or soil (8.7%). Less-commonly used methods included transect sampling for scat/faeces, interviews with local residents or use of historical records, hair snares, roadkill surveys, and checking lemming nests for weasel occupancy. Nine of the 69 studies involved multiple non-invasive methods (Fig. 1).

Nearly one third (33%) of studies used some type of bait. Of those studies, a common practice for monitoring weasels (either intentionally or incidentally in monitoring nest fate) was placing cameras at active or artificial bird nests (23% of bait studies), followed by use of rabbit (12%), fish (12%), chicken (7.7%) or some unnamed type of meat (12%). Various other baits used less commonly were eggs, peanuts or peanut butter, mayonnaise, and lure-infused poison blocks. While

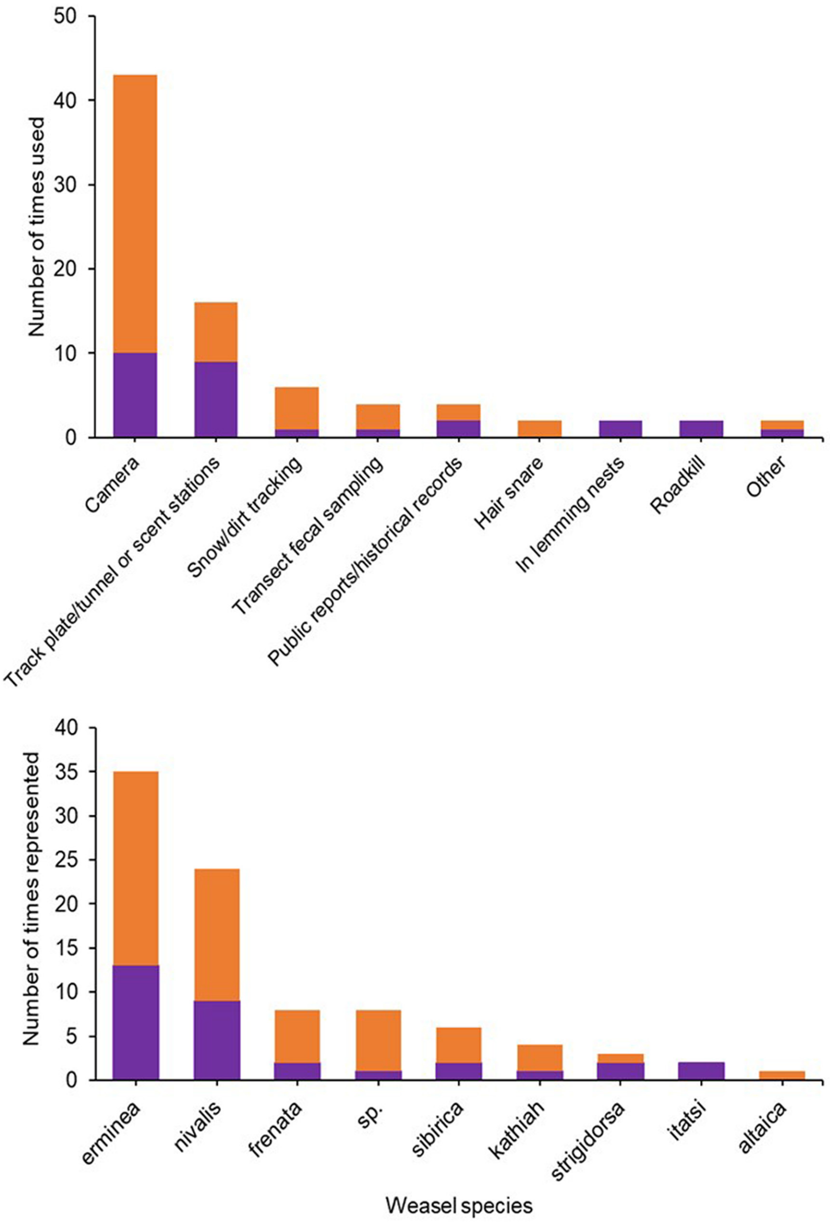

Fig. 1. Literature search results for non-invasive weasel monitoring methods used globally over the past 20 years highlighting the frequency with which each type of method was used (top panel) and which focal species were detected (bottom panel). If a specific species was not mentioned in a study, it was tallied as species or 'sp'. The portion of each bar in orange represents publications produced in the past 10 years (since 2013).

numerous lures were commonly used across camera and track-based survey techniques, no individual study in our literature search explicitly compared multiple lure or bait types on detection probability (although see Buyaskas et al. 2020).

