Journal for Nature Conservation 85 (2025) 126865

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.com/locate/jnc

The role of small structures for stoats in agricultural landscapes

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ARTICLE INFO

Keywords:
Branch and stone pile
Camera trap
Detection dog
Mustela
Small mammal
Stoat
Farmland

ABSTRACT

The installation of small structures such as branch and stone piles has been recommended by experts for enhancing habitat conditions for biodiversity in intensively used agricultural landscapes, particularly for stoat (*Mustela erminea*) and weasel (*Mustela nivalis*). However, quantitative evidence regarding the effectiveness of such structures is lacking. In this study we investigated the influence of small structures and other surrounding landscape elements on these two mustelid species across the Swiss lowland agricultural landscape. Over the course of two years (2022 and 2023), we used scat-detection dogs, visual scat surveys, and camera traps to sample populations of these species in 420 plots distributed across 28 study sites. Of these plots, 187 harboured a branch pile, 94 a stone pile, while 139 had no small structure. Overall, when considering both scat and camera trap data, stoats were detected at 26 of 420 (6.2%) plots, but only one weasel was recorded, indicating a low mustelid occurrence across our sampling sites. Multi-scale linear models revealed a significant positive effect of small structures on stoat abundance and a preference for stone piles over branch piles. Forest negatively affected stoat occurrence, possibly reflecting a preference for open habitat where small rodents thrive, notably water voles and common voles. Our results underscore the importance of retaining or reinstating small structures, in particular stone piles, in the agricultural landscape to support stoat populations. Nevertheless, we call for ensuring the presence of both stone and branch piles to provide habitat features benefitting a diverse array of species.

1. Introduction

Over the last few decades, European agricultural ecosystems have undergone a strong homogenization because of the increased adoption of monoculture, improved mechanization, and field size expansion, which has led to the disappearance of semi-natural landscape elements such as hedgerows, extensive field margins, and stone walls (Batáry et al., 2017; Poschlod & Braun-Reichert, 2017; Stoate et al., 2001). This loss of habitat heterogeneity is directly connected to a large-scale decline in farmland biodiversity (Benton et al., 2003), negatively affecting birds (Rigal et al., 2023), insects (Habel et al., 2019), and plants (Storkey et al., 2012). Switzerland is no exception, with agricultural intensification exacerbating the loss of semi-natural habitats, which is in turn further amplified by the expansion of road networks and urban areas (Diacon-Bolli et al., 2012; FOEN, 2017).

Small structures (Fig. 1) that once were present both naturally and semi-naturally across agricultural landscapes have mostly vanished. Natural small structures include deadwood and scree slopes, whereas semi-natural small structures are manmade and include branch, log, and stone piles, as well as dry walls. These linear and point structures contribute to landscape diversity and connectivity, providing primary as well as stepping-stone habitats for a multitude of species. Reptiles, for example, are assumed to benefit greatly from stone and branch piles, which serve as cover, shelter, and basking sites (Meyer et al., 2011; O'Sullivan et al., 2023). Sperry & Weatherland (2010) described Texas ratsnakes (*Elaphe obsoleta*) using branch piles in oak and juniper woodlands and savannahs, likely taking advantage of the cooler microclimate and higher prey availability in these structures. For amphibians, branch piles are similarly crucial, not only harbouring a high number of prey but also offering moist shelter and cover from their own

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https://doi.org/10.1016/j.jnc.2025.126865
Received 10 October 2024; Received in revised form 11 February 2025; Accepted 12 February 2025
Available online 13 February 2025

predators (Indermaur & Schmidt, 2011). Linear stone structures such as dry stone walls are especially beneficial to rock-dwelling amphibians and terrestrial molluscs (Manenti, 2014). Furthermore, small structures may offer nesting and feeding sites for pollinators as well as for various mammal species, including small carnivores such as stoats (*Mustela erminea*) and common weasels (*Mustela nivalis*, weasels hereafter) (Koller et al., 2017; Kolly et al., 2019; Steel et al., 1999; Sullivan & Sullivan, 2023; Westerfelt et al., 2015).

Stoats and weasels, also referred to as small mustelids, have been identified as target and indicator species within the framework of the Swiss Federal Offices for Environment and Agriculture (Walter et al., 2013). These small mustelids have a diverse diet, including bird eggs, reptiles, invertebrates, and small mammals, but are specialized in preying on water voles and common voles (Arvicolinae), therefore acting as pest control (Boschi et al., 2018; Debrot, 1983; King & Powell, 2007). Despite this pest control role in the Swiss agricultural landscape, small mustelid distribution and population size are not well known, likely in part because of these animals' elusive behaviour (Capt & Marchesi, 2012). Experts suggest that Swiss populations have declined in recent decades (Rossier et al., 2021), and the weasel has been listed as vulnerable on the Swiss Red List of endangered species (Capt, 2022). Similar suspected declines have been noted in stoat or weasel populations in other European countries (Coomber et al., 2021; McDonald et al., 1998; Sidorovich & Solovej, 2007; Torre et al., 2018) and in North America (Jachowski et al., 2021). Suspected drivers of these declines include disease, changes in prey availability, competition or predation, as well as landscape change through climatic shifts, afforestation, or farming intensification. In Switzerland, the main reason for the decline is assumed to be the general intensification of agricultural practices and the resulting landscape homogenization (Rossier et al., 2021). As *meso*-predators, stoats and weasels not only are hunters but also are preyed upon by foxes, domestic cats, and various birds of prey (King & Powell, 2007; Korpimäki & Norrdahl, 1989). Small structures provide suitable cover and shelter for stoats and weasels as they move through the landscape (Feige et al., 2012), and this protection from predators makes small structures important breeding grounds for them (King & Powell, 2007; Kolly et al., 2019).

In Switzerland, experts currently recommend the implementation of small structures to promote small mustelid population and to enhance habitat connectivity (Benz, 2017; Boschi et al., 2018). Despite these recommendations, a detailed literature research by Rossier et al. (2021) uncovered no scientific study that has quantitatively examined how branch and stone piles affect stoats and weasels. Consequently, there is a gap in understanding of how the addition of small structures in the landscape promotes the population of these small mustelids.

In this study, we used camera traps and scat surveys to monitor for the presence of stoats, weasels, and other small mammals on small structures. Through statistical modelling, we sought to determine how small structures and their characteristics, along with the surrounding landscape elements, affect stoat and weasel populations in the Swiss

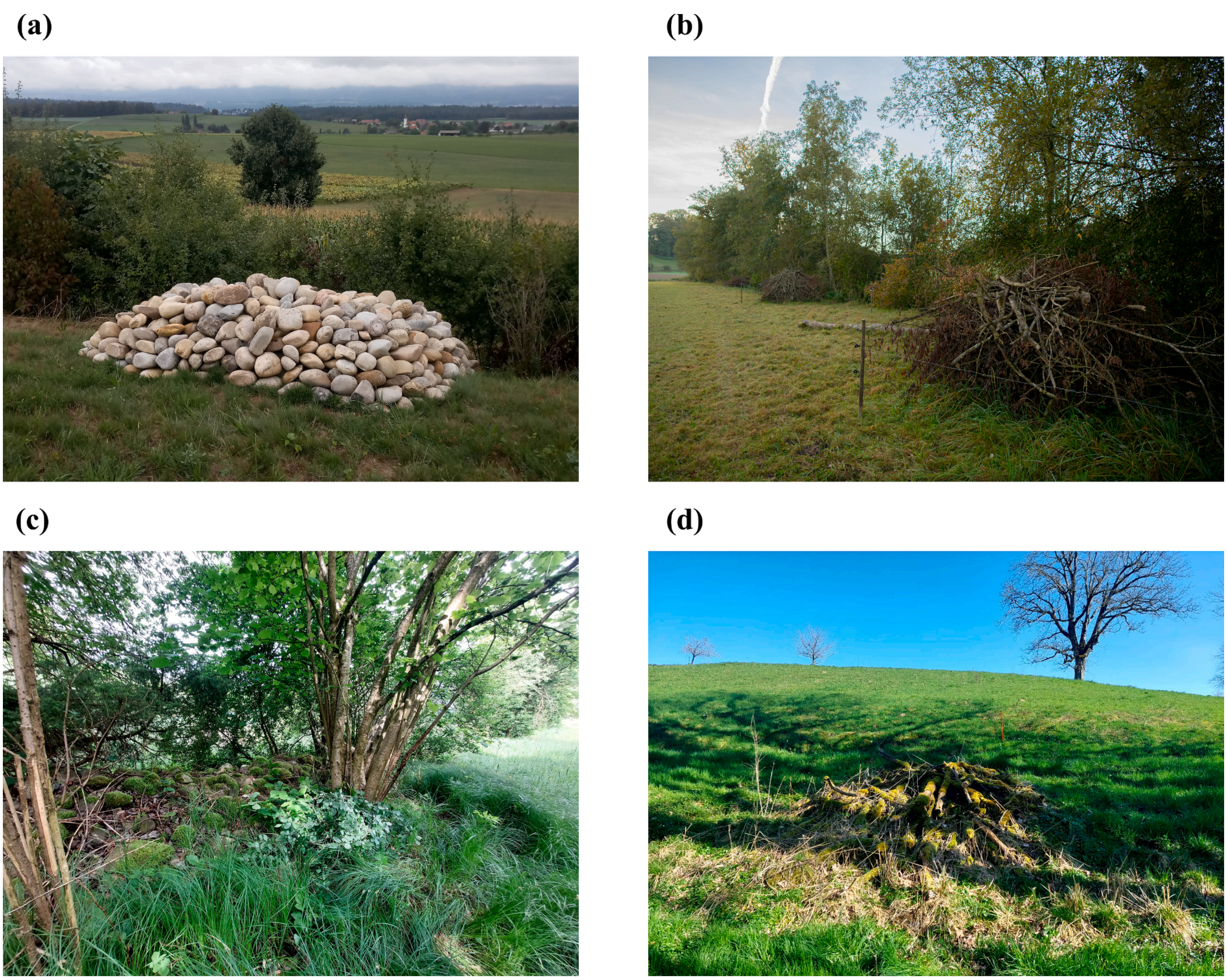

Fig. 1. Branch and stone piles. Examples of small structures encountered in the field. (a) and (b) show high-quality stone and branch piles, respectively. The stone pile was not completely overgrown by vegetation and cavities were accessible, and the branch pile was stocked with new, non-degraded material. In contrast, (c) and (d) show examples of lower quality stone and branch piles, both of which lacked sufficient volume and adequate cavities.

countryside. Ultimately, our findings are expected to inform targeted conservation efforts and contribute to the promotion of small mustelid populations.

2. Material and methods

2.1. Study location

Sampling occurred in 14 regions across the Swiss lowlands in 2022 and 2023 (Fig. 2, Appendices A and B). Each region consisted of a focal and a pseudo-control site. The focal sites were selected according to the following criteria: they must have contained small structures that had previously been installed as part of a regional biodiversity conservation (RBC) project and were located in one of the first three administrative agricultural zones in Switzerland (i.e. plain, hill area, or mountain area 1; BLW, 2022). The aim of these RBC projects was to offset biodiversity loss in agricultural landscapes, and small structure installation was one of many measures implemented. The pseudo-control sites were randomly selected at a distance of 5 km from the respective focal sites (Fig. 2, Appendix A2) and had to be in the same agricultural zones but located outside of the RBC project borders. A 500 x 500 m grid was placed over each site, dividing it into 25-ha squares. Five connected squares were selected for sampling at each site (125 ha per site), with a matching arrangement of squares between the focal and pseudo-control sites within the same region, but with arrangements potentially differing across regions. In every square, three circular sampling plots with a 5-m radius were selected (Fig. 2, Appendix A3). In the focal sites, each plot contained a small structure in its centre, installed as part of the RBC project. The preference was for the three plots to be located along a single landscape element (e.g. a hedgerow). In the pseudo-control sites, plots were selected along a similar landscape element but did not contain any small structures installed as part of the RBC project. Sometimes, small structures placed by farmers independent of RBC projects were present in the pseudo-control sites. In such cases, plots were adjusted to incorporate these structures. Overall, there were 14 regions consisting of two sites each, each composed of five squares containing three plots each, for a total of 420 study plots (all scales visible in Fig. 2).