Most studies were in North America (22%), Europe (43%) or New Zealand (17%; Fig. 2), and most (38%) reported on *Mustela erminea* (Fig. 1), although several studies targeted multiple species simultaneously. There were very few ($n < 3$) studies on Asian weasel species *Mustela altaica*, *Mustela itatsi* and *Mustela strigidorsa*, and no studies on weasel species endemic to Africa or South America (although see Cepeda-Duque et al. 2023, published after our literature search). Most studies used methods to estimate species presence or to assess distribution (45%), followed by estimating relative abundance (44%), and species occupancy and/or detection probability (11%).

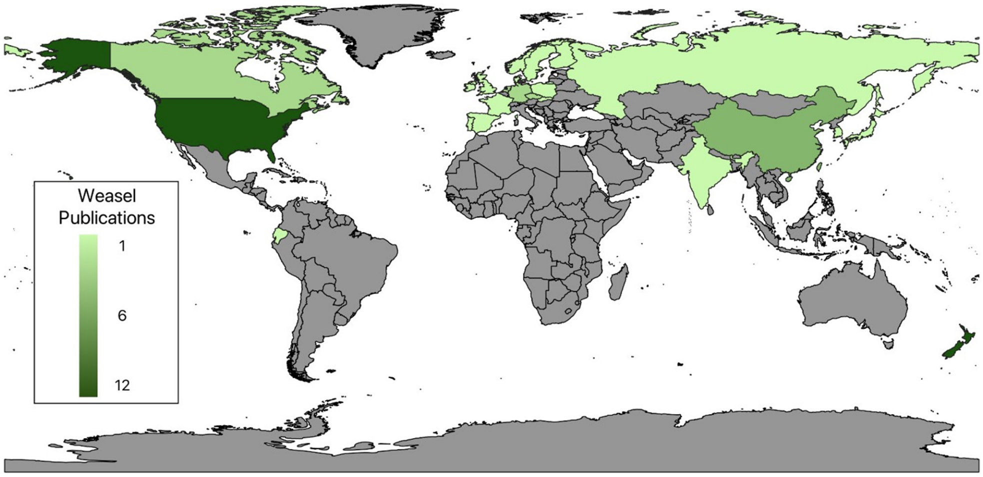

Fig. 2. Global map with countries highlighted where dedicated studies have taken place on non-invasive weasel monitoring methods in the past 20 years based on our literature review.

Current non-invasive monitoring methods

CITIZEN SCIENCE

HISTORY OF DEVELOPMENT

Citizen science is a collaborative approach to scientific research that involves active participation from the public. This has emerged as a powerful tool, bridging the gap between scientific research and society, with numbers of projects having increased substantially over the last three decades (Davis et al. 2023). Citizen science and participatory volunteer networks have increasingly been utilised to assist with small carnivore research and monitoring (Silvertown 2009). Examples include interviews and questionnaire surveys of local residents to gather data on distribution of weasel species (Lau et al. 2010, Bolduc et al. 2023, Hayder et al. 2023), including an ongoing survey of the Irish stoat (*Mustela erminea hibernica*) based on reported sightings of live or dead animals throughout Ireland (https://biodiversityireland.ie/surveys/irish-stoat-survey/).

Data gleaned from social media posts can yield information on species' distribution (Wright et al. 2023), and social media group pages are emerging as a way for members of the public to share information about small carnivores. One example is the Small Carnivore Conservation Project Thailand Facebook Group (https://www.facebook.com/groups/128334450533090/), which has generated many valuable records of weasel species from northern Thailand.

ADVANTAGES AND STRENGTHS

A key benefit of citizen science is its ability to increase the capacity of a project. With collective efforts of numerous volunteers, scientists can gather vast amounts of data over large geographical areas and extended periods, which would be impossible for traditional research teams alone (Conrad & Hilchey 2011). Sightings can be used to refine estimates of population size in combination with other monitoring techniques such as trapping data via integrated removal models (Zub et al. 2022). Wide scale public engagement can potentially enhance the scope of data collection and strengthen the connection between scientific research and society.

CURRENT LIMITATIONS

Challenges of citizen science include ensuring data quality and integrating systematically and non-systematically collected data. For weasels in particular, standardised protocols for data reporting and expert ID are important given the high probability of false positives and species misidentification (Fig. 3). Requiring pictures to be submitted along with observations is critical, as >90% of reported weasel sightings in Florida, USA that included photos have been incorrectly identified (L. Smith, unpublished data).

Citizen science projects face a trade-off between opportunistic sampling, which may generate more samples with few restrictions, and involving citizens in a structured sampling design that may discourage their participation (Shirk et al. 2012). To address habitat and spatial sampling gaps, Lasky et al. (2021) adopted a hybrid sampling design, monitoring progress towards sampling goals during the study and supplementing volunteer efforts with additional field work by project staff to fill gaps. In addition, emerging statistical models, such as integrated species distribution models, enable

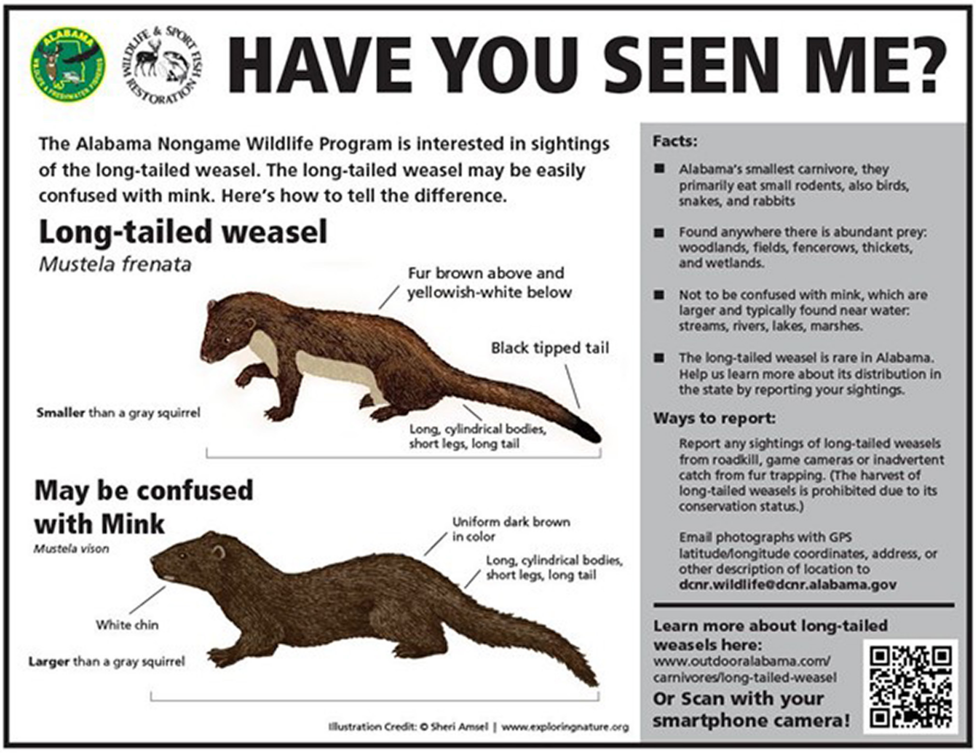

Fig. 3. Outreach material produced by Alabama Nongame Wildlife Program (USA) to gain sightings information for long-tailed weasels, which are infrequently reported in their state (illustration credit: Shari Amsel).

integration of presence-only records from citizen science with detection/non-detection data from structured surveys (e.g. Koshkina et al. 2017).

FUTURE DEVELOPMENT

Reliable, user-friendly software is one of the most important aspects of scaling up citizen science. Examples include a mobile phone application for citizen science projects that provides a user interface for administrators without the need for programming skills (Ellul et al. 2013) and SciStarter, which can help project coordinators manage their volunteers (Hoffman et al. 2017).

While some platforms are built for specific projects, others have evolved into more integrated platforms that serve generic projects (Liu et al. 2021). iNaturalist is an online portal and smartphone app that anyone can use to upload photos of mammals for identification, verification and reporting. This currently has 3034 research grade observations for *Neogale frenata*, 1876 for *Mustela nivalis*, and 1679 for *Mustela erminea* worldwide, although these observations likely require further verification given some species cannot be told apart without full body photos in areas of overlap (Kays et al. 2022). Regardless, new analytical approaches such as integrated species distribution models offer ways to utilise citizen science data to improve our understand of species distribution and environmental relationships (e.g. Gilbert et al. 2021) that could be expanded to weasels.

DETECTION DOGS

HISTORY OF DEVELOPMENT

The earliest use of detection dogs for conservation is thought to be the 1890s in New Zealand for kiwis *Apteryx australis*, *Apteryx owenii* and kakapos *Strigops habroptilus* (Hill & Hill 1987). Since 1930, detection dogs have been used for a minimum of 408 animal species and 42 plants (and fungi and bacteria; Grimm-Seyfarth et al. 2021). In at least 102 cases (72 scientific), dogs were used for detecting mustelids (Grimm-Seyfarth et al. 2021), including long-tailed weasels (Stuery 2012), fishers *Pekania pennanti* (Long et al. 2007, Thompson et al. 2012, Zielinski et al. 2013) and black-footed ferrets *Mustela nigripes* (Reindl-Thompson et al. 2006).