2.2. Sampling methods

As Jachowski et al. (2024) recently recommended for *Mustela* species, we monitored study plots using two complementary non-invasive methods: scat surveys and camera traps. Detection dogs were used to search each plot once for mustelid scats. This non-invasive sampling method is being increasingly applied in conservation biology, especially for monitoring elusive and rare mammals (Long et al., 2007; Orkin et al., 2016; Wasser et al., 2004). In collaboration with Artenspürhunde Schweiz (www.artenspuerhunde.ch), three dogs were trained to detect the scat of our target species and distinguish them from the scat of other species (see details on training in Appendix C, reported as suggested in McKeague et al., 2024). Data were collected over the course of 18 days in 2022 in May, June, July, and October, and over the course of 10 days in 2023 between March and April. With the detection dog method, a mean of 23 (min. 15, max. 30) small structures were sampled per day, alternating two or three dogs. The focal and pseudo-control site of each region were sampled in parallel. During survey sessions, the entire circular plot area was inspected. The dogs inspected accessible cavities and climbed on top of structures if possible, but small structures were not manipulated to reach inaccessible points. Olfactory detection allowed dogs to also locate scats inside structures but only where airflow was available. The average survey duration was 8.5 min per plot. The temperature during the searches ranged from −2 to 34.6 °C (mean 17.8 °C) and humidity from 10 % to 97 % (mean 54.7 %). During 13 % of the

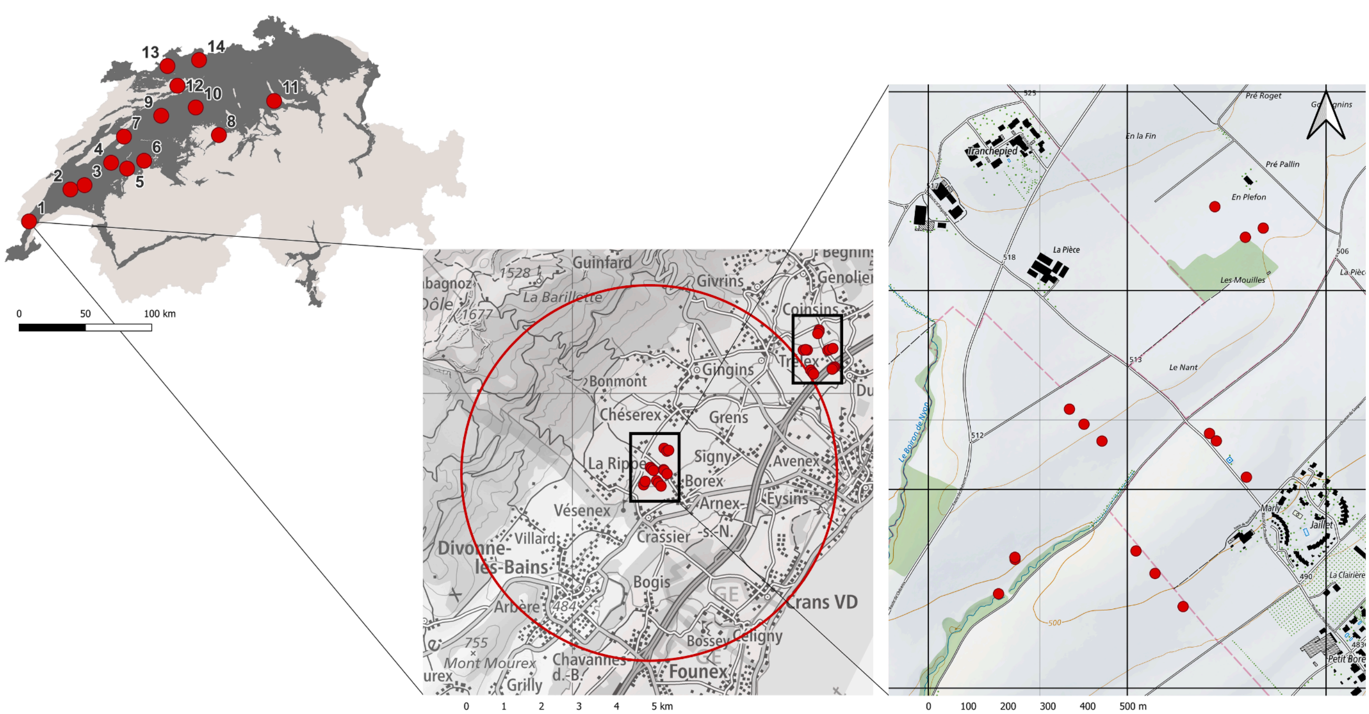

Fig. 2. Study site scales. Study sites and overview of the different sampling scales. Left: map of the 14 study regions (red dots) located in the Swiss lowlands (in dark grey). Middle: zoomed-in depiction of a study region composed of focal and pseudo-control sites, both outlined in black. The focal site was at the centre and the pseudo-control site at the top right, selected at a 5-km distance (red circle). Plot locations are indicated as red dots (15 per site). Right: zoomed-in depiction of the focal site. The 500 x 500 m grid determined five connected squares, each containing three plots indicated in red. Appendix A shows each map separately in higher resolution and with a more detailed description. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

searches, there was light or heavy rain. Faecal samples were collected in hermetic tubes and kept in a cooler box before being stored at −20 ℃ for later genetic analysis.

We also deployed enclosed camera traps to detect the presence of mustelids. For this survey, we used two types of camera trap boxes, a large box with an infrared flash camera and a small box with a white flash camera. The small boxes ("Kleinsäugerbox") were acquired from wls.ch, and the large boxes were custom made, adapted from the "Mostela" developed by Mos & Hofmeester (2020) and incorporating suggestions presented by Aegerter et al. (2019). In both types of boxes, an entrance 5 cm in diameter restricted larger species from entering the box (see Appendix D for a detailed description of the camera trap box designs).

Camera trapping occurred between June and August 2022 and March and July 2023. A box of each type was randomly allocated to two of three plots in each square, totalling ten cameras per site (270 of 420 plots sampled with camera traps). Camera traps were placed within plots, adjacent to the small structure if present. If a linear structure (e.g. hedgerow, dry stone wall) was located within a plot, the box entrances were positioned to align parallel to the linear structure. Image data covering two consecutive weeks were analysed for each camera. Among the 270 planned camera trapping locations, six cameras malfunctioned and two were not granted installation by the landowner, so that 262 plots were sampled with camera traps for two consecutive weeks. Each focal and corresponding pseudo-control site of a region were sampled over the same time period. Forty camera boxes were available, allowing for the simultaneous sampling of two regions. All cameras were programmed to take three successive pictures one second apart upon motion trigger, with a one-minute quiet period. Camera sensitivity was set to medium–high to prevent invertebrates from triggering the device while guaranteeing motion detection of small mammals. As bait for small mammals such as mice and voles, a tablespoon of peanut butter and six hazelnuts were placed inside the box, with an additional four hazelnuts placed outside the box. The activity of small mammals in the camera traps was intended to attract stoats, as their body scent has been shown to work as bait (Murphy et al., 2022).