ADVANTAGES AND STRENGTHS

Detection dogs (Fig. 4) are useful for surveying for weasel presence and resulting data have primarily been used to

Fig. 4. Left, Cowboy the detection dog and Kendyl Hassler searching for long-tailed weasel in Florida, USA (photo credit: Lisa Smith). Right, Django the mustelid detection dog (*Lutra lutra*, *Mustela erminea*, *Mustela nivalis*) in Switzerland (photo credit: Denise Karp, Artenspürhunde Schweiz).

understand small carnivore habitat associations (Smith et al. 2006, Zielinski et al. 2013). Scats detected by dogs can be analysed to determine sex, individual identification, physiological measures (such as faecal cortisol and progesterone metabolites), some parasites, and diet (Wasser et al. 2004). Results from detection dog surveys are used to target subsequent trapping efforts, both for conservation and eradication. Dogs can cover a large area systematically in a single visit (compared to point locations of track plates or camera traps), are often able to find scats in areas missed by human observers and can follow scent trails and guide towards spots with increased activity (Egloff et al. 2022, Schenker et al. 2023).

CURRENT LIMITATIONS

While detection dogs are highly effective at locating their targets, there are limitations to their use. As with many other target species (Bennett et al. 2019), there are no standardised guidelines or protocols for training detection dogs or conducting weasel scat surveys. Different dogs and dog-handlers may have different detection rates. While these factors can be included as covariates in subsequent modelling, the diverse attributes of each dog and handler make comparability of survey results among sites and over time difficult. Sourcing of scats for training detection dogs can be difficult as scats used for training are ideally from multiple wild individuals (DeMatteo et al. 2019). Dogs should ideally be trained in a wild setting on untouched scat samples after they have been trained on 'put out' samples, requiring knowledge of areas where weasels are present and the phenotype of weasel scats, which can vary seasonally and regionally. Dogs require at least 6 months of specialised training (Schenker et al. 2023). Unlike passive monitoring approaches like camera traps, dogs in a field setting can only be used for limited hours per day. They require maintenance and health care, and continued motivation if detection rates are low. Climate and terrain may impact the length of time a dog is able to work, as well as its ability to locate scats (Leigh & Dominick 2015). Scat can degrade quickly in warm and wet conditions and can be removed quickly by dung beetles or other animals (Livingston et al. 2005, Norris & Michalski 2010). Detection distance for weasel scat is low, especially when it has dried out, so dogs need to cover an area extensively. Reed et al. (2011) found that dogs in controlled trials detected >75% of carnivore scats within 10 m of transects, with detection rates decreasing with distance. For weasel scats, maximum detection distance is estimated to be around 3 m, and more often 50 cm with dried scats (D. Karp, personal communication). Collectively, given these issues and the cost involved, it is important to evaluate the return on investment detection dogs provide in monitoring for weasels (Long et al. 2007).

FUTURE DEVELOPMENT

Development of protocols is needed for training, running trials, and search methodology used when working with dogs. There is a need to assess the influence of site-specific conditions (habitat, terrain, weather) on scat detection probability, and account for this variation in modelling of data. Strategic integration of detection dogs with other techniques is another area for further development. For example, where the small carnivorous marsupial *Antechinus arktos* was not previously detected using live-trapping and passive camera-trapping efforts, Thomas et al. (2020) used camera traps at locations where detection dogs had alerted on target odour and confirmed the species in 100% of detections. Finally, more natural history information on weasel scent-marking behaviour is needed to guide targeted searching for scats during detection dog surveys.

TRACKS

HISTORY OF DEVELOPMENT

Footprint track methods were among the first non-invasive techniques for studying weasels (Quick 1944) and were adapted for surveying stoats in the 1970s (King & Edgar 1977). Methods include observing tracks made by animals in snow and soil (Sundell et al. 2013) or actively setting track plates or footprint tunnels where animals walk through a substance such as ink, graphite, or carbon paper before stepping onto a clean surface to leave prints (Tempero et al. 2007, Červinka et al. 2014).

ADVANTAGES AND STRENGTHS

Track monitoring is mostly used for surveying weasel distribution, occupancy, and habitat use (King & Edgar 1977). Track techniques are generally cheap and easy to implement. Despite the recent growth of camera-based monitoring, a study in northeast North America found that weasels were detected more frequently using track plates than with standard open baited camera traps (Gompper et al. 2006). Thus, track surveys still provide a valuable method for small mammal monitoring, particularly when funding is limited.

CURRENT LIMITATIONS

Track quality can be influenced by weather or field conditions. It is important to quantify factors that could impact detection such as prey density and time of year (Graham 2002), or snow cover and depth if conducting snow tracking (Forsey & Baggs 2001). Tracking tunnels protect tracks from weather, but require regular checks, especially where small rodents are abundant. Footprints of *Mustela nivalis* and *Mustela erminea* overlap in size, so where they co-occur it is not always possible to identify tracks to species.

FUTURE DEVELOPMENT

Track-based surveying could be advanced by automated track identification software. In addition to faster processing of tracks within track plates for dedicated studies, programs such as WildTrack (https://www.wildtrack.org/our-work/fit-technology) offer potential crowdsourced track-based locational data for weasels. Individual identification based on weasel tracks has been limited to studies that practice toe clipping (King & Edgar 1977), although evidence of successful individual identification of fishers using high-quality track plate images (Herzog et al. 2007) suggests it could be possible for weasels.

NON-INVASIVE GENETIC SAMPLING

HISTORY OF DEVELOPMENT

Molecular techniques have provided information on multiple topics of weasel ecology, such as population structure (McDevitt et al. 2013), ancestral relationships (Masuda & Yoshida 1994, Kurose et al. 2005a), and levels of inbreeding (Huang et al. 2007). These objectives typically require numerous samples of high-quality DNA from blood or tissue cells of live or dead animals. Although non-invasive genetic sampling of faeces, dead animals or hair samples is well established for many species (Taberlet & Luikart 1999), very few studies on weasels have been published (see Kurose et al. 2005b, Zielinski et al. 2020, Schenker et al. 2023). Hair snaring with subsequent DNA analysis has been used with mixed success for stoats and weasels. In New Zealand, Wales and Ireland, 20 cm lengths of 45 mm diameter plastic pipe with a sampling strip covered in adhesive across the entrance at each end have had limited success for collecting hair samples from stoats (Clayton et al. 2011, McAney 2011) and weasels (MacPherson, unpublished data). However, García and Mateos (2009) found that hair snaring was more successful at detecting least weasels than track censuses or scat sampling.

Recently, environmental DNA (eDNA) surveys have gained popularity (Ruppert et al. 2019) and become a viable tool for detection of rare species (Leempoel et al. 2020, Sales et al. 2020). To identify the presence of a species, samples of soil, water or air are screened for mitochondrial DNA shed by animals (Thomsen & Willerslev 2015). Surveys using these techniques have successfully detected several mustelid species, including the critically endangered European mink *Mustela lutreola* (Croose et al. 2023), least weasel, stoat (Broadhurst et al. 2021), European pine marten *Martes martes* and Eurasian otter *Lutra lutra* (Sales et al. 2020). Yet their use for detection of weasels remains limited, likely due to the species' relative rarity, with few metabarcoding studies reporting successful detection (e.g. Bolton 2021), and others failing to detect weasels by eDNA despite detection by camera traps in the same study (e.g. Leempoel et al. 2020, Sales et al. 2020).

ADVANTAGES AND STRENGTHS

Non-invasive genetic sampling of faeces or hair can be used to identify individuals and thus estimate population size and density using mark-recapture or spatial capture–recapture models (Royle et al. 2013). This has yet to be tested on weasels (but see Fuller et al. 2016 for an example with American mink *Neogale vison*). A benefit of eDNA sampling from soil has been improved detection of stoats, which tend to be undetected by surveying devices (e.g. Mostela, footprint tunnels; Bolton 2021).

CURRENT LIMITATIONS

Along with their relatively high costs, eDNA analyses can result in false negatives with soil (Leempoel et al. 2020) and water samples (Sales et al. 2020). As weasels occur in relatively low densities the probability of randomly collecting their DNA is lower than for other species. However, targeted sampling and baited devices can improve detection rates of low-density and cryptic species using eDNA (Ichu 2022). The success of eDNA also depends on sampling design and animal behaviour (Leempoel et al. 2020). Probability of detection can be reduced during the PCR process if poor quality or small quantity of eDNA results in a very low number of reads (Bolton 2021). Use of targeted primers instead of metabarcoding can improve detection probabilities, especially of rare species, for which small amounts of DNA can be swamped out early in the PCR process.

FUTURE DEVELOPMENT

Improvements are required in eDNA techniques specifically for the detection of weasels or small carnivores. Species-specific assays would greatly increase sensitivity and reduce costs of qPCR techniques over metabarcoding (Harper et al. 2018). Development of optimal sampling protocols using baited stations or predated nests would be useful as these can likely increase the probability of detection. Linking eDNA sampling with detection dogs might be considered when dogs alert on target species activity but no scat can be found. It also could be linked with track tunnels, enclosed camera traps or hair traps, the latter potentially used to identify individuals.