The images were classified in an Excel form sheet provided by the Christianson Wildlife Ecology Lab (Christianson, 2017). Mustelids were identified to the species level, Arvicolinae to the sub-family level, and Muridae and Soricidae to the family level. Within each respective species, sub-family, or family, specimens were conservatively identified to the individual level based on body size, marks like ear scars, and coat patterns, giving minimum abundance data for each sampled plot.

During the scat surveys with the dogs, we learned to morphologically recognize stoat scats (size, shape, colour, and content). While setting up and collecting back the camera boxes, as well as when we visited the study sites for the mapping of the habitat characteristics (see next subsection), we also visually searched the plots for scats on these three occasions.

2.3. Habitat characteristics mapping

To investigate the habitat preferences of the mustelid species, we mapped the characteristics of each study plot. First the characteristics of any small structures present in the plot were described according to variables listed in Appendix E. To estimate the relative abundance of voles per plot, we followed the method of Giraudoux et al. (1995), placing a 5 x 5 m square at 10 m perpendicular distance from the plot's landscape element, followed by a search of this area for vole holes, hills, or galleries (winter tunnels that become visible upon collapse). If the square could not be placed in the intended location, it was moved to the nearest possible point. Small mammal activity stemming from camera trap data (other than mustelids) was included as an additional variable comprising the abundance of Arvicolinae, Muridae, and Soricidae separately, as well as the sum of all three families. Finally, the habitat characteristics around each plot were mapped in a 200-m radius using QGIS 3.24.0 (QGIS Development Team, 2024). The cover (in m^2) for different habitat types was converted to relative percentage cover for data analysis (see Appendix E for a description of all variables recorded).

2.4. Genetic analysis

Genetic species identification was based on sequences of the mitochondrial control region from scat samples in comparison with stoat and weasel entries in the NCBI GenBank sequence database. Novel primers for PCR amplification of small mustelid DNA from scat samples were established after initial testing of published primers (Harrington et al., 2010; Pun et al., 2009; Statham et al., 2007) showed a low success rate. The novel primers amplify a relatively short region of approximately 200 bp, which increases the success rate of amplifying potentially highly degraded faecal mitochondrial DNA (Broquet et al., 2007). PCR amplification conditions were established using DNA from muscle tissue samples from stoats and weasels as the target species and from common voles and water voles as negative controls (Braaker & Heckel, 2009; Fink et al., 2004; Sutter et al., 2013). PCR amplification was then validated with stoat and weasel scat samples from zoo or wildlife rescue centres, as well as from scat samples collected in the wild where stoats were known to occur.

DNA was extracted using a high-salt extraction method (Aljanabi & Martinez, 1997), and the concentration was standardized to 5 ng/μl for amplification. Novel primer pairs Mermin166L (5′-GCCTCGAGAAACCATCAACC-3′) and Mermin166R (5′-TCGAGATGTCCCATTTGAAGG-3′), as well as Mermin150L (5′-ACGAGCTTTATCACCATGCC-3′) and Mermin150R (5′-GGATTGAGGACTGACATGGC-3′) were used. Both pairs specifically target a portion of the mitochondrial control region of stoat and weasel but do not amplify the most common prey species, i.e. the common vole (*Microtus arvalis*) and water vole (*Arvicola terrestris*). PCR reactions were performed in a 25-μl volume, including 12.5 μl sterile water, 0.5 μl dNTPs, 5 μl buffer, 0.2 μl Taq polymerase, 0.5 μl of 10 mg/ml bovine serum albumin, 1 μl of each primer (10 pmol/μl), and 4.5 μl DNA. The amplification conditions consisted of an initial denaturation at 95 °C for 3 min, followed by 40 cycles of denaturation at 95 °C for 30 s, annealing at 54 °C for 30 s, extension at 72 °C for 1 min, and a final elongation at 72 °C for 5 min. PCR products were visualized on 1.5 % agarose gels. If the PCR product was too weak for sequencing, a new PCR was conducted with 9 μl of DNA. If no PCR product was visible, another PCR was performed using less specific primers (L15995 and H16498; Pun et al. 2009) to check if the scat belonged to a species that could not be amplified with our small mustelid-specific primers. PCR products were sequenced by Microsynth (Balgach, Switzerland). Sequences were compared with entries in the GenBank database using the BLAST function and the e-value to verify their correspondence. Samples that failed to amplify with any primer pair or did not match mustelid control region sequences in the database were treated as negative for stoat and weasel in further analyses.

2.5. Statistical analysis

To assess the factors influencing the occurrence probability and relative abundance of mustelids, we carried out generalized linear models at three scales: structure, square, and site (Fig. 2). The explanatory variables, which differed for each scale, are listed in Table 1. The response variable, i.e. detection/non-detection of mustelids, but regarded as presence/absence or relative abundance, was computed by merging the data from the camera traps and genetic surveys. Note that occupancy model (sensu MacKenzie et al., 2002) could not be used because, in some locations, our repeated survey spanned over a year and thus the closed population assumption was not met.

At the structure scale, each plot was regarded as an independent sampling unit to identify how structure-specific characteristics influenced mustelid occurrence. Note that plots without small structures

Table 1
Explanatory variables.