UNENCLOSED CAMERA TRAPS

HISTORY OF DEVELOPMENT

Most research using camera traps has targeted mammals in the order Carnivora (Burton et al. 2015), including some early studies targeting mustelids (e.g. González & Lara 2007, Rosellini et al. 2008). However, small mustelids such as weasels and stoats often were not detected in camera trap surveys (Zielinski & Kucera 1995, Kelly & Holub 2008) or were removed from analyses due to small sample sizes (Johnson et al. 2009). Ineffectiveness of early camera trap methods at detecting small mustelids, even with bait, is likely due to their small body size and fast movement (Kelly & Holub 2008) and low trigger sensitivities of early camera traps (Wearn & Glover-Kapfer 2019). Recent increases in sensitivity of camera traps have resulted in an increasing number of unenclosed camera trap studies reporting detection of weasels (Moser et al. 2017, Ghose et al. 2018) and even targeting weasels specifically (Evans & Mortelliti 2022).

ADVANTAGES AND STRENGTHS

Camera traps are likely more cost- and time-efficient than other methods because they passively collect data and require little time and few supplies. Camera traps can be deployed for prolonged periods, making them effective for broad spatial- or temporal-scale studies (Hsing et al. 2022). The cost of using camera traps can be 2–5 times lower than that of live traps (De Bondi et al. 2010, White et al. 2023). Costs were similar between camera trap surveys and wildlife detection dogs (Glen et al. 2016), eDNA surveys (Lyet et al. 2021), and non-invasive genetic sampling (Twining et al. 2022). However, much less technical expertise and training is required to employ camera traps, and the cost of supplies and equipment is relatively low after a large initial investment to purchase the cameras. Lengthy surveys are likely more cost-effective with camera traps than with methods that require lab equipment/supplies (e.g. eDNA) or specialist practitioners (e.g. detection dogs).

CURRENT LIMITATIONS

Detection rates (0.02–0.44 detections/100 camera days; Ross et al. 2013, Kolowski & Forrester 2017) and detection probabilities (0.05–0.24; Croose et al. 2022, Evans & Mortelliti 2022) of weasels are relatively low and vary greatly across camera trap studies with differing weasel species and survey methods. The speed, agility and small body size of weasels can enable them to pass through the small zone of detection, or become blocked from view, before a camera is triggered (Evans et al. 2019). This is especially evident as distance of the animal from the camera increases. However, with addition of bait, unenclosed camera traps have successfully collected detailed data on weasel occupancy patterns (Evans & Mortelliti 2022).

Sympatric weasel species are often difficult to differentiate using external physical traits (King & Powell 2007), limiting species identification in camera trap surveys. The ratio of tail length to combined head and body length has been confirmed with DNA to distinguish between some weasel species (a ratio >44% distinguishing long-tailed weasels from stoats; Hall 1951, Elsasser & Parker 2008). This ratio can be calculated from morphometric data using camera images if a reference of scale is within view (Evans & Mortelliti 2022). However, there is doubt if this ratio is effective throughout the species' shared range (St-Pierre et al. 2006). Additional work is needed to find effective ways of distinguishing sympatric weasel species in camera images. Excepting the *Mustela nivalis vulgaris* morph, which has unique patterns of gular spots and irregular back-belly margins, weasels typically lack markings that can be used to identify individuals (King & Powell 2007). Analyses that require individual recognition (e.g. spatial capture–recapture analyses) are likely to need other techniques (e.g. PIT-tags, hair samples for DNA analyses, collaring), or using structures that funnel animals close to the camera (e.g. Mostela; Mos & Hofmeester 2023). Statistical models that avoid the need to identify individuals may be an option (e.g. unmarked spatial capture–recapture; Santini et al. 2022).

While camera traps are relatively time-efficient, it takes time to check them regularly to download data, change batteries and clear vegetation from the field of view. Frequency of checks depends on memory card capacity and battery life, which vary with activity recorded by the camera and environmental conditions. Also, image management and analysis can be very time consuming, especially if done manually. Image management and processing software can help (e.g. Niedballa et al. 2016), but the usual need for human skill to identify species limits overall efficiency of the method.

FUTURE DEVELOPMENT

Studies employing unenclosed camera traps would greatly benefit from advances in automated species identification, methods to estimate body condition, and development and standardisation of best practices. Software has been used to identify small mustelid species from images collected by camera traps (Yu et al. 2013) and is now widely available through platforms such as Wildlife Insights (Ahumada et al. 2019). Further development of these methods (i.e. training using species-specific data) is needed to generate more reliable species identification. Calculation of body condition is difficult using camera traps due to the requirement of body mass data (Krebs & Singleton 1993, Schulte-Hostedde et al. 2001). A method to simultaneously collect body size and mass data from individual weasels or an alternative method using visible characteristics that are highly correlated to body condition (e.g. Pérez-Flores et al. 2016) would be valuable.