Explanatory variables	Structure scale (50 m radius)	Square scale (100 m radius)	Site scale (200 m radius)
Structure characteristics			
Avg. max. size of material	✓ *		
Avg. min. size of material	✓		
Avg. size of material	✓ *		
Canopy cover	✓ *		
Structure	✓ ·		
Structure type	✓ *		
Vole index	✓	✓	✓
Habitat characteristics			
Artificial place	✓ *	✓ ·	✓
Cropland	✓ *	✓	✓
Extensive grassland	✓	✓	✓
Farm	✓	✓	✓
Forest	✓ *	✓ *	✓
Hedgerow	✓	✓	✓
Intensive grassland	✓	✓	✓
Number of structures	✓	✓ *	✓ ·
Road	✓	✓	✓
Settlement	✓	✓	✓
Water body	✓	✓	✓
Small mammals			
Arvicolinae		✓	✓
Muridae		✓	✓
Soricidae		✓	✓
Sum small mammals		✓	✓

List of explanatory variables used in the statistical analysis at the structure, square, and site scales. For the "Habitat characteristics" variables, scales were defined by the radius around each plot in which variables were measured: 50 m for structure scale, 100 m for square scale, and 200 m for site scale. Variables used in the univariate model pre-selection at each scale are marked with (✓). Variables that showed a potential influence ($P < 0.1$) in the univariate model are marked with (·), and variables that showed a significant effect ($P < 0.05$) are marked with (*). See Appendix E for a detailed description of the variables and Appendix F for univariate model outputs.

were excluded from this analysis. Structure characteristics, vole index, number of structures present in a 50-m radius, and habitat types in a 50-m radius were used as explanatory variables. Small mammal camera trap data were not included at this scale, as camera traps were installed in only two-thirds of all plots.

At the square scale, the three plots in each square were grouped. The presence/absence data of these plots were summed, giving a relative mustelid abundance ranging from zero to three. Structure characteristics were no longer included as explanatory variables, but vole index and small mammal camera trap data were included as averages per square. Furthermore, the habitat types and number of small structures recorded in a 100-m radius around each plot were included as explanatory variables, with overlapping radius surfaces merged per square.

At the site scale, the relative mustelid abundance data of all 15 plots within each site were grouped. The same explanatory variables as in the square scale were included, with vole index and small mammal camera trap data averaged across all 15 plots. Habitat types and the number of structures were measured in a 200-m radius around each plot, with overlapping radius surfaces merged across all 15 plots.

Following the statistical analysis approach of Kurtogullari et al. (2019), first univariate models were run to pre-select explanatory variables with a potential influence (significance threshold set at $P < 0.1$) for each scale (Table 1, Appendix F). This pre-selection process prevented model overfitting and led to simpler models that are clear and interpretable to practitioners. Specifically, binomial generalized linear mixed-effects models (GLMMs) and Poisson GLMMs with site as random intercept effect, or Poisson generalized linear models (LM) were run at the structure, square, or site scale, respectively, using the *glmer* or *glm* function (*lme4* package, Bates et al., 2015). In a second step, using the pre-selected variables, we constructed a global model for each scale using the same respective distributions and functions as above. Note that all paired variables were tested for collinearity, but none showed a strong correlation (Spearman's rank correlation coefficient $r_s \geq 0.7$; Spearman, 1904). Finally, the *dredge* function (*MuMIn* package, Bartón, 2020) was used to run and rank all possible models (i.e. combinations of explanatory variables) based on the Corrected Akaike's Information Criterion (AICc). The model with the lowest AICc was chosen as the best model for each scale. To calculate and plot predicted occurrence probabilities and relative abundances based on the best models, we used the *ggpredict* function (*ggeffects* package, Lüdecke, 2018) and the *ggplot2* package (Hadley, 2016). Finally, a Wilcoxon sign-ranked test (non-normally distributed data; Wilcoxon, 1945) was applied to compare the dimensions (length, width, height) of small structures with stoat presence versus absence, as well as the number of small structures in a 100-m radius around plots with stoat presence versus absence (Wilcoxon, 1945). All statistical analyses were performed in RStudio version 4.2.1 (RStudio Team, 2022).

3. Results

Of the 420 plots sampled, 187 contained a branch pile, 94 contained a stone pile, and 139 had no small structure. All 420 plots were sampled with detection dogs and visual survey and 262 also with camera traps. Sampling via detection dogs and visual survey yielded a total of 120 scats, of which 92 were identified as belonging to stoats. Three stoats and one weasel were recorded on camera, of which the weasel and one stoat were captured on the same plot, the other two stoats were each captured in plots of different sites. Altogether, stoats were detected on 26 different plots, 20 located in focal sites and 6 in pseudo-control sites. Of these 26 plots, 17 contained a stone pile and 9 a branch pile. Assuming that multiple detections per plot represented the same individual but that neighbouring plots with presence represented different individuals, 26 individuals were detected across 3500 ha (sum of all sampled study sites), meaning one individual per 135 ha or 0.0074 individuals per ha.

Among the 120 sampled scats, 55 were collected using detection dogs. Of these, 48 were genetically identified as *M. erminea* and one as *Martes foina*, and six could not be classified because samples were too degraded for DNA amplification. Detection dogs thus achieved a 98 % true-positive success rate among classifiable scats. The remaining 65 scats (out of the 120) were collected during visual surveys. Of these, 44 were genetically identified as *M. erminea,* five as *Martes martes*, and one as *Vulpes vulpes*, and the remaining 15 were unidentified. Overall, 120 scats were collected during detection dog and visual surveys, and 76.7 % of them were identified as *M. erminea*. Including the *M. foina*, *M. martes*, and *V. vulpes* samples, 82.5 % of all samples were successfully genetically identified.

There were 262 plots sampled with camera traps for two consecutive weeks each, resulting in a total of 212′278 pictures (Fig. 3). Of these, four mustelids were identified on three plots, in three different sites. One plot showed the presence of both a stoat and a weasel, and on the other two plots, the presence of one stoat each was determined. On two of these three plots, no mustelid scats were detected. Of the remaining classified small mammal families captured by the camera traps (out of the 262 plots), 394 were Arvicolinae, 728 Muridae, and 105 Soricidae.

For the linear models, camera trap and scat survey data were merged (except for the structure scale). The sole detected weasel was not included in the analysis. Univariate models at the structure scale pre-selected eight explanatory variables (Table 1, Appendix F). The best model following AICc-based variable selection showed a significant difference between the mean occurrence probability of stoats on stone piles (0.14, SE = 0.05) compared with branch piles (0.04, SE = 0.02, $P = 0.004$; Table 2, Fig. 4), as well as a negative effect of forest cover in a 50-m radius around each plot on stoat occurrence ($P = 0.044$; Table 2, Fig. 5). Additionally, an increasing volume of small structures showed a positive trend with stoat occurrence, though not significant ($P = 0.068$;

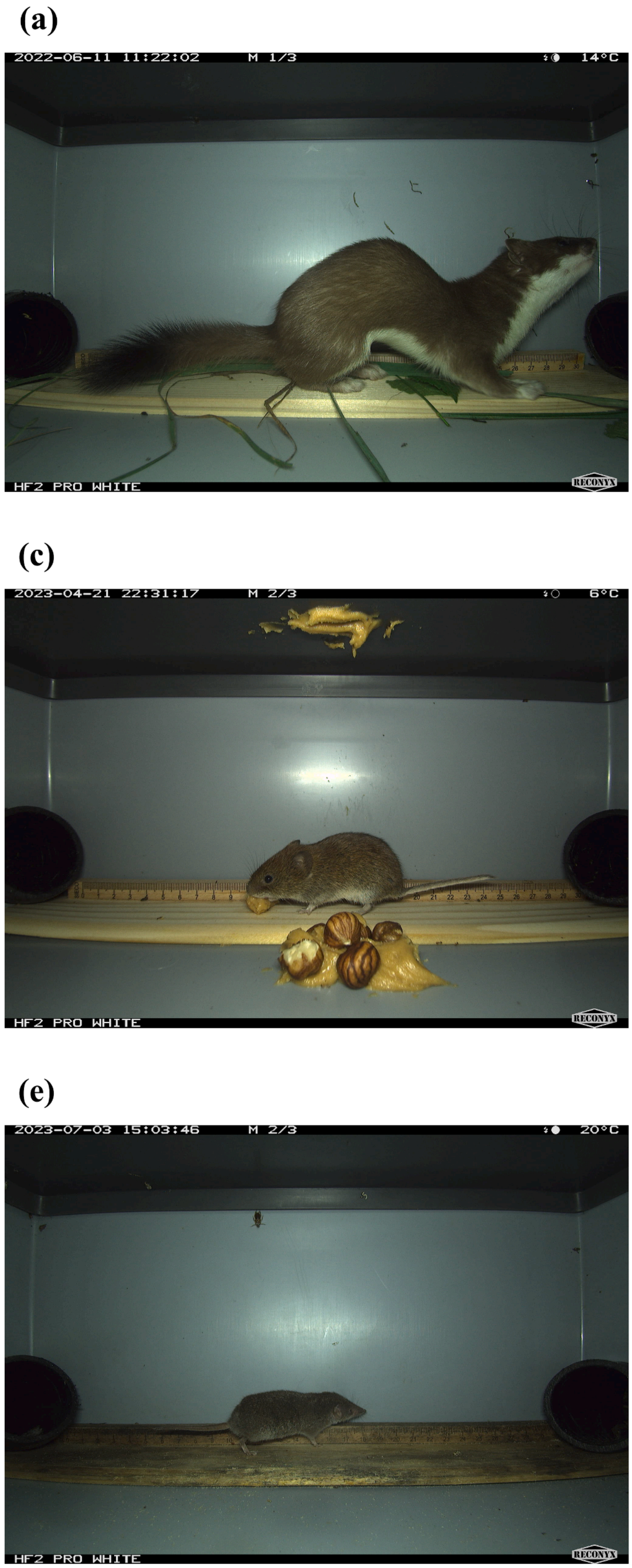

Fig. 3. Camera box images. Images captured by the camera boxes of (a) stoat (*M. erminea*), (b) weasel (*M. nivalis*), (c) vole (Arvicolinae), (d) mouse (Muridae), and (e) shrew (Soricidae). Also visible are a wooden track pad and scale, as well as two 5-cm entrance tunnels. The peanut butter and hazelnut bait are visible in (b), (c), and (d), and already fully consumed in (a) and (e).

Table 2
Statistical outputs.

Explanatory variables	Estimate	SE	P-value
Structure scale (50 m radius)			
Intercept (structure type branch)	−2.891	0.493	< 0.001
Forest	−2.572	1.279	0.044
Structure type (stone)	1.416	0.497	0.004
Structure volume	0.032	0.018	0.068
Square scale (100 m radius)			
Intercept	−1.850	0.426	< 0.001
Forest	−3.795	1.468	0.010
Number of structures in 100 m radius	0.133	0.056	0.017
Site scale (200 m radius)			
Intercept	−0.556	0.343	0.106
Number of structures in 200 m radius	0.018	0.009	0.052

Statistical outputs of the structure, square, and site scale analyses. At the structure scale, a binomial GLMM was built, and a Poisson GLMM and Poisson LM were constructed for the square and site scales, respectively. Estimate, standard error (SE), and p-value are listed for each model.

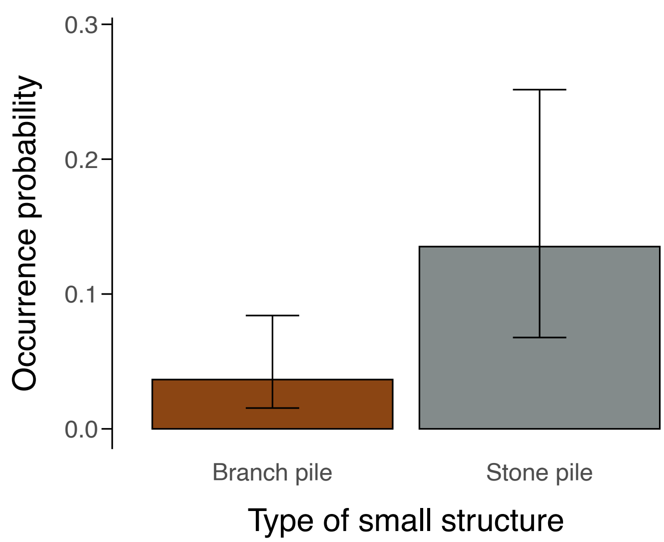

Fig. 4. Stoat occurrence probability according to small structure type. Stoat occurrence probability according to the type of small structure, predicted by the best multivariate model on the structure scale analysis. 95% confidence intervals are indicated as black lines. See Table 2 for model outputs.

Table 2). In the same vein, a Wilcoxon signed-rank test revealed a significantly higher stoat occurrence on longer and wider stone piles, as well as on higher branch piles (Appendix G). At the square scale, three variables were pre-selected (Table 1, Appendix F). Of these, the best model demonstrated a significant negative effect of forest cover in a 100-m radius around each plot ($P = 0.010$) and a significant positive effect of the number of small structures present in a 100-m radius ($P = 0.017$) on relative stoat abundance (Table 2, Fig. 6). See Appendix H for the list of models within 4 delta AICc of the best selected models for the structure and the square scale. Finally, at the site scale, the number of small structures present in a 200-m radius around each plot was the only univariate model showing a positive, though just non-significant, effect on relative stoat abundance ($P = 0.052$; Tables 1 and 2, Appendix F).