Developing best practices that enhance detection of weasels on unenclosed camera trap surveys would benefit the design of site- or species-specific as well as landscape-scale camera-trapping protocols. This includes determining which camera models and settings are better, where to place cameras and which lure(s) are most attractive. While best practices will likely vary among species, landscapes and project objectives, such information is critical to designing long-term monitoring strategies using unenclosed and enclosed camera traps (Jachowski et al. 2021).

ENCLOSED CAMERA TRAPS

HISTORY OF DEVELOPMENT

Methods that confine camera traps in enclosed spaces have been developed to survey smaller-bodied vertebrates more effectively. By directing animals closer to the camera trap they improve detectability and get better photographs. The Mostela system, designed for small mustelids, has a camera trap aimed horizontally at an opening in the side of a tracking tunnel in a box (Fig. 5). Mostela has mainly been used for studying least weasel and stoat in the Netherlands (Westra 2019, Mos & Hofmeester 2020), England (Croose & Carter 2019), and Poland (Hofmeester et al. in press). After publication of its design (Mos & Hofmeester 2020), Mostela has been used in additional studies including least weasel in the USA (Holloway et al. 2022) and the endemic Irish stoat (Croose et al. 2022). Other studies adopted similar camera trap designs, such as foldable plastic boxes for weasels and stoats at high altitudes in Spain (Fig. 5; Salvador et al. 2022) and metal boxes for long-tailed weasel and Colombian weasel *Neogale felipei* in Colombia (Cepeda-Duque et al. 2023). Another boxed camera trap, developed to monitor small mammals under snow (Soininen et al. 2015), has shown success in detecting *Mustela nivalis nivalis* and *Mustela erminea* in arctic systems (Kleiven et al. 2023).

The AHDriFT system (Fig. 6) uses camera traps in boxes, with each camera aiming downward from inside the top of a box. Animals are funnelled to box entrances by drift fence(s) with a camera box at each end. This method, originally described by Martin et al. (2017), was developed from the Hunt trap designed by McCleery et al. (2014). AHDriFT systems are typically used to survey herpetofauna and rodent communities (Martin et al. 2017, Boynton et al. 2021). However, substantial weasel bycatch has been reported (Amber et al. 2021a, White et al. 2023).

ADVANTAGES AND STRENGTHS

Data from enclosed camera traps have been used to estimate occurrence, relative activity, and daily and seasonal activity patterns (Mos & Hofmeester 2020, Amber et al. 2021b, Croose et al. 2022), and predator–prey dynamics (Kleiven et al. 2023). Hofmeester et al. (in press) compared relative abundance estimated from Mostela data using Royle-Nichols models (Royle & Nichols 2003) with the minimum number of weasels known to occur in the area based on live-trapping. They found Mostela to have potential for tracking yearly fluctuations in weasel abundance. An attempt to estimate density using Mostela data for individually identified least weasels in the Netherlands has promising results (Fig. 5; Mos & Hofmeester 2023). Mos and Hofmeester (2020) suggested that absolute densities can be estimated from Mostela data using capture-mark-recapture and spatially explicit capture–recapture methods for species with fur patterns that allow individual identification (e.g. the pattern of spots between dorsal and ventral fur colours of *Mustela nivalis vulgaris*; Fig. 5).

While enclosed camera traps share advantages with unenclosed systems, they can be deployed in a wider range

Fig. 5. Top: Mostela boxes transported by foot in the Catalan Pyrenees, Spain (photo credit: S. Salvador). Bottom: an example of four individual least weasels (*Mustela nivalis*) recorded within 1 week on one camera trap location (photo credit: Small Mustelid Foundation).

of habitats, such as under vegetation, under snow, and among rocks in areas where trees are scarce. Mostela seems to work best for the least weasel, likely because it can be placed in microhabitats that are frequented by this species. AHDriFT systems have only been reported to detect long-tailed weasels (Amber et al. 2021a, White et al. 2023), likely because studies were in regions where long-tailed weasels were the dominant or only weasel species.

Enclosed camera trap systems are able to detect both weasels and their small mammal prey. These 'bycatch' data can be valuable, especially where limited information is available on the small mammal community or where methods such as live-trapping, are hard to implement (see, e.g. Soininen et al. 2015). Simultaneous sampling of weasels and their potential prey can reveal interactions and provide data to analyse prey-related demographic fluctuations (Hamed MK, Holloway AW, Watts C, Webster A, Tanner K, and Moore T, unpublished data, Kleiven et al. 2023). Because drift fences associated with AHDriFT systems increase the overall

Fig. 6. Top: AHDriFT system deployment showing drift fence with modified overturned trash can at end to direct animals into the trash can. Bottom: Inside the trash can a downward facing camera takes a photo of a weasel in Indiana, USA (photo credit: Scott Bergeson and Carsten White).

area sampled by the device, they might make these systems more effective at recording weasels and their prey.