4. Discussion

To our knowledge, this study is the first to investigate the role of small structures in the agricultural landscape for stoats in Switzerland and beyond, despite such structures becoming increasingly popular and being recommended by conservation practitioners to improve habitat conditions to promote farmland biodiversity. Using scat-detection dogs, visual scat surveys, and camera trapping boxes, we sampled 420 plots over a two-year period, of which 187 contained a branch pile, 94 a stone pile, and 139 had no structure. Only one weasel was detected and thus excluded from the analyses. Nevertheless, this single isolated observation aligns with the classification of the weasel as an endangered species and its low densities in the Swiss lowlands (Capt, 2022). Stoat presence was detected on 26 plots. Results showed that the number of small structures present in the landscape had a significant positive effect on relative stoat abundance, and a higher stoat presence was detected on stone piles compared to branch piles. These findings underscore the importance of small point structures within agricultural landscapes, providing valuable insights for further conservation and management strategies targeting stoats and other small mammal species reliant on similar habitats.

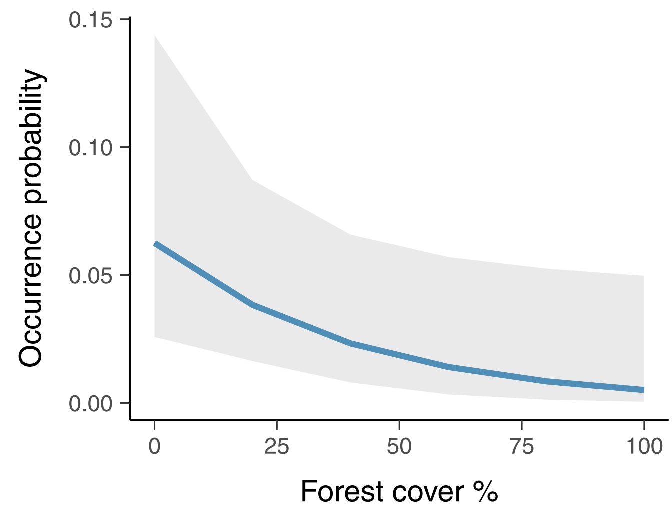

Fig. 5. Stoat occurrence probability according to forest cover. Stoat occurrence probability according to the proportion of forest cover (%) in a 50-m radius, predicted by the best multivariate model at the structure scale analysis. Predicted values are shown in blue and confidence intervals in grey. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.1. Sampling methods

Scat-detection dogs proved to be remarkably effective for sampling small mustelids in Switzerland, with 97.8 % (true-positive rate) of genetically identified samples belonging to stoats. With our study design, however, we could not evaluate the false-negative rate (false absence) of the detection dogs. Nevertheless, the deployment of dogs enabled the detection of small mustelid presence across the sampled plots to a degree that would not have been possible without their assistance. Additional scats were found during multiple visual surveys outside of the sampling sessions carried out with the dogs, although it is highly likely that had they been present, the detection dogs would have found these samples as well. Combined, 120 scats were collected, of which 76.7 % were identified as stoat. The overall proportion of 82.5 % identified scats is similar to the 80.7 % reported in a previous study of the genetic identification of mustelid faeces (Vigués et al., 2021).

Of the three stoats detected via camera trap in three separate plots, scat presence was detected on only one, indicating that the two sampling methods were complementary. Despite the discrepancy in detections between the two methods, camera traps offered different advantages, such as continuous monitoring over extended periods of time, exact timestamps of presence, and the simultaneous monitoring of other species captured on camera.

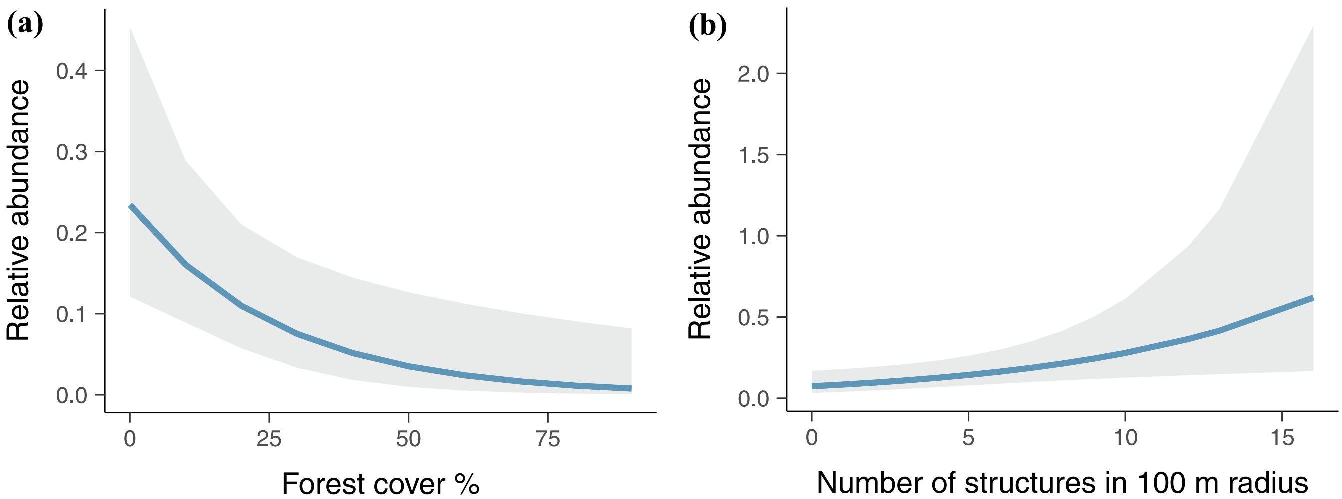

Fig. 6. Relative stoat abundance according to forest cover and small structure number. Relative stoat abundance according to (a) the proportion of forest cover (%) in a 100-m radius, and (b) the number of small structures present in a 100-m radius. Predicted values, by the best multivariate model at the square scale, are shown in blue and the confidence intervals in grey. See Table 2 for model outputs. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.2. Ecological value of small structures and other landscape elements

Our surveys detected a relatively low density of stoats in the Swiss agricultural landscape. Forest cover appeared to have a negative effect on stoat occurrence at the structure (50 m) scale and on relative abundance at the square (100 m) scale. This finding aligns with research by Debrot and Mermod (1983) in the Swiss Jura mountain range that identified stoat avoidance of forested areas, likely because their preferred prey, such as water voles, mostly occur in grasslands (King & Powell, 2007; Meylan, 1977). Note that no wild rabbits occurred in our study sites.

The number of small structures within a 100-m radius (square scale) around each plot was positively associated with relative stoat abundance, and there was a similar but non-significant trend ($P = 0.052$) at the site scale (200 m). These results are consistent with suggestions and calls from experts to install small structures to promote mustelid populations, as they provide new nesting habitat, cover and shelter, and facilitate movement (Boschi et al., 2018; Kolly et al., 2019). Similarly, Hernández and Zaldívar (2013) and Mougeot et al. (2020) found that small mustelids in Spain favour linear structures such as hedgerows, drainage ditches, and field margins with high vegetation cover. The implementation of small structures also can promote the presence of a multitude of other species, in particular amphibians and reptiles (e.g. Indermaur & Schmidt, 2011; Sperry & Weatherland, 2010).

We detected a higher stoat occurrence probability on stone piles compared to branch piles, as well as a positive trend to an effect of structure volume. Stone piles may offer more durable and stable habitat for stoats over time, as these structures are less prone to degradation compared with organic materials such as branches. Moreover, cavities within stone piles may provide better shelter from predators and a more secure nesting environment. Some branch piles, as observed in the field, may consist only of hedgerow trimmings and lack the chambers found in stone piles. Several Swiss experts have recommended constructing small structures with a certain level of heterogeneity in material size and cavities of 4–10 cm (Boschi et al., 2018; Kolly et al., 2019). Our finding of a trend to a preference for structures with a larger volume aligns with expert recommendations, which emphasize the importance of building small structures of sufficient size to benefit mustelid populations (Boschi et al., 2018). Larger structures can provide more cavities, more shelter opportunity, and more nesting potential. Our additional analyses further stressed the importance of larger structures and revealed that stone piles with stoat presence were on average longer and wider than stone piles without stoat presence. Similarly, branch piles with stoat presence were on average higher than branch piles without.

The occurrence of small mustelids was very low in this study. Across our study area, we recorded an estimated density of 0.0074 stoat individuals per ha. Given than we cannot guarantee perfect detection, our estimate may slightly underrepresent the true stoat density. Nevertheless, it is lower than values reported in previous studies estimating stoat density (e.g. 0.01 individuals per ha in New Zealand, Smith et al., 2008; 0.025–0.125 individuals per ha in Swiss Jura mountains, Debrot & Mermod, 1983; 0.03–0.1 individuals per ha in Sweden, Erlinge, 1983), with some exceptions (e.g. 0.004–0.009 individuals per ha in Scotland, Pounds, 1981). Sampling regions in the current study were characterized by high-intensity agriculture, dominated by croplands, permanent grasslands, and forests (see Zingg et al., 2018), and this intensive land use may drive low small mustelid densities. Other studies across Europe and the United States have identified low or declining population sizes, and possible drivers include agricultural intensification, afforestation, climatic shifts, rodenticides, competition with or predation by invasive species, and disease (Coomber et al., 2021; Jachowski et al., 2021; McDonald et al., 1998; Sidorovich & Solovej, 2007; Torre et al., 2018).

4.3. Conclusion and management recommendations

Overall, stoat presence was detected on 6.2 % of the plots, indicating a low occurrence in our sampling sites. Despite this limitation, multiscale linear models revealed the importance of small structures, particularly stone piles, in a 100-m radius around sampled plots. Based on these findings, we call for the installation of small structures throughout the agricultural landscape to promote small mustelid populations. Combining model prediction and our observations (Appendix I), we suggest installing five or more small structures within a 100-m radius. As larger small structures appear to offer greater benefit for stoats, we recommend a minimum stone pile size of 200 x 200 x 50 cm and branch pile size of 200 x 200 x 100 cm. Stoats play a vital role as predators of water voles and common voles, animals that can have detrimental impacts on agricultural systems such as grassland and fruit tree production. In this context, stoats may act as natural pest control (Boschi et al., 2018; King & Powell, 2007; Mougeot et al., 2020). Although our results indicate the importance of keeping or reinstating stone piles for stoats, we call for the installation of both stone and branch piles to provide habitat features that benefit a diverse array of species, such as amphibians, birds, and reptiles (Castillo-Escrivà et al., 2019; Indermaur & Schmidt, 2011; Manenti, 2014; O'Sullivan et al., 2023; Rossier et al., 2021; Sperry & Weatherland, 2010). The installation of small structures can be easily accomplished, as rocks and dead wood, often perceived as unusable or excess materials, are often readily available on-site. By informing conservation strategies, our findings can benefit not only the Swiss agricultural landscapes but also the protection of mustelids at a broader scale.

CRediT authorship contribution statement

Gregory B. Egloff: Conceptualization, Data curation, Formal analysis, Writing – review & editing, Validation, Methodology, Software. **Laurent Schenker:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Sandra Riverendo:** Methodology. **Andrin C. Dürst:** Conceptualization, Data curation, Formal analysis, Writing – review & editing, Validation, Methodology. **Gerald Heckel:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Formal analysis, Conceptualization. **Denise Karp:** Writing – review & editing, Validation, Resources, Methodology, Investigation, Conceptualization. **Jean-Yves Humbert:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

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

Acknowledgements

We thank Marie-Sarah Beuchat from Artenspürhunde Schweiz, Ramona Bruderer, Lukas Egloff, Dominik Epli, Léa Höhener, Lars Marti, Shaquille Matthys, Marion Meli, and Aline Sonderegger for their field assistance, Susanne Tellenbach for her assistance in the lab, Prof. Raphaël Arlettaz for his general support and insights on the project, all involved regional biodiversity conservation projects, the accompanying group, and farmers for their collaboration. Finally, we thank the foundations Dreiklang für ökologische Forschung und Bildung, Ernst Göhner, Gerda, Pancivis, Parrotia, Sophie und Karl Binding, and Temperatio, as well as Pro Natura and the cantons Aargau, Berne, Fribourg, Geneva, Lucerne, Neuchâtel, Solothurn, Thurgau, Vaud, and Zurich for financial support.

Appendices. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2025.126865.

Data availability

Data will be made available on request.

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