CURRENT LIMITATIONS

Application of enclosed camera systems to multiple weasel species is not yet properly tested. Stoats avoid Mostela in some cases (Croose et al. 2022). When using bait, and in certain locations, enclosed systems can collect numerous photos or videos of non-target species (especially small rodents), making data analysis difficult, particularly without an effective data management system. Using bait also increases the risk of attracting bears, cows or other large animals that can disturb equipment. Enclosed camera traps are relatively cumbersome to transport. It is unclear what the effective sampling area of a single enclosed camera system is (with the possible exception of the AHDriFT system), a measure that is important to estimate as a basis for interpreting data. We also need to test if estimates of occurrence and (relative) abundance based on enclosed camera systems are accurate and sensitive enough to detect trends over time.

FUTURE DEVELOPMENT

Full-scale application of enclosed camera systems as monitoring devices would benefit from lighter and cheaper designs that allow deployment of a larger number of units. Finding materials other than PVC for cameras would reduce potential problems caused by animals (e.g. bears) being attracted by PVC. Addition of a hair snag within or at the entrance of the device would enable collection of samples for analyses based on DNA. Wider testing of cameras with white flash would be helpful (Herrera et al. 2021). White flash might be more disturbing to animals, but it would enable easier identification of species and individuals (e.g. Mos & Hofmeester 2020). Comparison of enclosed systems to other methods is needed to test their suitability for monitoring weasel occurrence and density at larger scales. A comparison of Mostela data to live-trapping data of least weasels in Poland shows promising results (Hofmeester et al. in press) but needs to be replicated under different circumstances and for different species. Comparisons of AHDriFT data to live-trapping data from midwestern USA are promising (Amber et al. 2021a, White et al. 2023), but more comparisons are required. Because ongoing studies indicate that availability of alternative underground structures and holes might influence the chance that a weasel enters an enclosed camera system, investigation of this relationship would be beneficial. Differences among species and individuals in their tendency to enter enclosed systems needs to be tested. Simultaneous deployment of enclosed and unenclosed camera traps in proximity enables comparison of their detection probabilities (Croose et al. 2022, Cepeda-Duque et al. 2023). Finally, there is a need to train a machine learning algorithm to automate labour-intensive identification of species from images similar to that which exists for unenclosed camera trap photos (Böhner et al. 2023).

TOWARDS IMPROVED WEASEL MONITORING

Whether attempting a first survey for weasels or sustaining a long-term monitoring program, important contributions are needed to advance weasel monitoring. Where long-term weasel monitoring data exist, it makes sense to sustain those efforts using similar methodologies. However, traditional methods should be tested against other emerging non-invasive techniques reviewed here to evaluate the rigour of those results and utility of emerging techniques (Smith & Weston 2017). For example, long-term studies in northern latitudes using lemming nest occupation and snow track surveys as indices of weasel abundance (Sundell et al. 2013) allow for the comparative evaluation of other weasel monitoring approaches (e.g. baited cameras or track tunnels). Where new monitoring is planned, it is important to trial multiple techniques reviewed here simultaneously. Such comparative studies are critical to providing insight into the utility of differing monitoring techniques for a given species and site characteristics (e.g. habitat, range of densities, non-target bait consumption/decomposition rate).

Where weasels are of management concern and little is known, there is an emerging pattern of using an iterative, multi-method approach to gain an understanding of weasel distribution and population ecology. First, citizen science and historical records are often used to identify where weasels persist. Second, baited camera traps (and to a lesser extent detection dogs or molecular approaches) are used to gather information on spatial distribution and factors influencing occupancy of weasels within those focal areas (e.g. Ghose et al. 2018, Cepeda-Duque et al. 2023). Third, where weasels are known to be resident, researchers use enclosed camera trap setups (Mostela and/or AHDriFT systems) to gain insights into weasel behaviour and factors influencing their relative activity or abundance. Formalising this process within management plans and across political boundaries could help build towards large scale, comparable trend data needed to information management.

CONCLUSIONS

The management concerns surrounding weasels across many portions of their range globally, either as a declining or invasive species, necessitates improved monitoring methods. While our review highlights the diversity of methods used to non-invasively monitor weasels, there are clear trends in certain methods becoming more commonly used than others. Rather than relying on any single method, there is great promise in using a multi-method approach to long-term weasel monitoring that combines citizen science with adaptations of both common and emerging technologies. Regardless of the approach used, there is a need for strong commitment to dedicated weasel monitoring that is replicated over space and time to inform future management action.

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DATA AVAILABILITY STATEMENT

Data sharing not applicable as no new data generated.

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